National Aeronautics and Space Administration

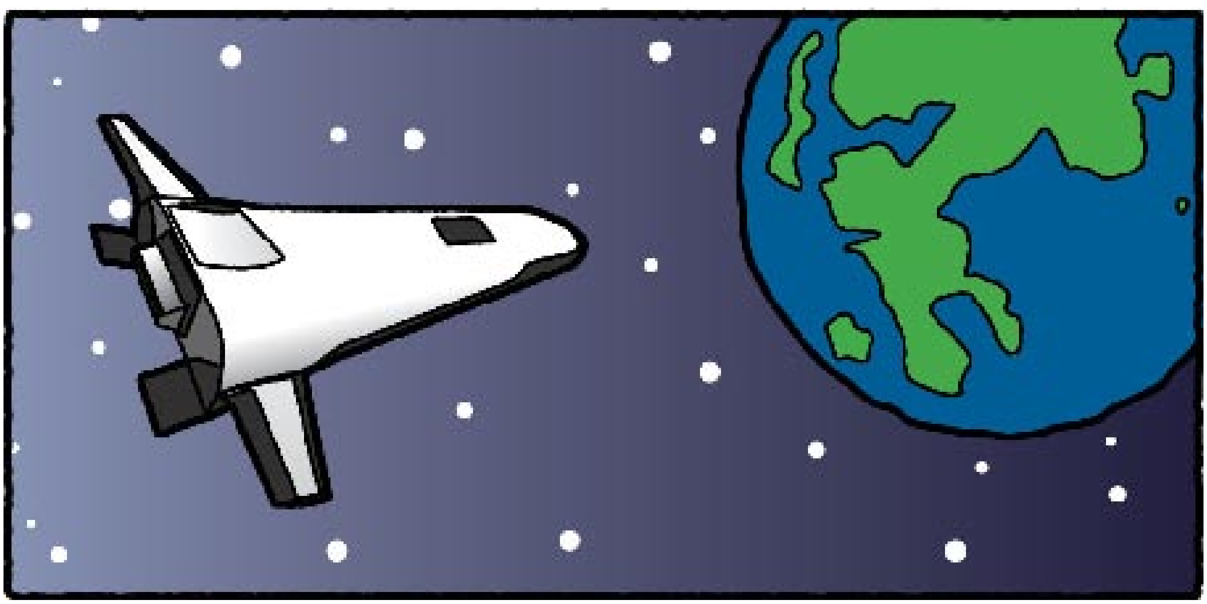
NASA Explorer Schools Pre-Algebra Unit

Lesson 4 Student Workbook

Solar System Math

Analyzing Payload Size and Cost

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



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Name: ____ Date:______________________

Estimating a Payload

When considering what astronauts have to take with them on a crew vehicle, we first must focus on what the astronauts need to stay alive. The most basic items that a crew needs are air, water, and food. Water is separated into two categories: potable water (for drinking) and hygiene water (for bathing).

Astronauts also take with them basic hygiene necessities such as toothbrushes, toothpaste, soap, shampoo, etc.

The amount of mass that is carried on board a space vehicle is called the *payload*. Most of the payload for a human mission consists of the basic supplies necessary for astronaut survival (food, water, and air); we call this the ***survival payload***.

You are going to ***estimate the mass of the survival payload*** needed for a crew of 3 astronauts on a roundtrip mission to your chosen destination.

1. First, *convert the length of your mission from years to days* using a unit ratio.

   A roundtrip mission to _______________ would last __________ days.

2. Next, decide with what *unit of measurement* you will measure the *mass* of the payload.

   The mass of the survival payload will be measured in ___________________.

3. Then, using the unit of measurement you selected in step 2, *estimate the daily amount of food, water, and air* that the 3-person crew will need. (Hint: 1 liter H_2O = 1 kilogram)

   I estimate the crew will need ____________kg of food, water, and air each day.

4. Finally, using the values in steps 1 and 3, *calculate the amount of food, water, and air needed for the entire length of the mission for a crew of 3 people.* (Round to the nearest whole number.)

I estimate the crew will need approximately _________kg of food, water, & air for the mission.

Name: Date: .

