National Aeronautics and Space Administration

NASA Explorer Schools Pre-Algebra Unit

Lesson 4 Teacher Guide

Solar System Math

Analyzing Payload Size and Cost

http://quest.nasa.gov/vft/#wtd

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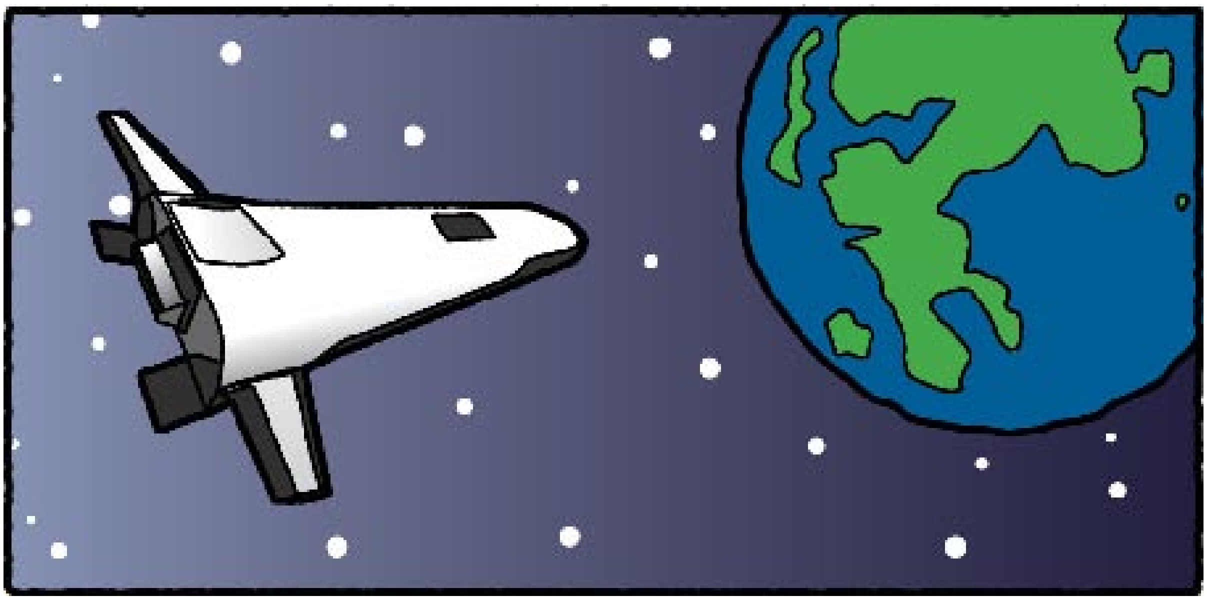
LESSON 4 COMPONENTS

NOTE: A “session” is considered to be one 40-50 minute class period.

Solar System Math

Analyzing Payload Size and Cost



Lesson 4

How do missions to different planets and moons compare in terms of payload size and cost?

Introduction

In this lesson, students will calculate the total mass that is needed to support a mission to a possible destination in the solar system. Students will calculate the mass needed to keep a crew of three astronauts alive for the duration of a mission, the amount of science materials that can be transported on each mission, and the total cost of a mission. Students will compare the costs relative to the amount of scientific materials that can be transported to determine which planets or moons would be the best place(s) to send humans in our solar system.

Lesson 4 – OBJECTIVES, SKILLS, & CONCEPTS

Main Concept

The more time required for a mission to a planet or a moon, the more crew survival resources are needed. This affects both the cost of the mission and the amount of room available for scientific instruments.

Instructional Objectives

During this lesson, students will:

- Calculate the mass of the resources needed to sustain a three-person crew on a mission to a given planet or moon.
- Calculate the proportion (as a fraction, decimal, or percent) of a crew vehicle that is available for scientific instruments for a particular destination and plot the proportion on a number line to compare it with other destinations.
- Calculate the cost of a launch to each destination and create graphs to compare these costs and the amount of room that is needed for scientific instruments for each mission.

Major Focus Skills

Math

- Ratio and proportion
- Comparing and ordering fractions, decimals, and percents
- Units of measurement (metric and standard)
- Data collection and representation

Major Focus Concepts

Math

- Fractions, decimals, and percents are used to represent relationships between numbers.
- Estimation
- Whole numbers, fractions, decimals, and percents can be placed on a number line to represent their relative values.

Major Focus Concepts

Science

- Room on a spacecraft is very limited. Astronauts will not have much room during long missions.
- Longer missions will require more supplies on board the vehicle to sustain the crew.
- Room for scientific instruments depends on how much space is not filled by supplies for the astronauts.
- Missions to destinations that are further away from Earth will require more supplies, will need more fuel, and therefore will be more costly.
- More massive planets or moons will require higher escape velocities and will therefore require more mission fuel.

Prerequisite Skills and Concepts

Math

- Multiplying and dividing large numbers
- Using appropriate units for length (Lesson 1), volume, and mass (Lesson 2)
- Unit conversion including conversion between customary and metric units (Lesson 1)
- Different types of graphs and which types are appropriate for comparing sizes or proportions (Lesson 1)
- How to construct bar graphs for comparing amounts of materials (Lesson 1)
- How to construct pie charts and number lines that are helpful in comparing percents or parts of a whole (Lessons 1-3)
- Mass is the amount of matter in an object and is frequently measured in kilograms. (Lesson 2)
- Comparing fractions, decimals, and percents (Lesson 2)
- Converting among fractions, decimals, and percents (Lesson 2)
- Reducing fractions to their simplest forms

Science

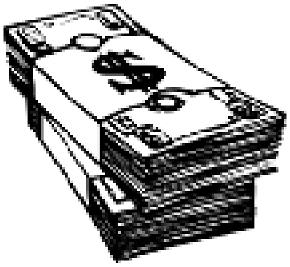
- Minimum time required for a mission to travel to planets and moons in the solar system (Lesson 3)
- Humans need air, food, and water to stay alive.
- Recycling products can reduce the overall amount of materials needed.

NATIONAL EDUCATION STANDARDS	
Fully Met	Partially Met
NCTM (3-5) Data Analysis and Probability #1.3 (6-8) Number and Operations #1.2 (6-8) Number and Operations #1.4 (6-8) Measurement #1.1 Problem Solving #1 Problem Solving #2 Communication #2 Connections #3	NCTM (3-5) Measurement #1.2 (3-5) Measurement #2.2 (6-8) Data Analysis and Probability #1.2

SW = student workbook TG = teacher guide EG = educator guide

Lesson 4 – ENGAGE

- **Estimated Time:** 1 session, 50 minutes
- **Materials:**
  - Transparency #1: A Trip to the Mountains (TG p.9)
  - Transparency #2: A Trip to the Arctic (TG p.10)
  - Transparency #3: A Trip to Outer Space (TG p.11)
  - Estimating a Payload worksheet (SW p.2)



1. COST RELATED TO DISTANCE AND TIME

Remind the students of their final goal:

To determine where in the solar system NASA should send humans.

In Lesson 3, students calculated the travel distance and travel time from Earth to the planets and moons in the solar system. They will now use those results to calculate the cost of a mission to selected planets and moons.

In the previous three lessons, students made a size and distance scale model, constructed a mass and circumference scale model, and calculated the travel distance and mission length for each possible destination. To review prior concepts and conclusions, ask the class the following questions:

- In Lesson 1, what important things did you want to know about possible destinations?
- What have you learned so far?
- Which planets or moons have been ruled out due to surface conditions? (The gas giants: Jupiter, Saturn, Uranus, and Neptune)
- Which planets or moons have been ruled out for safety reasons? (Venus because of temperature. Io and Europa due to radiation. *Note: Io and Europa may still be possibilities if technologies are designed to protect against radiation.*)
- Which planets and moons have you ruled out due to their distance from Earth and the time it would take to get there? (Some students may consider Pluto and Triton too far away.)
- Which planet or moon do you now think is the best possible destination for humans? Why?

At the end of Lesson 3, students were asked to choose the planet or moon they thought would be the best destination.

Acceptable Destinations	Unacceptable Destinations
Mercury Mars Io (pending safety adaptations) Europa (pending safety adaptations) Titan Triton (consider mission length) Pluto (consider mission length)	Venus (extreme temperature) Jupiter (gaseous surface) Saturn (gaseous surface) Uranus (gaseous surface) Neptune (gaseous surface)

Based on the destinations chosen by the class, assign each acceptable destination to at least two students or two groups so that the calculations throughout Lesson 4 can be compared.

2. SELECTING SUPPLIES

To help students realize the challenges of providing everything astronauts need for space travel, have them discuss the 3 scenarios on **Transparencies 1, 2, and 3.** (TG pp.9-11).