Daily Survival Mass for a 3-Person Crew

1. Calculate the total survival mass needed for 1 astronaut each day based on recycling and non-recycling. Record your answers in the table below.

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:		

2. Average the two totals and round to the nearest whole kg: ______________ kg

   This averaged value represents the survival mass needed for 1 astronaut for 1 day with some degree of recycling.

3. Using the value in step 2, calculate how much daily survival mass is needed for a crew of 3 astronauts:

   A crew of 3 astronauts will require _____________ kg of survival mass each day.

On page 4, you will use the daily crew survival mass calculated in step 3 to help you calculate the total survival payload needed for a roundtrip mission to your chosen planet or moon.

Name: Date: .

Mission Survival Payload for a 3-Person Crew

Now that you know how much survival mass is required each day for a 3-member crew, you will be able to calculate the total mass of survival materials needed for the entire mission. We will call this mass the "survival payload."

Survival Payload — the total amount of a payload that is needed for survival materials.

1. Name your destination planet or moon: ___________________

2. Using words, write an equation that shows how to do this calculation:

   survival payload = ________________ • ________________

3. Now, using your calculation for mission length on page 2 and the calculation for daily survival mass on page 3, calculate the survival payload required for a roundtrip mission to your chosen destination. (*Round to the nearest whole kilogram.*)

   survival payload = __________kg/day • ___________days

   ≈ ________________

4. How does this actual value compare to the estimated value you made on page 2?

   ________________ vs ________________

   Estimated value Actual value

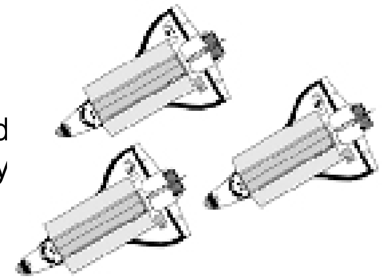
Just for fun!

An empty bus has a mass of 12,000 kg. How many empty buses, *in terms of mass*, are equal to your mission's survival payload?

Survival payload for a mission to _____________ ≈ _____ buses

Name: Date: .

Fleet Size



The new crew vehicle being designed by NASA has a payload capacity of 21,000 kg, which is actually smaller than the capacity of the current space shuttle.

1. Write the corresponding mass values in kilograms for the two items below:

____________________	____________________
Survival payload for a mission to your chosen planet / moon	Payload capacity of the new NASA crew vehicle

2. Will the entire survival payload that you calculated for your mission fit into 1 crew vehicle? ___ yes ___ no

3. We know that the payload capacity of 1 NASA crew vehicle is 21,000 kg. Write two ratios that express this relationship.

    ____________ or ____________

4. Using words, write an equation that will allow you to calculate the number of crew vehicles that will be needed to transport the payload for your mission.

    number of crew vehicles = ______________ • ______________

5. Using the equation in step 4, calculate the number of crew vehicles that will be needed to carry the survival payload for your mission. (Round to the nearest hundredth of a vehicle—two decimal places.)

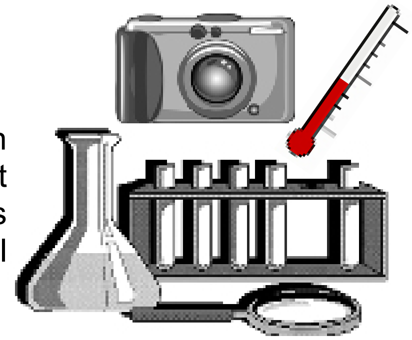
    number of crew vehicles = ____________kg ____________kg

    ≈ ____________ vehicles for survival payload

6. Your answer in step 5 is most likely a decimal, so how many ***whole*** vehicles are needed for your mission? (*The remaining space will be used for science payload.*)

    A total of ________ crew vehicles are needed for a trip to ______________.

Name: Date:



Science Payload

Scientific instruments and equipment are important to the mission because they allow astronauts to perform experiments and collect data. Not all of the room set aside for payload in the crew vehicles will be occupied by survival payload. This remaining space will be used for the scientific materials, or the ***science payload***.

You know the total payload capacity of the crew vehicle, and you know how much of that capacity is set aside for survival payload. Now you are going to calculate the *portion of a crew vehicle* remaining for science payload and the *mass of the payload*.

1. Using words, write an equation that will allow you to calculate the *portion of a crew vehicle* available for science payload.

   science payload portion of vehicle = ________________ – ________________

2. Using the equation in step 1, calculate the portion of a crew vehicle that is available to carry the science payload for your mission. (Round to the nearest hundredth of a vehicle—two decimal places.)

   science payload portion of vehicle = ________________ – ________________

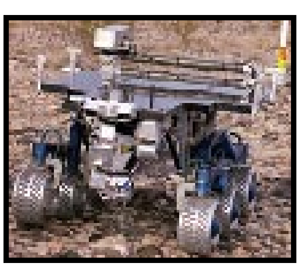
   = ________________

   The portion of a crew vehicle available for science payload is: _______ vehicle.

3. Write an equation in words that will allow you to use a ratio to calculate the *mass of the science payload in kg* based on the number of crew vehicles in step 2.

   mass of science payload in kg = ________________ • ________________

4. Using a ratio (page 5) and the equation in step 3, calculate the mass of the science payload that you would be able to include on your mission. Round to the nearest whole kilogram.



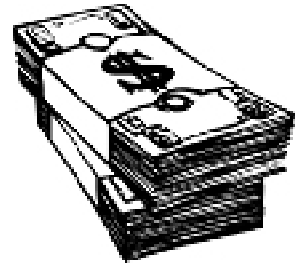
mass of science payload = ______ vehicle • $\dfrac{\text{\_\_\_\_\_\_\_\_ kg}}{\text{vehicle}}$

= __________ kg

The science payload can have a mass up to ___________kg.

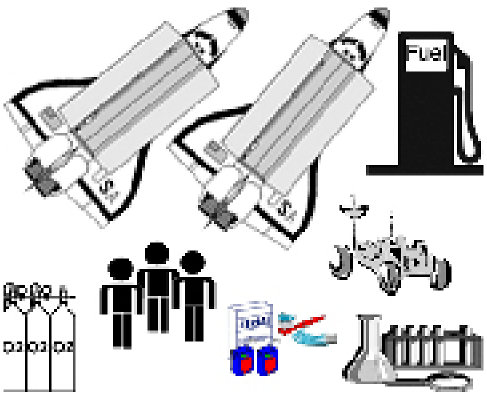
Name: Date: .

Mission Cost - Part I



To determine the cost of a mission, we must first calculate the total mass of the mission, including fuel.

I. The total mass of the mission will be the sum of the masses of 5 components:



- astronauts
- crew vehicles
- fuel
- survival payload
- science payload

I. Using words, write an equation for calculating the *total mass* of the mission.

total mass of mission = __________ __________ __________ __________ __________

II. Before you can calculate the total mass of the mission, you must know the mass of each of the 5 mission components. You already calculated the mass of the *survival* payload (p.4) and the mass of the *science* payload (p.6), so next you will calculate the mass of the ***crew vehicles***.

On page 5, how many crew vehicles did you determine you will need for your mission? _____ vehicles

If each crew vehicle has a mass of 85,000 kilograms, then what is the total mass of your fleet (group of vehicles)? Calculate your answer below...

total mass of crew vehicles = ________________ • _________

= ________________

The total mass of the crew vehicles needed for my mission is ____________ kg.

Name: Date: .

Mission Cost - Part II

III. To determine the amount of fuel needed for your mission, you must first know the total mass of the other 4 mission components.

A crew of 3 astronauts will have a combined mass of 245 kilograms.

Using the values you calculated on the previous pages, record the data for your mission in the spaces below. Then calculate the total mission mass *before* fuel.

Name of planet or moon: ________________

Total astronaut mass: 245 kg

Total crew vehicle mass (p.7): ________________

Total survival mass (p.4): ________________

Total science mass (p.6): ________________

SUM (mission mass without fuel)**:** ________________

IV. Now that you know the total mass of your crew, the vehicles, and the two payloads, you can determine how much fuel you will need.

For every 1.79 kg of mass to be launched, 1 kg of fuel is needed.