Begin with **Transparency #1: A Trip to the Mountains** and **Transparency #2: A Trip to the Arctic.** Have students *compare* their responses for the two scenarios. What could they use from each environment?

Mountains	Arctic
plants or animals for food trees or caves for shelter wood for fire streams for water	fish or animals for food blocks of snow for shelter snow or ice for water

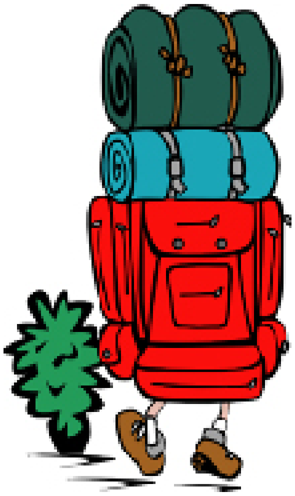
Next add the responses to **Transparency #3: A Trip to Outer Space** to the discussion. Focus on items necessary for survival vs. items desired for comfort. Given the limited space of a crew vehicle, have students *prioritize* their list of supplies.

Transparency #1: A Trip to the Mountains

Imagine you are planning a trip to the mountains where you will reside for several years. There will be no stores, no electricity, no roads, no vehicles, no other people—no civilization whatsoever. Furthermore, you will have to carry all your supplies, and items that require batteries will be useless once the batteries run out of power.

Using the questions below, make a list of supplies and adaptations. Discuss your answers as a class.

1. What will you take with you?
2. Which items are necessary for survival?
3. Which items will make the trip more comfortable?
4. How will you adapt to living in the mountains?
5. How will the wilderness environment help you? How will it hinder you?



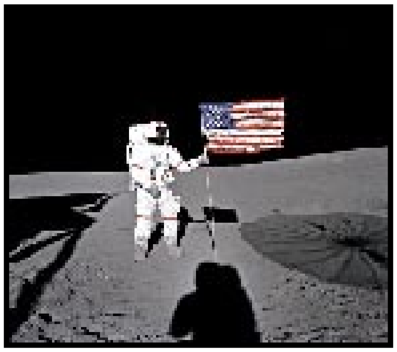
Transparency #2: A Trip to the Arctic

Imagine you are planning a trip to the Arctic Circle for several years. As in the wilderness, there will be no stores, no electricity, no roads, no vehicles, no Inuit people—no civilization whatsoever. You will have to carry all your supplies, and you will need to consider the harsh, polar environment where plants and shelter are limited.

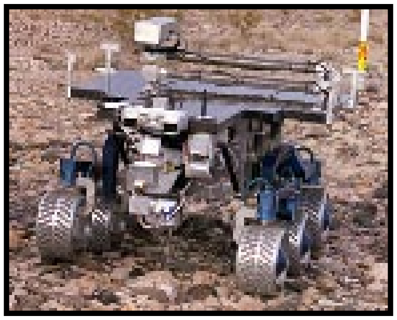
Using the questions below, make a list of supplies and adaptations. Discuss your answers as a class.

1. What will you take with you?
2. Which items are necessary for survival?
3. Which items will make the trip more comfortable?
4. How will you adapt to living in the arctic?
5. How will the polar environment help you? How will it hinder you?

Transparency #3: A Trip to Outer Space



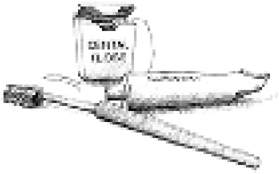
Imagine you are planning a trip to another planet. Like a trip to the mountains or a trip to the arctic, this journey will span several years. There will be no stores, no electricity, no roads, no forms of life, and little or no liquid water. You will have to carry all your supplies, and you will need to consider the harsh, extreme environment of space and the fact that you are very far from home.



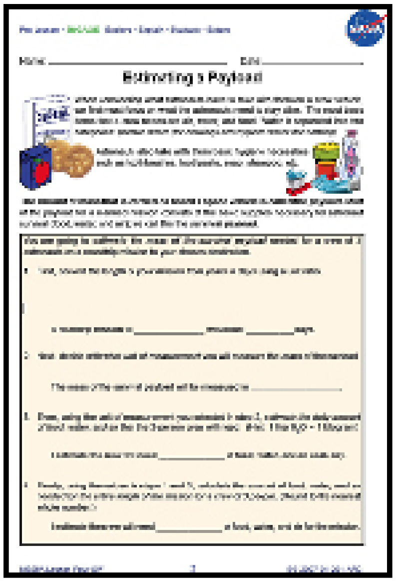
Using the questions below, make a list of supplies and adaptations. Discuss your answers as a class.

1. What will you take with you?
2. Which items are necessary for survival?
3. Which items will make the trip more comfortable?
4. How will you adapt to living on another planet?
5. How will the environment of outer space help you? How will it hinder you?

3. NECESSITIES IN SPACE: ESTIMATING A PAYLOAD



Students are going to calculate the mass of the survival payload needed for a crew of 3 astronauts on a roundtrip mission to their selected planet or moon.



Use the **Estimating a Payload** worksheet (SW p.2) to guide students through the process.

Make sure students choose an *appropriate* unit of measurement for the mass of their payload. To provide students with some point of reference, give students the following benchmark:

1 liter of water has a mass of 1 kilogram

Have students share their estimates and explain the basis of their estimates. How do the estimates compare among students with the same destination?

At this point, students have only *estimated* the mass of the survival payload. In the EXPLORE section of this lesson, students will calculate the *actual mass* of the survival payload and will compare the two to see how close their estimates were to the actual values.

Extension

Ask the students to estimate how much they think a mission to their selected planet or moon would *cost*. Would missions to the planets and moons further away from Earth cost more or less? Why?

Note: The **ANSWER GUIDE** for the Student Workbook uses a mission to Venus as an example for all calculations. (A human mission to Venus has been ruled out due to the planet's inhospitable atmosphere.) It is recommended that teachers share these sample worksheets with the class as a tool to help guide students through the calculations for missions to the other planets and moons.

SW = student workbook TG = teacher guide EG = educator guide

Lesson 4 – EXPLORE

- **Estimated Time:** 2 sessions, 50 minutes each
- **Materials:**
  - Transparency #4: The Space Shuttle's Relative Size (TG p.14)
  - Transparency #5: The Space Shuttle's Exterior Dimensions (TG p.16)
  - Yardsticks, metersticks, or tape measures
  - Masking tape or chalk
  - Transparency #6: Living Space and Payload Capacity (TG p.17)
  - Transparency #7: An Astronaut's Survival Requirements (TG p.21)
  - Transparency #8: An Astronaut's Survival Requirements with Recycling (TG p.22)
  - Daily Survival Mass of a 3-Person Crew worksheet (SW p.3)
  - Mission Survival Payload for a 3-Person Crew worksheet (SW p.4)
  - Calculating the Cost of a Mission—Option 2 worksheet (SW p.x)

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1. CAPACITY OF A CREW VEHICLE

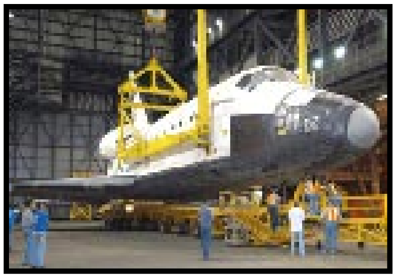
To gain an idea of the dimensions of NASA's current crew vehicle and the amount of room in which astronauts have to live, students will mark out a representation of the *living space* inside a space shuttle.

Students know from their calculations in Lesson 3 that a mission to another planet or moon will take an extended period of time, especially to the outer planets. While the crew vehicle that will transport astronauts to other planets and moons has not yet been developed, we can use a current space shuttle as a representative crew vehicle. **Transparency #4: The Space Shuttle's Relative Size** (TG p.14) illustrates the scale of NASA's current crew vehicle.

Note: The space shuttle DOES NOT travel to other planets or moons. It is designed for Earth orbit only and is used here merely as an example. The living accommodations for a long-term crewed planetary spacecraft will likely be VERY different than those of the space shuttle.

Although from the outside, the space shuttle may seem large, a great deal of its space is occupied by payload (the cargo) that the shuttle carries. There is a limited amount of living space that remains for the astronauts inside.

Transparency #4: The Space Shuttle's Relative Size



Hands-on Activity

Using **Transparency #5: The Space Shuttle's Exterior Dimensions** (TG p.16), have students estimate the area and the volume of a shuttle inside the classroom with masking tape or outside the classroom with chalk. Students can measure the length, width, and height of the shuttle dimensions with yardsticks, metersticks, or tape measures, and they should try to adjust their outline so that it looks like an actual shuttle. If possible, create the model next to a wall so that the height of the shuttle can also be indicated.

Students will use the following dimensions for the outline of the shuttle.

Length: 122.17 feet ≈ 37.24 meters

Height: 56.58 feet ≈ 17.25 meters

Span: 78.06 feet ≈ 23.79 meters
(width of shuttle from one wingtip to the other wingtip)

Once the shuttle dimensions have been marked, ask the students if the shuttle is larger or smaller than they would have guessed?

Students will use the following dimensions for the cargo bay and living area.

Payload Cargo Bay (rear of shuttle between the two wings)

Length: 60 feet ≈ 4.57 meters

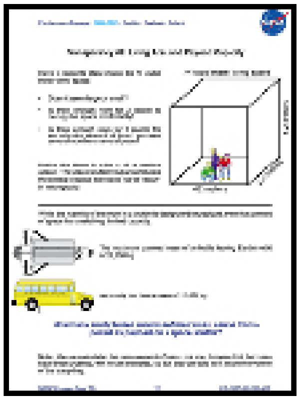
Width: 15 feet ≈ 18.29 meters

Astronaut Living Space (nose of the shuttle)

Length: 13.78 feet ≈ 4.2 meters

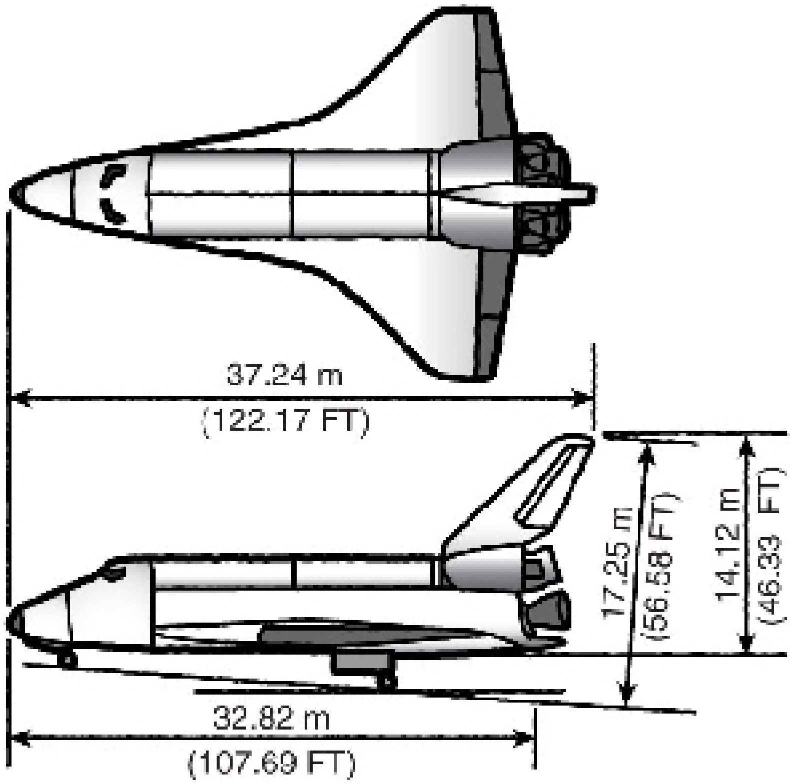
Width: 13.78 feet ≈ 4.2 meters

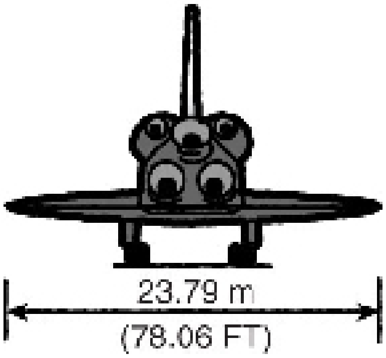
Height: 13.78 feet ≈ 4.2 meters



While it may appear that there is plenty of room remaining for the crew (approximately 74 cubic meters or 2,616 cubic feet), most of the interior of the shuttle is full of storage lockers for food, water, equipment, and a few personal items. Use **Transparency #6: Living Space and Payload Capacity** (TG p.17) to host a class discussion on astronaut comfort and maximum payload. Later in the lesson, students will consider the maximum payload mass of 28,800 kg when calculating the total mission payload mass that they will need for a mission to their chosen planet or moon. [*Note: The solution to the bus question is 2.4 buses.*]

Transparency #5: The Space Shuttle's Exterior Dimensions





First, create a model of the overall volume (LxWxH) or the area (LxW) of the shuttle.

1. Decide if you will use meters or feet.
2. Using a meterstick, yardstick, or measuring tape, create an outline of the shuttle with masking tape or chalk.

Next, identify the cargo bay, which is the area used for payload.

3. At the rear of the shuttle between the two wings, mark off an area that is 4.57 m by 18.29 m (or approximately 15 ft by 60 ft).

Finally, identify the crew's living area.

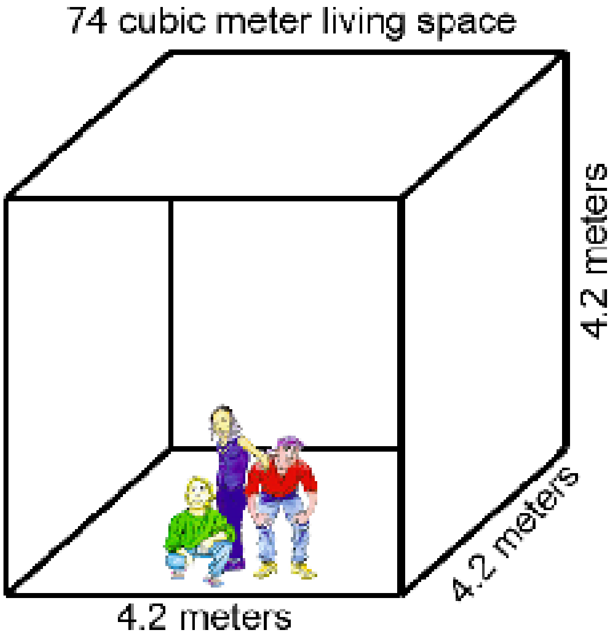
4. In the nose of the shuttle, mark off any area that is 4.2 m by 4.2 m (or approximately 13.78 ft by 13.78 ft)
5. If possible, mark a height of 4.2 m (or 13.78 ft), which then gives a volume of approximately 74 cubic meters (or approximately 2,616 cubic feet).

Transparency #6: Living Space and Payload Capacity

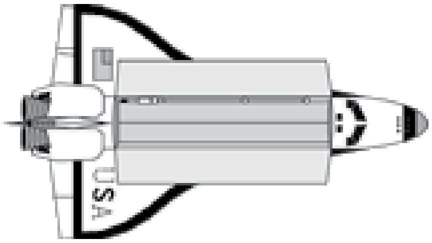
Have 3 students stand inside the 74 cubic meter *living space*.

- Does it seem large or small?
- Is there enough room for 3 people to occupy the space comfortably?
- Is there enough room for 3 people for an extended amount of time... perhaps several months or several years?

Notice that there is quite a bit of *vertical space*. The shuttle's living space includes the ceiling because there is no "up" or "down" in microgravity.



While the majority of the room in a shuttle is designated for *payload*, even that amount of space has a relatively limited capacity.



The maximum payload mass of a shuttle leaving Earth's orbit is 28,800 kg.

An empty bus has a mass of 12,000 kg.

How many empty buses, *in terms of their mass*, can be transported as payload on a space shuttle?

Note: *You are calculating the measurement of mass, not size.* Imagine that the buses have been crushed, with no air left inside, so that they are able to fit inside the volume of the cargo bay.

2. RECYCLING: HOW MUCH MASS CAN BE SAVED?

In this section, students will consider how much recycling may be done on a long mission, which can lower the total mass of the survival payload needed by the astronauts.

Using the questions below, host a brainstorming session on how to reduce the mass of materials needed for astronauts on a long mission.

- Should astronauts take enough plates and cups to use a different set every day for the duration of the trip?
- Should astronauts pack enough clothing to wear a different outfit every day for the entire mission?
- Will water be used one time, or can it withstand multiple uses?

On Earth, we are able to reuse cans, bottles, and paper through the process of recycling. Some of the same principles can be applied to certain items on a space shuttle.

In the ENGAGE portion of the lesson, students learned that astronauts must have food, water, and air to survive. According to one source, for a space shuttle mission NASA allocates:

- 4.20 kilograms of food and drinking water for 1 astronaut each day.
- 23.00 kilograms of hygiene water for 1 astronaut each day.
- 0.73 kilograms of oxygen for 1 astronaut each day.

Note: Remind students that these amounts of food, water, and oxygen are for a space shuttle mission. The actual values for a long-term planetary mission will differ from these amounts.