Using the information in the box above and your answer in part III, calculate the mass of fuel you will need to complete your mission. (Round to the nearest whole number.)

Fuel mass =

The mass of fuel needed for a mission to ________________ ≈ ______________ kg.

Name: Date: .

Mission Cost - Part III

V. You have now determined the total mass of each of the 5 mission components: 1) a crew of 3 astronauts, 2) a fleet of crew vehicles, 3) the survival payload, 4) the science payload, and 5) the fuel needed to transport these items.

Using the equation you wrote in part I on page 7, calculate the total mass of a mission to your chosen planet or moon.

total mass = ________ + ________ + ________ + ________ + _________

= _________kg

VI. Discuss your findings with the class and compare the different values of mass required for a mission to the different planets and moons.

Which planet/moon requires the *greatest* mission mass?

Which planet/moon requires the *least* mission mass?

VII. The total mass of the mission directly affects the *cost* of the mission.

The average cost to launch a mission is $10,000.00 per kilogram.

Use a ratio to determine how much it would cost to conduct your mission based on the total mission mass in part V. (State your final answer as a decimal point.)

$$\text{Cost of mission} = \underline{\qquad\qquad}\text{kg} \bullet \frac{\$\underline{\qquad\qquad}}{\text{kg}}$$

$$= \underline{\qquad\qquad\qquad\qquad\qquad}$$

$$\approx \_\,.\,\_ \quad \underline{\qquad\qquad} \text{ dollars}$$

Are you surprised at how much it will cost? How does the cost of your mission compare to the cost of your classmates' missions?

Name: Date: .

Cost vs Payload

The purpose of a mission is to conduct scientific research and experiments. Therefore, it is important to compare the cost of a mission to the amount of science payload that can be transported to a planet or moon.

In order to assess the value of your mission in terms of its cost, you will calculate the ratio of scientific materials (the science payload) to the total mass of the mission.

Using words, write a ratio for comparing the mass of the science payload to the total mass of the mission:

____

Now, using the numerical values you calculated for the mass of your science payload (p.6) and the total mass of your mission (p.9), write the ratio of science payload to total mission mass as a fraction, a decimal, and a percent.

ratio of science payload to total mission mass = ______________ (fraction)

≈ (decimal)

≈ (percent)

Finally, compare the percent of science payload to the total cost of your mission.

The cost of the mission is $ _______________, and the science payload represents about _____ % of the total mission mass.

Compare the cost and percent of science payload for your mission with those of your classmates.

Name: Date: .

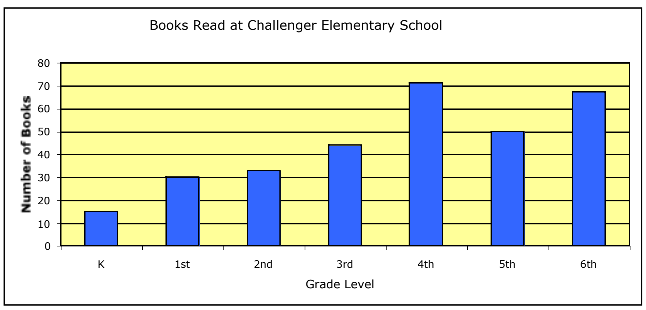
Graphing Resource

Student Guide

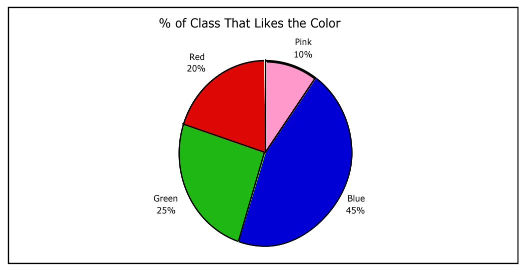
Types of Graphs

There are several types of graphs that scientists and mathematicians use to analyze sets of numbers or data.