Show students **Transparency #7: An Astronaut's Daily Survival Requirements** (TG p.21) and discuss the five questions. As students consider question #4 and what happens to drinking water, they will probably conclude that drinking recycled water is a bad idea. However, in considering question #5, students may conclude that with proper filtration, recycling hygiene water is a good idea.

Oxygen and water recycling go hand-in-hand. Currently on the International Space Station, all water is reclaimed from wastewater, urine, and even the water vapor that the astronauts (or any living thing) on the space station exhale. The water is cleaned and purified, as is the air in the shuttle. The carbon dioxide that the astronauts exhale is removed from the air. Oxygen is mixed back into the air from storage tanks, or oxygen can be released from water by separating it from the hydrogen molecules (a water atom is H_20—two hydrogen molecules and one oxygen molecule).

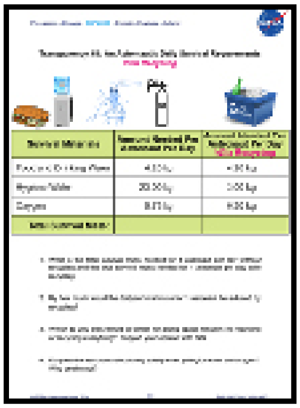
According to one NASA source, if ALL of the hygiene water were recycled, this would reduce the amount of hygiene water needed by an astronaut each day to 3 kg. Likewise, if oxygen were recycled, the amount needed by an astronaut each day would be reduced to 0.2 kg.

Show students **Transparency #8: An Astronaut's Daily Survival Requirements With Recycling** (TG p.22), and discuss the four questions.

1. Total survival mass per person per day without recycling vs. with recycling:

   Without recycling: *total survival mass = 27.93 kg*

   With recycling: *total survival mass = 7.40 kg*



2. Amount of survival mass reduction as a result of recycling:

   27.93 kg - 7.40 kg = 20.53 kg

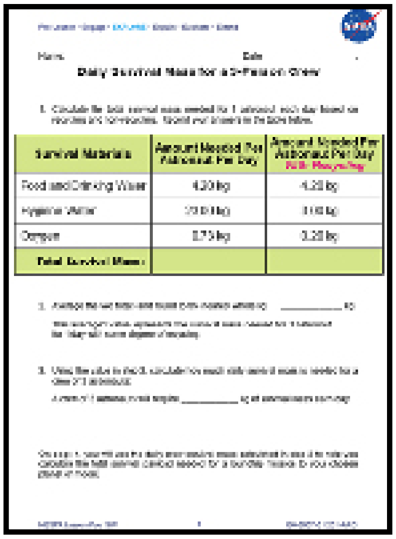
3. To recycle or not to recycle? That is the question:

   Recycling is best because it reduces the daily survival mass by over 20 kilograms per person.

4. Is it a good idea to rely **solely** on recycling water and oxygen?

   No, because if the recycling equipment is damaged and the astronauts cannot repair it themselves, then this could create a dangerous and potentially deadly situation. However, it would be a waste of valuable payload mass to not recycle at all.

Note: NASA is exploring many new technologies and methods for reducing the amount of resources that would be required for human space travel. For example, NASA is interested in developing the capability to create fuel, oxygen, and water from the resources available on planets and moons. The Earth's Moon is one place NASA would like to extract such resources. If we could manufacture these resources on the moon, we could launch spacecraft from the moon, which has a lower gravity than Earth, requiring much less fuel to launch. Also, NASA has been researching how to grow food in space, which would also help to reduce payload.



Daily Survival Mass for a 3-Person Crew

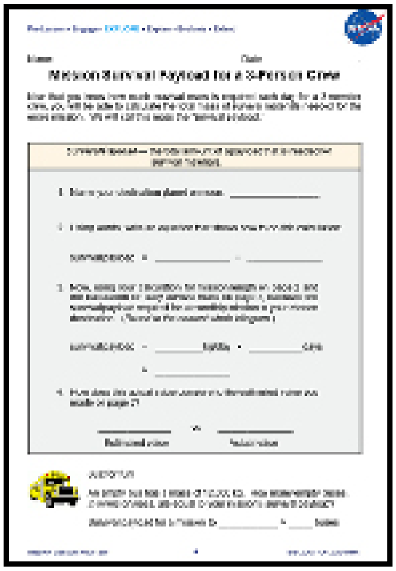
Set the stage for the next section, Calculating Survival Payload, by having students complete the **Daily Survival Mass for a 3-Person Crew** worksheet (SW p.3).

The values calculated on this worksheet will be used to calculate the total survival payload for a mission in section 3 below.

3. CALCULATING SURVIVAL PAYLOAD

In section 2 above, students calculated the daily survival mass needed for a crew of three astronauts. Using this value and the length of the mission to their chosen planet or moon, students will calculate the total *survival payload* needed for the survival of three astronauts on such a mission.

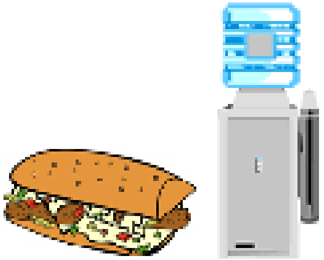
Have students complete the **Mission Survival Payload for a 3-Person Crew** worksheet (SW p.4). Ask students or groups who are calculating this value for the same destination to compare their results. Then, as a class, share and compare the total survival payload needed for each possible destination.

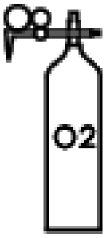


Mission Survival Payload for a 3-Person Crew

Discuss: If the new NASA crew vehicle has a payload capacity of 21,000 kg (< 2 buses), then how will you be able to transport all of the necessary payload? (*utilize multiple crew vehicles*)

Transparency #7: An Astronaut’s Daily Survival Requirements

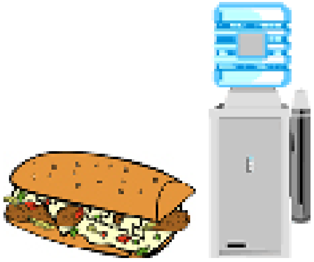


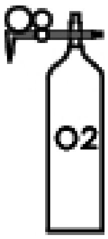


Survival Materials	Amount Needed Per Astronaut Per Day
Food and Drinking Water	4.20 kg
Hygiene Water	23.00 kg
Oxygen	0.73 kg

1. What material takes up the most mass?
2. What material takes up the least mass?
3. What items can be recycled?
4. Would you want to recycle drinking water?
5. Would you want to recycle hygiene water?

Transparency #8: An Astronaut's Daily Survival Requirements
With Recycling





Survival Materials	Amount Needed Per Astronaut Per Day	Amount Needed Per Astronaut Per Day *With Recycling*
Food and Drinking Water	4.20 kg	4.20 kg
Hygiene Water	23.00 kg	3.00 kg
Oxygen	0.73 kg	0.20 kg
Total Survival Mass:		

1. What is the total survival mass needed for 1 astronaut per day *without* recycling and the total survival mass needed for 1 astronaut per day *with* recycling.

2. By how much would the daily survival mass for 1 astronaut be reduced by recycling?

3. What do you think would be better for a long space mission: no recycling or recycling everything? Support your opinion with data.

4. Do you think astronauts should rely solely on recycling for water and oxygen? Why or why not?

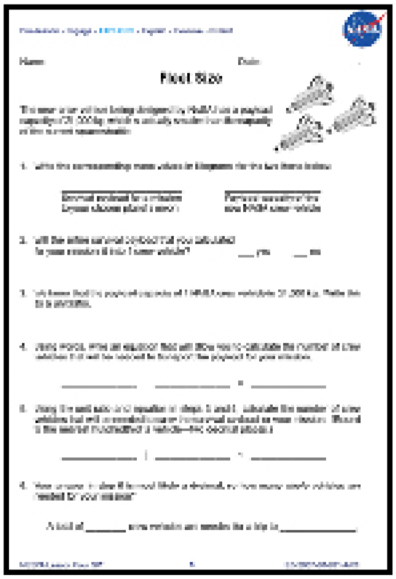
4. HOW MANY VEHICLES WOULD IT TAKE?

In section 3, students should have concluded that a single crew vehicle will not be sufficient to hold the total survival payload needed to keep three astronauts alive for a lengthy mission. Students will now calculate the number of vehicles that will be necessary to hold enough supplies for their 3-person crew.

> **Note:** At the time of this writing, NASA was preparing to retire the space shuttles. New crew vehicles are being designed to carry humans into Earth orbit, to the Moon, and beyond. The values for the cargo capacity and weight of the crew vehicle used in this lesson are based on the lunar heavy cargo launch vehicle, currently being designed by NASA.

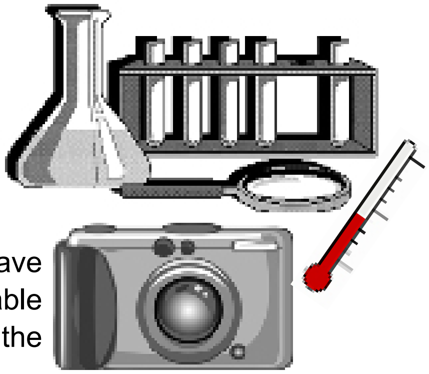
Students who are calculating the mass for a mission to the Moon or Mercury will be able to fit their survival payload into one vehicle; however, students with any other destination will not. Using the **Fleet Size** worksheet (SW p.5), have students use a unit ratio to calculate how many vehicles (including a decimal or fractional part of a vehicle) are needed to transport their survival payload.

Next, have students round their fractional or decimal answers to the next whole number to determine the total number of crew vehicles needed for their mission. As a class, compare the number of vehicles needed for missions to all the destinations.


Fleet Size

> **Note:** If students wonder how three astronauts could travel with several vehicles to distant planets and back, assure them that space vehicles can be controlled remotely. The Mars Exploration Rovers are controlled from Earth through artificial intelligence and transmission. Other vehicles can be controlled in a similar manner. They can also consider sending some shuttles or supplies ahead of time, or using another planet or moon as a base for missions to the outer planets. It is likely that a spacecraft would be designed or customized for the needs of a particular mission. For long-term trips, astronauts could grow their food by planting "crops" and set up additional recycling systems once they reach a planet.

5. SCIENCE PAYLOAD



Students will use the payload space in their crew vehicle not occupied by survival payload to hold scientific instruments and equipment, or the *science payload*. The science payload value will be compared to the overall cost of the mission to decide if enough scientific materials can be taken on the mission to make the cost worthwhile.

Using the **Science Payload** worksheet (SW p.6), have students calculate the number of crew vehicles available for science payload as well as the maximum mass of the science payload.

How does the mass of the science payload compare to the mass of the survival payload? Which is larger?

As a class, brainstorm the types of scientific equipment astronauts on the surface of a planet or a moon would need. Students may suggest cameras, geology equipment (rock picks, hand lenses), weather equipment (thermometers, barometers), and microscopes.

Scientists would need several types of scientific equipment on the surface of a planet or a moon. High quality digital cameras would be important for recording how the surface looks. As technology continues to improve, cameras are getting smaller and lighter with higher resolution. The two cameras included on the Mars Exploration Rover (MER) were capable of producing high quality panoramic pictures, but each only weighed about 270 grams. In order to capture even greater detail, cameras attached to microscopes would also be helpful in recording and analyzing soil and rock samples.

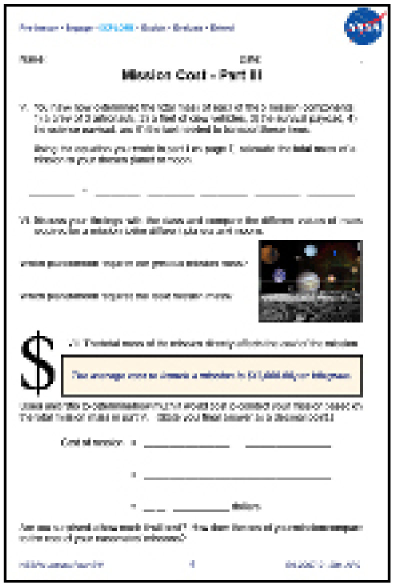
Spectrometers are important pieces of scientific equipment that would be very valuable. Spectrometers analyze heat and light to determine what elements make up a particular object. This would be an extremely valuable tool for analyzing rocks and soil. Spectrometers can range in size and mass. A miniature spectrometer on the MER has a mass of 2.1 kilograms.

Other tools that astronauts may need on the surface of a planet or moons include magnet arrays (to gather magnetic rocks, soil, or dust) and rock abrasion tools (to grind or break rocks so that their interiors can be studied). The rock abrasion tool on the MER has a mass of 720 grams.

While the size and the mass of most individual tools would be relatively small and light, the sum of all of the sizes and masses of the tools needed by astronauts would be relatively large. Also, some larger and more massive objects may need to be included in a science payload, such as solar panels to produce much needed energy while on a planet or a moon. A rover is another important consideration. If astronauts are to explore a large region of a planet or a moon, they will need motorized transportation. The lunar rover used by Apollo astronauts had a mass of 210 kg.

6. TOTAL COST OF THE MISSION

Taking into account the fuel needed to transport the total payload and the vehicles, students can calculate the total mass of the mission and, in turn, calculate the cost of the mission.



Using the **Mission Cost – Parts I, II, III** worksheets (SW pp.7-9), students will systematically derive the total mass of each of the five mission components...

Survival payload	(calculated on SW p.4)
Science payload	(calculated on SW p.6)
Fleet of crew vehicles	(number of crew vehicles • 85,000 kg)
Crew of 3 astronauts	(245 kg)
Fuel	(mission mass before fuel ÷ 1.79)

and then plug these five values into an equation to calculate the total mass of the mission:

mission mass = survival mass + science mass + vehicle mass + astronaut mass + fuel mass

Note: For every 1.79 kilograms of mass to be launched, 1 kilogram of fuel is needed. This value is based on a source outlining the amount of fuel needed to launch a probe to Neptune. NASA uses different fuels depending on the mass being launched and the destination. Different types of fuel can produce different thrusts. Fuel for space shuttles is a combination of hydrogen and oxygen.

Note: If students discuss the mass of personal items for the astronauts, explain that the amount of mass allotted for personal items is very small compared to the rest of the mass for the mission.

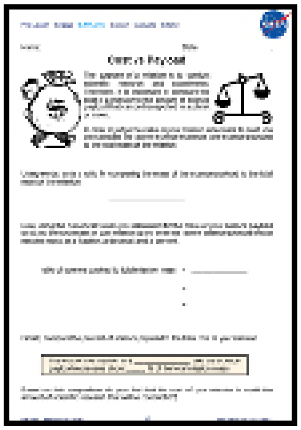
Next, students will use their calculation for total mission mass to determine the cost of launching their mission. They will use the average cost of $10,000 per kilogram to calculate their answer. (This is based on the current average cost at the time of this publication).

Note: The calculations can be set up as a ratio and proportion problem, using the ratio:

$$\frac{\$10{,}000.00}{1 \text{ kilogram}}$$

7. ESTIMATING SCIENTIFIC VALUE IN RELATION TO COST

Students can calculate the ratio of science materials to the total payload using either units of mass or units of cost. They can then compare that ratio to the total cost of the mission. This is one way to estimate the scientific value of the mission.



Using the **Cost vs Payload** worksheet (SW p.10), students will see that the ratio is the mass of the science payload over the mass of the total mission payload.

To bring more meaning to their data, students will express their ratio both as a decimal and as a percent.

Note: These calculations are based on the use of current technology. In general, students may conclude that human missions to the outer planets and moons require such a great amount of survival payload, that the remaining capacity for science payload seems small. One solution would be to add another crew vehicle to the mission to transport additional science payload; however, this would increase cost.

Note: You might discuss with students that the amount of scientific research that will be possible on a mission will depend not only on the scientific equipment that is brought, but also on the amount of time the mission allows for science. ***Another ratio that might be interesting to consider is the amount of time spent on a planet's surface compared to the total mission time.***

SW = student workbook TG = teacher guide EG = educator guide

Lesson 4 – EXPLAIN

- **Estimated Time:** 1 session, 50 minutes
- **Materials:**
  - Students' notes from EXPLORE section
  - Graphing Resource—Student Guide (SW pp.11-14)
  - Graphing Payload and Cost student worksheet (SW p.15)
  - All Things Considered student worksheet (SW p.16)
  - Graph paper/ adding machine tape, or large chart/ poster paper
  - Calculators, rulers, markers
  - Graphing Rubric (TG p.29)
  - Sample Graphs (TG pp.30-31)

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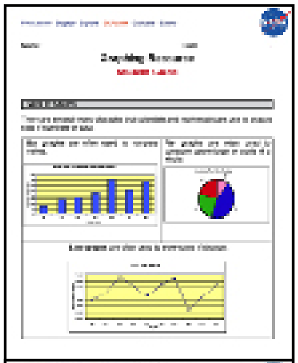
1. GRAPHING OPTIONS: Different Methods of Representing Results

Now that students have calculated the *cost* of their mission and the amount of *scientific materials* (payload) that their mission can support, it will be useful for them to *graphically represent their data* so they can interpret and discuss the results.