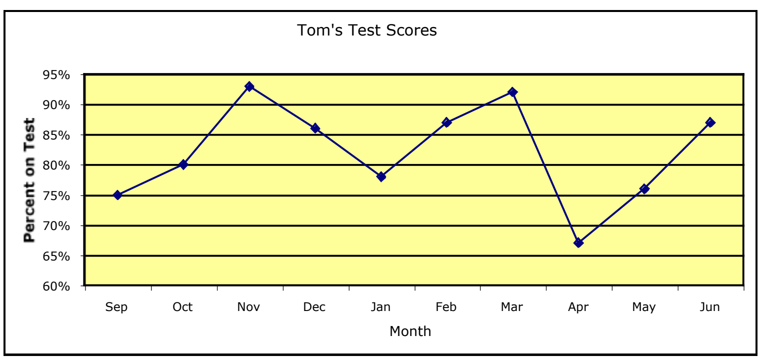
Bar graphs are often used to compare values.



Pie graphs are often used to compare percentages or parts of a whole.



Line graphs are often used to show rates of change.



Name: Date: .

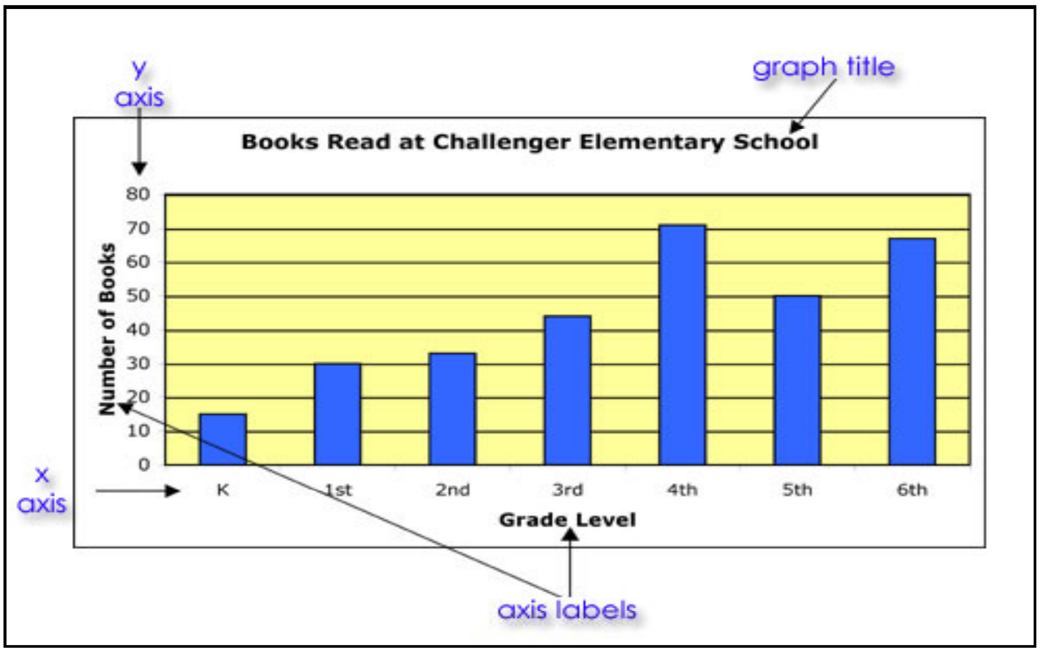
Before You Begin

When you are planning to graph data, you need to answer some questions before you begin.

1. What type of graph will you use?
2. What unit of measurement will you use?
3. What scale will you use?
4. What will be the minimum and maximum values on your graph?
5. Will your graph start at 0?

Making Bar Graphs and Line Graphs

Every graph needs a **title** and **labels** on the horizontal "x" axis (side-to-side) and the vertical "y" axis (up and down).



The **unit of measurement** you are using needs to be clearly shown (inches, kilograms, etc.). The unit for the bar graph above is "number of books" as is written in the vertical y-axis label.