Divide the students into groups and task them to graph one or more of the following:

- survival payload mass
- science payload mass
- total mission cost



Students can choose from pie graphs, line graphs, bar graphs, or number lines to represent their data. It would be helpful to have two types of graphs for each set of data for students to compare. For example, "percentage of a lifetime" could be represented in both a pie chart and a bar graph.

Before beginning the activity, review the **Graphing Resource—Student Guide** (SW pp.11-14) with the class. Students should use this resource to help them choose appropriate graphs for their data set. Each graph must have labels, a title, and a scale, as described in the Graphing Resource. With guidance from the **Graphing Payload and Cost** student worksheet (SW p.15), have each group complete a sketch of their graphs for you to check before making a final copy on a poster or chart paper.

When each group has completed their graph(s), have the students present their work to the class. Students can compare graphs and note the similarities and differences between the different representations. Ask the following questions to ensure that each group communicates all of the important information:

- How did you decide to use this particular data set and graph? Explain.
- How do you know your graph is accurate?
- Do other students have questions about how you graphed the data? Does anyone disagree with your graph?
- Does your graph make sense? (For example, does a mission to Pluto stand out as the most massive and most expensive mission?)
- How do different students' strategies for graphing the data compare? Which strategy do you like best? Why?

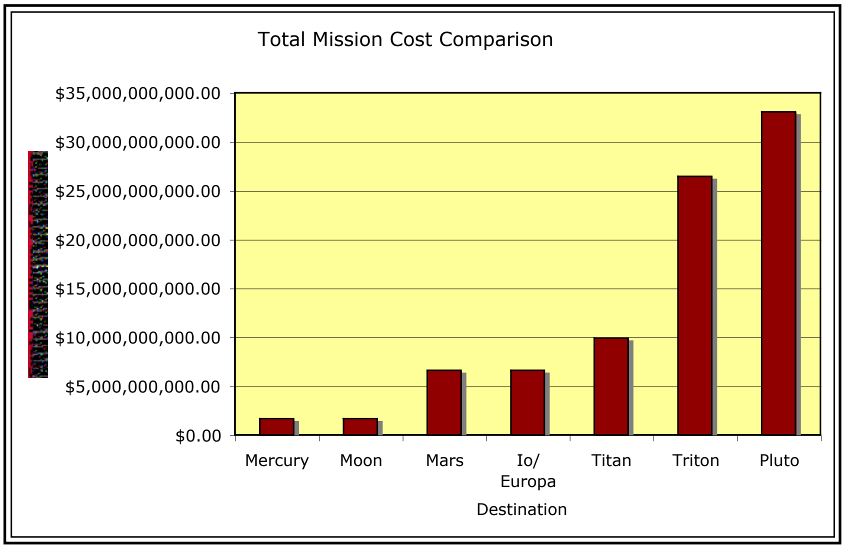
Have students reflect on which type of graph is most effective for communicating the data. Which type of graph makes the most impact? Student graphs may be assessed using the **Graphing Rubric** (TG p.29). **Sample graphs** are included on pages 30-31 of this guide.

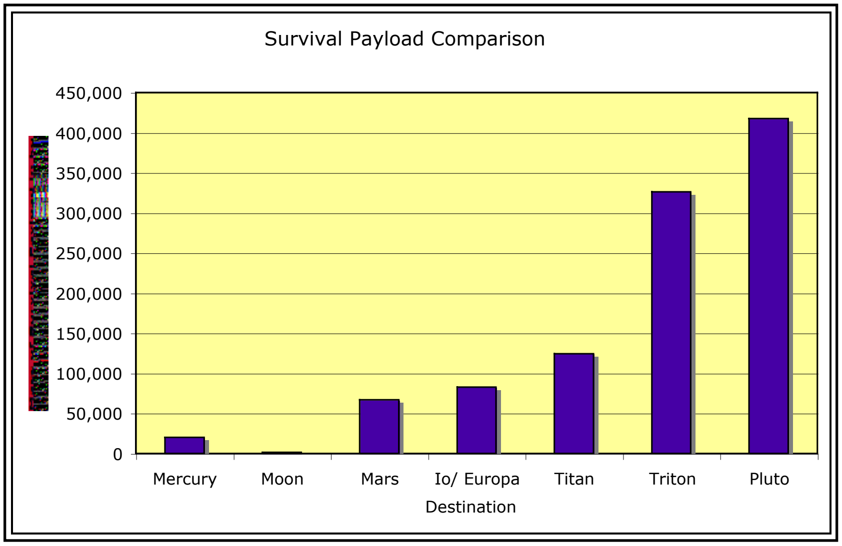
Graphing Rubric

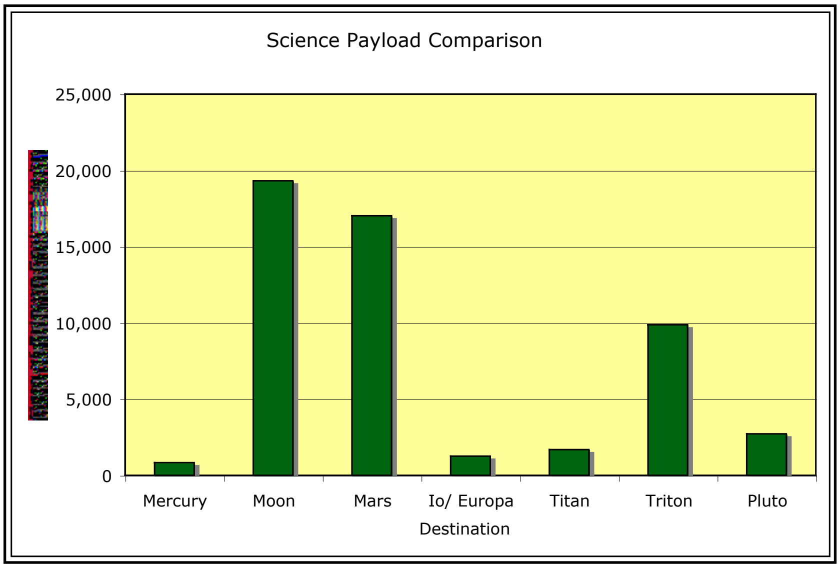
Student graphs and presentations can be assessed with the following rubric. Sample graphs are included on pages 46-50 of this guide.

4	• All data is graphed extremely accurately. Decimals and fractions are taken into account. • Graph is titled and all axes are correctly and neatly labeled. • Graph includes a consistent scale on the y-axis. • Graph type is appropriate for data used. • Choices for graph type, scale, and units are fully justified and related to the data.
3	• All data is graphed accurately. Decimals and fractions were rounded to whole numbers. • Graph is titled and all axes are labeled. • Graph includes a consistent scale on the y-axis. • Graph type is appropriate for data used. • Choices for graph type, scale, and units are justified and may be related to the data.
2	• Data is graphed somewhat accurately. Decimals and fractions were ignored. • Graph is missing either title or axis labels. • Graph includes a consistent scale on the y-axis. • Graph type is somewhat appropriate for data used. • Choices for graph type, scale, and units are not justified and/or may not be related to the data.
1	• Data is not graphed accurately. • Graph does not have a title or axis labels. • Graph does not have a consistent scale for y-axis. • Graph type is inappropriate for data used. • Choices for graph type, scale, and units are not justified and are not related to the data.

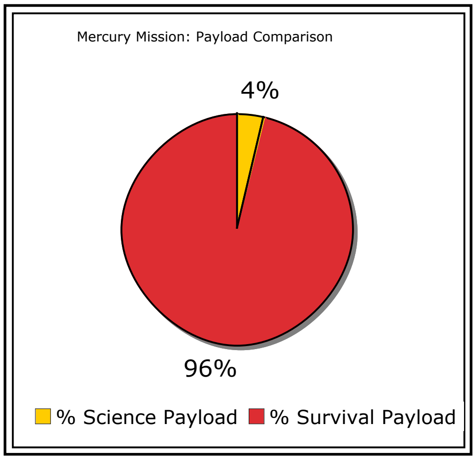
Sample Graphs:

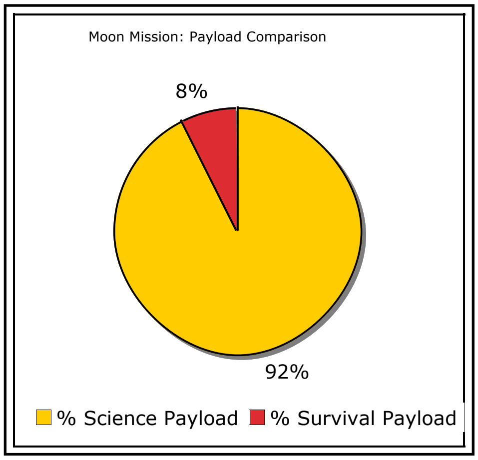


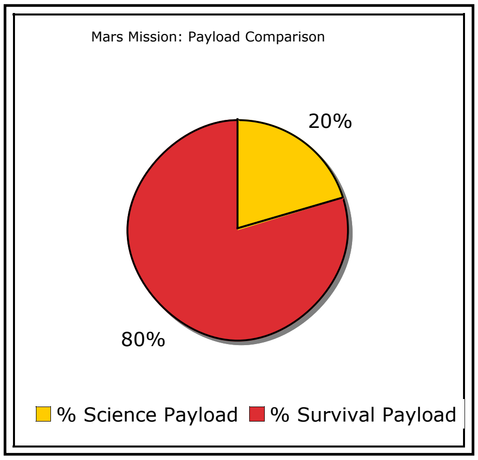


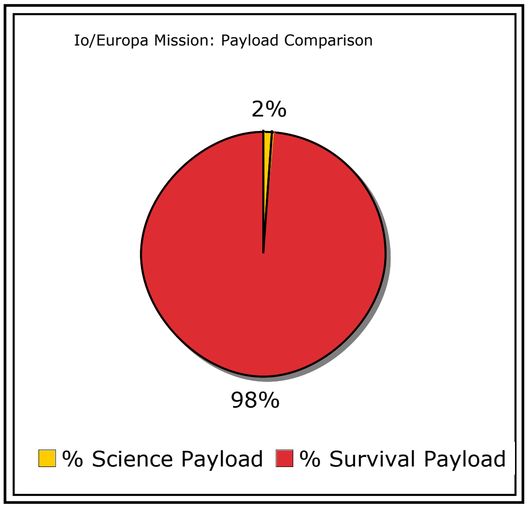


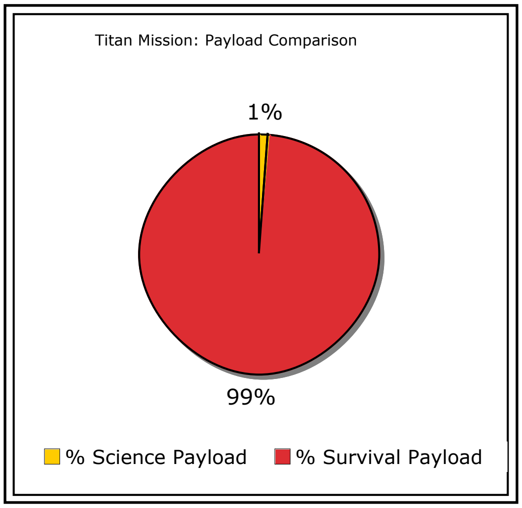
Sample Graphs:

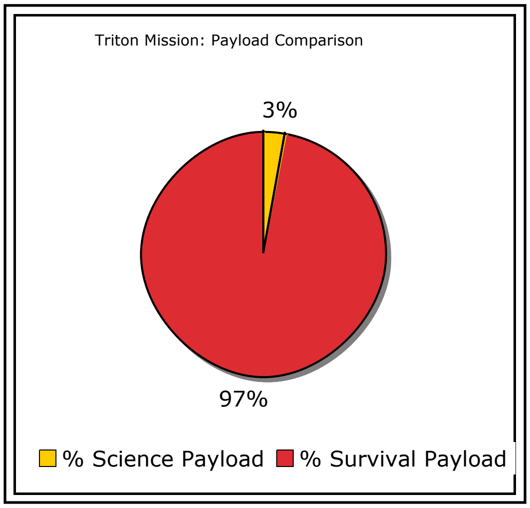


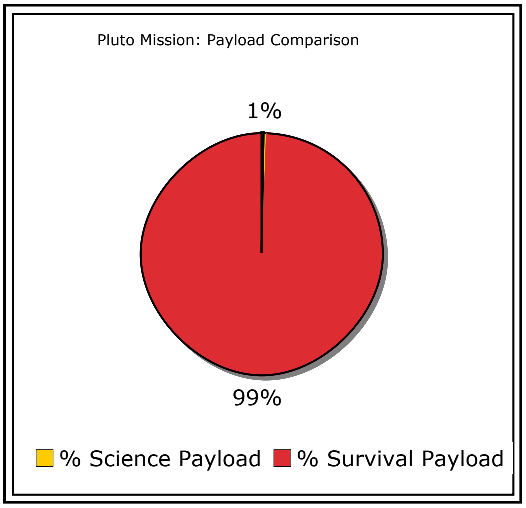












2. CHOOSING A DESTINATION

Now that students have evaluated the cost, length of time, and room for science materials as related to a mission to various planets and moons, they should discuss which destinations appear to be the best choices. Begin a class discussion by asking students what they notice about the data.

- How do the graphs represent the costs of the missions and the amount of scientific materials that each mission could transport?
- Do these comparisons change their opinions about which planet or moon would be the best place to send humans in our solar system?

Students should also consider the data they collected and calculated in the previous lessons.

- For what length of time will astronauts spend on the planet or moon's surface? (synodic period)
- Are there items of scientific interest that could be researched on a given destination, such as volcanoes (Mars, Io) or the possibility of water or life (Mars, Europa).

Next, instruct students to make a prioritized list of considerations.

- What do they think is more important:
  - the total cost of the mission?
  - the length of travel time to and from their destination?
  - the amount of science materials (payload) that can be transported?
  - the length of time to be spent at the destination conducting reserach (synodic period)?
  - other factors or planetary/lunar features?
- Based on their priorities, ask students to decide which planet or moon they think would be the best place to send humans in our solar system.

SW = student workbook TG = teacher guide EG = educator guide

Lesson 4 – EVALUATE

- **Estimated Time:** 1 session, 50 minutes
- **Materials:**
  - Student notes, observations, and graphs
  - Problem Solving Rubric (TG p.35)

To reflect on and review the lesson, lead the class in the following discussion.

Check for understanding:

1. Describe the size of a space shuttle.
2. What essential materials need to be taken on a space vehicle for the survival of the astronauts?
3. What are some challenges when planning manned missions to the outer planets?
4. What kind of adaptations can be made to conserve resources?
5. Which planet or moon would cost the most amount of money to visit?
6. Which planet or moon would cost the least amount of money to visit?
7. Which planet or moon would allow for the most scientific research in terms of time (synodic period) and materials (science payload)?

Reflection:

1. What do we gain by sending humans into the solar system?
2. Do you think there is much room for astronauts living on board a space shuttle?
3. What do you think it would be like to live on a spacecraft for many years?
4. What do you think would be difficult about living on a spacecraft for many years?
5. Why is recycling so important on manned space missions?
6. Why is recycling important here on Earth?
7. How important is it to have room on a space vehicle for scientific instruments? Why?

8. If there was no room on a space vehicle for a large number of scientific instruments, what equipment do you think would be most important to take? Why?

A **Problem Solving Rubric** (TG p.35) is provided for evaluating students' work throughout this lesson.

Brief closing assignment:

The following can be given as a brief, one paragraph writing assignment. Students can respond on index cards (which keep responses concise) or in a journal. Alternatively, students can discuss their answers in pairs or small groups and report their answers back to the class.

- What did you learn during this lesson?
- Is there anything else that you want to know about a planet or a moon before you make your decision? If so, how will you gather that information?
- Based on your experience in this lesson (and in the previous lessons), where do you think is the best place to send humans in our solar system? Why?
- Did your ideas about where to send humans in our solar system change because of this lesson? How?

Problem Solving Rubric

Problem-solving assignments and presentations can be assessed with the following rubric.

4	• Answers were calculated correctly to an appropriate degree of accuracy (rounded to a decimal place or whole numbers where specified). • Answers are fully explained and justified in detail. • All steps of the problem are explained in detail. • Information supplied by the students is accurate and the source of the information is given. • Picture that accompanies problem is relevant, labeled, and demonstrates how the problem was solved. • Written explanation completely outlines the problem and the solution.
3	• Answers were calculated correctly, but to an inappropriate degree of detail (rounded to whole numbers or not rounded where it was appropriate). • Answers are explained and justified. • All steps of the problem are explained. • Information supplied by the students is accurate, but the source of the information is not given in detail. • Picture that accompanies problem is somewhat relevant, may or may not be labeled, and somewhat demonstrates how the problem was solved. • Written explanation outlines the problem and the solution.
2	• Answers were mostly calculated correctly. • Answers are stated clearly but not explained or justified • All steps of the problem are not fully explained. • Information supplied by the students may not be accurate and the source of the information is not given. • Picture that accompanies problem is not relevant, is not labeled, or does not demonstrate how the problem was solved. • Written explanation does not clearly outline the problem and the solution.
1	• Answers were not calculated correctly. • Answers are not stated clearly and are not explained or justified. • Steps of the problem are not explained. • Information supplied by the students is not accurate. • No picture. • Written explanation does not outline the problem or the solution.