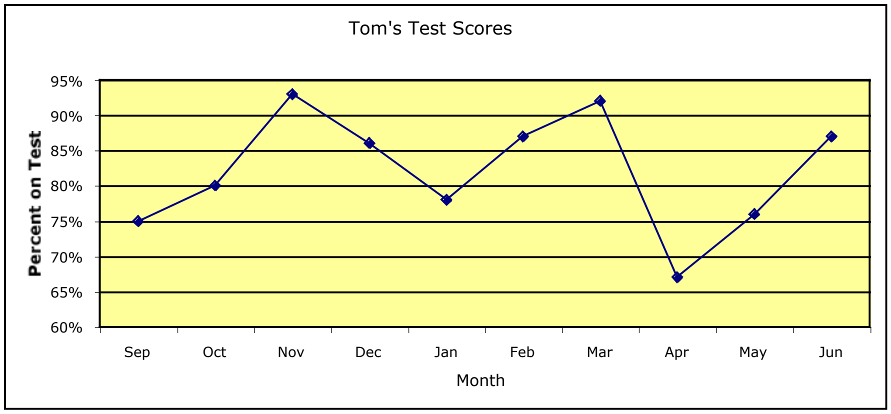
You also must choose a **scale** for your vertical y-axis. The vertical scale on the bar graph above goes from 0 to 80 in increments of 10.

Name: Date: .

The scale is determined by the data you are graphing. To determine the scale, look at the largest and smallest numbers you will be graphing.

For this line graph, the vertical y-axis goes from 60% to 95% in increments of 5%.

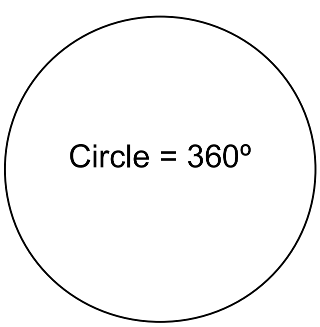
The unit of measurement for this graph is "percent." (%)



Making a Pie Graph

A pie graph is shown using a circle, which has 360 degrees. To make an accurate pie graph you will need a compass or a similar instrument to trace a circle and a protractor to measure angles in degrees.

Start by making a circle. You will then have to multiply your fractions or percents (in decimal format) by 360 degrees to find out how many degrees you will need in each wedge. For example:



Color	% of class that likes the color
Blue	45%
Green	25%
Red	20%
Pink	10%
Total:	**100%**

The sum of your fractions should total to 100%.

Name: Date: .

To find out how many degrees of the pie graph will represent the number of students in the class who like the color blue, you would multiply 360 degrees by 0.45. The result of your calculation is 162 degrees. To find out how many degrees of the pie graph will represent the number of students in the class who like the color green, you would multiply 360 degrees by 0.25. The result of your calculation is 90 degrees.

To mark off the blue portion of the pie graph, start by drawing a radius of the circle (a line segment from the center of the circle to the circle itself). Then use the protractor to measure an angle of 162 degrees and draw the corresponding radius. The green portion will have an angle measure of 90 degrees, the red portion will have an angle measure of 72 degrees, and the pink portion will have an angle measure of 36 degrees. The sum of these angles will equal an angle measure of 360 degrees, the number of degrees in a circle.