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Lesson 4 – EXTEND & APPLY (optional portion of lesson)

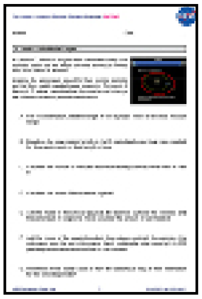
- **Estimated Time:** 1 session, 50 minutes
- **Materials:**
  - Lesson 4 Extension Problems (SW pp.16-20)
  - Problem Solving Teacher Resource (TG pp.37-39)
  - Graphing Resource—Student Guide (SW pp.11-14)
  - Paper for student work
  - Calculators (optional)

Have students work on the provided **Lesson 4 Extension Problems** (SW pp.26-32). These problems are multi-step open-ended challenges. Some will require the students to measure lengths inside the classroom, research the masses of everyday objects, and apply what they know about scale and ratio and proportion. For these problems, students may choose the units they work with, as long as they are “appropriate”. The problems can be done individually, in groups, or as a class.

You may want students to accompany each solution with a written and graphical explanation of how the problem was solved. Review the **Problem Solving—Teacher’s Resource** and sample write up (TG pp.37-39) with your students before having them complete their own write up.

> **Note**: In Extension Problem 2, students calculate the cost of a mission if only one crew member is sent on the misssion instead of three crew members. You might want to use this opportunity to explain to the students why NASA sends multiple astronauts on missions. One reason is so that a mission has backup personnel or help in case someone gets sick. Another reason is that each astronaut usually has an area of expertise (pilots, engineers, scientists, etc).
>
> On long missions, having a doctor on board will be a high priority. Also many tasks, such as building or conducting research, require more than one person to perform. NASA’s psychology research has revealed that odd numbered crews are the best as they allow the crew to vote and reach a majority decision.
>
> Ideal crews are made up of five or seven people, but for the purposes of long missions, such as those to other planets, sending three astronauts minimizes the amount of survival resources needed.





Problem Solving

Teacher's Resource

During the course of this unit, students will be presented with multi-step, open-ended challenges. The problems can be solved in a variety of ways, and there will often be multiple solutions. The problems can be done individually, in groups, or as a class.

Each problem can be accompanied by a written explanation and a picture explaining how the problem was solved. Students can use the following outline to explain their work in written form:

1. Restate the problem. What are you trying to find out?
2. What information do you have? What information do you need to find your answer? Explain how you got the information and record it.
3. Estimate what you think the answer will be. How do you know your estimate is reasonable?
4. Show your work. Include all calculations you made in order to solve the problem—even the ones that did not work.
5. Explain HOW you solved the problem. Step-by-step, what did you do? Use transitions like first, next, then, and finally.
6. State your answer. Explain HOW you know it is correct. Does it make sense? Why?
7. Draw a picture to go along with the problem. Label sizes and distances.

When you finish, read over your work. Pretend you are explaining this problem to someone younger than you.

- Is it clear?
- Does it make sense?
- Did you explain the problem and the answer well?

Example: Scale Movie Stars

Some fantasy characters, such as Hobbits from Lord of the Rings, or Hagrid from the Harry Potter series are on different scales than humans. The following calculations will demonstrate how an everyday object would need to be changed to fit the scale size of a character.

Hobbits are known as Halflings. They are about half the size of a human. Hagrid, however, is half-giant because he had a Giantess Mother. He is about twice the size of a human.

If your teacher became a Hobbit, estimate how tall he or she would be. Estimate how tall your teacher would be if he or she were Hagrid's size. Measure your teacher and calculate his or her Hobbit and Hagrid heights. If possible, mark the Hobbit height, Hagrid height, and actual height of your teacher on the wall or chart paper.

Sample Write Up:

1. I am going to calculate the height my teacher would be if she was a Hobbit or if she was a half-giant like Hagrid.

2. I know that Hobbits are half the size of humans, and I know that Hagrid is twice the size of a human. In order to solve the problem, I need to know my teacher's height. I will use a meter stick and measure her. My teacher is 1.75 meters tall.

3. I estimate that as a Hobbit my teacher will be less than a meter tall because Hobbits are much smaller. I think that as Hagrid my teacher will be over 3 meters tall because Hagrid is much bigger.

4.

Hobbit Height:	Hagrid Height:
1.75 meters • 1/2 = teacher's Hobbit height	1.75 m • 2 = teacher's Hagrid height
1.75 meters • 0.5 = 0.875 m	1.75 m • 2 = 3.5
My teacher's Hobbit height = 0.875 m	*My teacher's Hagrid height = 3.5 m*

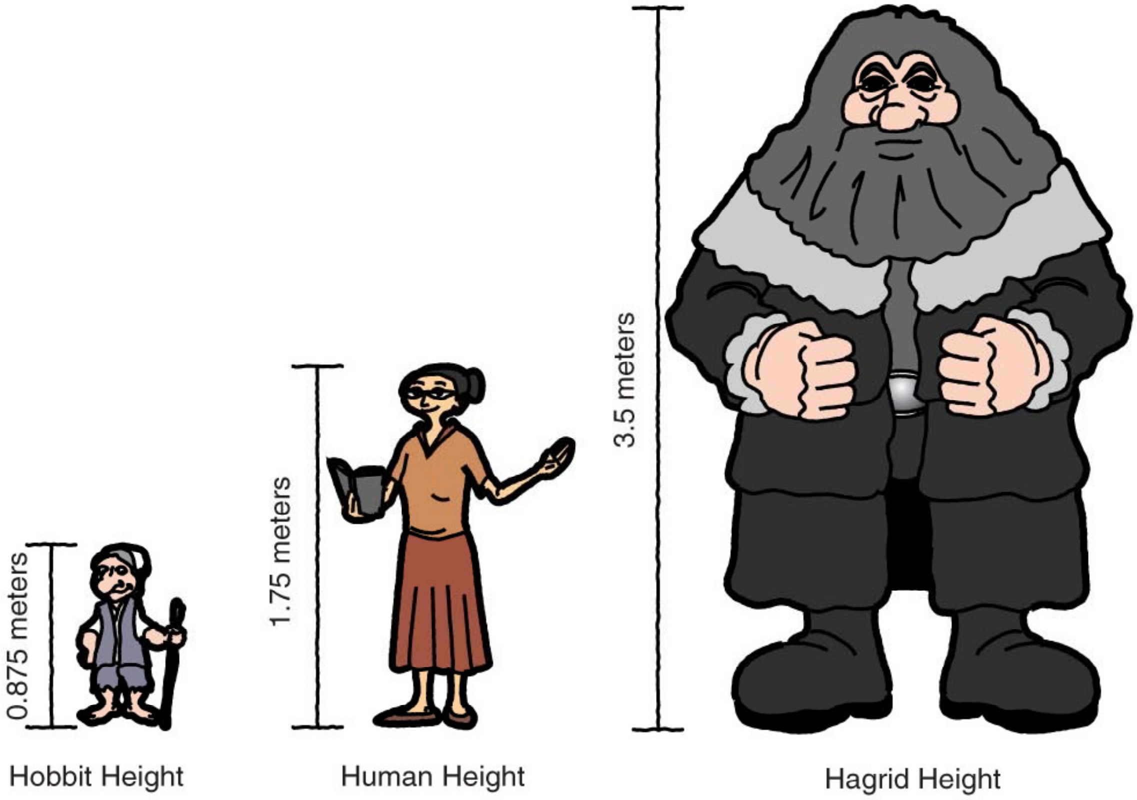
5. I solved the first part of the problem by multiplying my teacher's height by one-half. I solved the second part of the problem by multiplying my teacher's height by two.

   First, I solved for her Hobbit height. Hobbits are half the size of humans, so to get my teacher's Hobbit height I multiplied her normal height by one-half. I decided it would be easier to multiply decimals, so I multiplied 1.75 meters by 0.5 because 1/2 is equal to 0.5.

   Next, to get my teacher's Hagrid height, I multiplied her normal height by 2, because Hagrid is twice the size of a human.

6. I found that if my teacher were a Hobbit, she would be 0.875 meters tall because this is one-half of her normal height. I also found that if my teacher were like Hagrid, she would be 3.5 meters tall because this is two times her normal height. This makes sense because as a Hobbit she would be much smaller than her normal size, and as Hagrid she would be much bigger than her normal size. My estimates were pretty close. I was not off by that much.

7.



0.875 meters 1.75 meters 3.5 meters