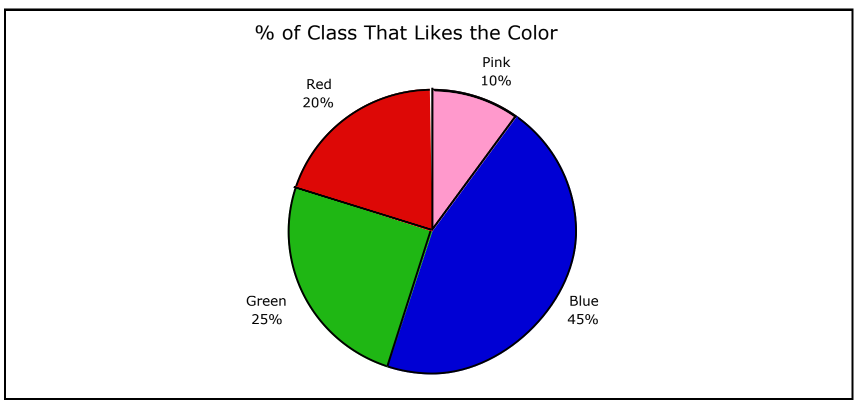
Pink = 36°

Blue = 162°

Green = 90°

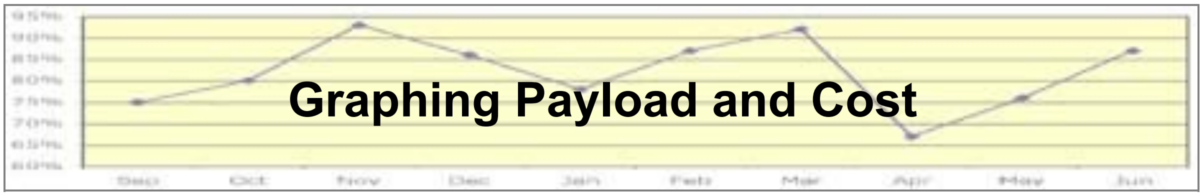
Red = 72°

Total = 360°



When the portions have been drawn into the circle, you then need to **color** each portion, label each portion with both the **category** and the **percent or fraction**, and give the graph an overall **title**.

Name: Date: .



Graphing Payload and Cost

Based on the calculations you have made, you are going to graph one or more of the following aspects of a mission: (Place a √ next to the data you will be graphing.)

___ survival payload mass for each possible destination

___ science payload mass for each possible destination

___ total cost of a mission to each possible destination

___ other: ____________________________________

First you need to plan your graph by answering the five questions below. Then you should create your graph on graph paper or chart paper. Be sure to give your graph a *title* and to *label* your x- and y-axis.

1. What type of graph will you use?

   ☐ bar graph ☐ pie graph ☐ line graph ☐ ______________ other

2. What unit of measurement will you use? _____________________________

3. What scale will you use? _____ to _____ in increments of _____

4. What will be the maximum and minimum data values on your graph?

   Maximum value = _____ Minimum value = _____

5. Will your graph start at 0? If not, with what number will your graph begin?

   ____

Name: Date: .

Lesson 4 Extension Problems

The following are problems that will take multiple steps to solve. You will need to measure lengths inside the classroom, research the masses of everyday objects, and then apply what you know about scale and ratio and proportion to solve them. You may choose the units you work with, as long as they are appropriate. Be sure to include descriptions and pictures to explain how you solved the problem.

1. How Much Water Can You Carry?

When astronauts travel away from Earth, they have to take their water with them or use machines that will recycle water from waste and from the air.

Imagine you are going on a backpacking trip and that you will have to carry water with you for an extended amount of time.

A. Fill an ordinary backpack with books until it reaches a weight that you think you could *comfortably* carry for a long walk (6-8 hours). You might want to try walking around for a while with the filled backpack to see how quickly you get tired.

B. Measure the weight of the backpack in pounds, and then convert the weight to a mass value in kilograms using ratio and proportion.

1 pound ≈ 0.45 kg

C. One liter of water has a mass of 1 kg. If you were carrying your supply of water in the backpack, then how many liters of water could you carry?

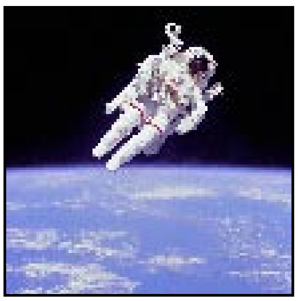
D. If you drank 1 liter of water a day, then how many day's worth of water could you carry?

Name: Date: .

E. The harder you work, the thirstier you get. If you needed to drink 1.5 liters of water a day, then how many days worth of water would you be able to carry?

F. Why do you think recycling water becomes so important for space travel?

2. Going Solo



In this lesson you calculated the mass that was needed for a three-person crew. Consider how much the mass requirements would change if the crew had only one person. For parts A through G below, calculate the values for a mission to each possible destination.

A. If only one person went on a mission to a planet or moon, then how much survival payload would be needed?

B. Calculate the number of vehicles a solo mission would need to transport the survival payload for one crew member.

C. Calculate the mass of a science payload that a one-person mission would be able to support .

D. Calculate the difference in mass of the science payload for a solo mission versus for a three-person mission.

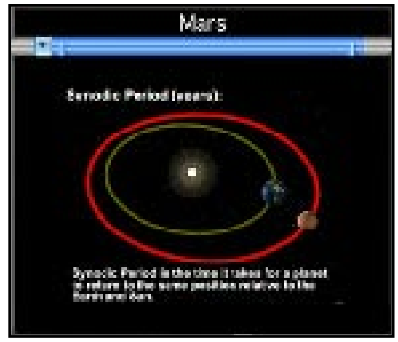
E. What are the risks involved for a solo mission? Are the risks worth the amount of money saved?

F. Why do you think NASA sends multiple astronauts on missions?

Name: Date: .

3. Just a Little While Longer...

In Lesson 3, mission lengths were calculated using one synodic period as the length of time astronauts would stay on a planet or a moon.



Imagine the astronauts stayed for *two* synodic periods so that they could conduct more research. For parts A through G below, calculate how the cost would change for a mission to each possible destination.

A. For the destination, add the length of one synodic period to the total mission length.

B. Based on the new mission length in Part A, calculate the survival mass needed for three astronauts for that length of time. (Round to the nearest whole kg.)

C. Calculate the number of vehicles required to transport the survival mass in Part B. (Round to 2 decimal points.)

D. Calculate the mass of the science payload in kg.

E. Add the mass of the survival payload, the science payload, the vehicles, and the astronauts (245 kg) in kilograms. Next, calculate the amount of fuel needed.

Remember: 1 kg of fuel is needed for every 1.79 kg of mass.

F. Add the mass of the fuel in kilograms to the mass of the survival payload, the science payload, the vehicles, and the astronauts. Next, multiply the total mass by $10,000 per kilogram to determine the cost of the mission.

G. How much more would it cost to have the astronauts stay at their destination for *two* synodic periods?

Name: Date: .

4. Comparing Space

The total living space (volume) for astronauts on a crew vehicle is 74 cubic meters.

How does this compare to other spaces that students occupy everyday?

A. Measure the dimensions of your classroom as accurately as possible. Next, calculate the volume of the classroom.

(This is more challenging for a non-rectangular classroom. In such a case, you may want to *approximate* the volume of the classroom.)

B. Calculate the ratio of the space inside the classroom to the space assigned for living in a crew vehicle. Write the answer as a fraction and as a percent. How do the spaces compare?

(You will need to be working with the same units. For example, if you measured the dimensions of the room in feet, then you will need to convert feet to meters so as to compare the volume of the room to the 74 m^3 of the crew vehicle.)

C. Follow steps A and B above with a room in your house. How does the space in your room compare to the space assigned for living in a crew vehicle?

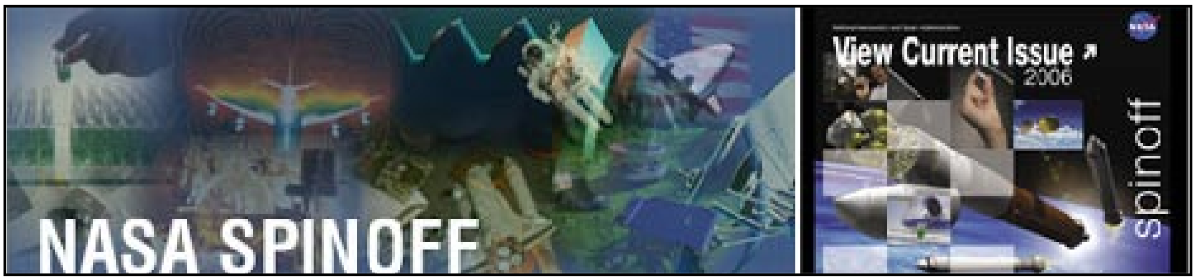
D. What is different about living in a crew vehicle? How can astronauts use space more efficiently than we can on Earth?

(Hint: Are you able to use the entire volume of your classroom, including the space up to the ceiling?)

Name: Date: .

5. Think About It / Write About It / Discuss It

Launching a mission to another planet or moon is extremely expensive. However, there are many positive outcomes of space exploration.



1. What value do we get from sending missions into the solar system?

2. Do some research on the Internet about "spinoffs" (http://www.sti.nasa.gov/tto/). What are some things that have benefited life on Earth that were developed by NASA for the space program? (For example, temper foam is a spinoff product of space exploration.)

3. Do these spinoff items you learned about in question 2 give missions greater value?

4. Make a list of all of the different types of people that are needed to build, equip, and control a crew vehicle. (For example, engineers help design the vehicle.)