National Aeronautics and Space Administration

NASA Explorer Schools Pre-Algebra Unit

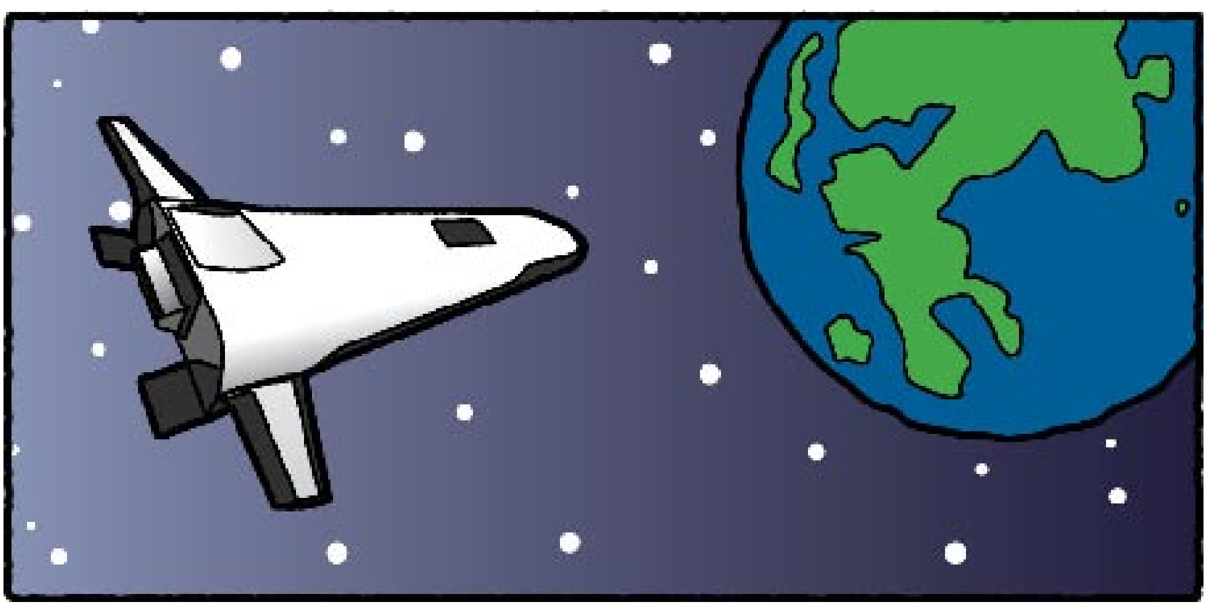
Lesson 4 Student Workbook

ANSWER KEY

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).

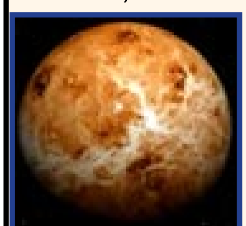
Astronauts also take with them basic hygiene necessities such as toothbrushes, toothpaste, soap, shampoo, etc.

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.

Since Venus is ruled out for its temperature, it will be used as an example throughout this lesson.

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



A mission to Venus would require 2.46 years (based on Lesson 3).

2.46 ~~years~~ • 365.25 days / 1 ~~year~~ ≈ 898.52 days

A roundtrip mission to Venus would last 898.52 days.

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

   Answers may vary but should be a reasonable and appropriate unit of mass.
   The mass of the survival payload will be measured in kilograms.

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)

   Answers will vary.
   I estimate the crew will need 15 kilograms 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.) Answers will vary based on the chosen planet or moon.

   survival payload mass = 15 kg/~~day~~ • 898.52 ~~days~~

I estimate the crew will need approximately 13,478 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:	**27.93 kg**	**7.40 kg**

2. Average the two totals and round to the nearest whole kg: 18 kg

$$\frac{27.93\text{ kg} + 7.40\text{ kg}}{2}$$

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:

$$\frac{18\text{ kg}}{1\text{ astronaut}} \cdot 3\text{ astronauts}$$

A crew of 3 astronauts will require 54 kg of survival mass each day.

(Ask students how their estimates on page 2 compare to this true value.)

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." Answers will vary.

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

1. Name your destination planet or moon: Venus

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

   survival payload = daily survival mass • total mission length in days

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 = 54 kg/~~day~~ • 898.52 ~~days~~

   ≈ **48,520 kg**

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

   13,478 kg vs 48,520 kg

   Estimated value Actual value

Just for fun!

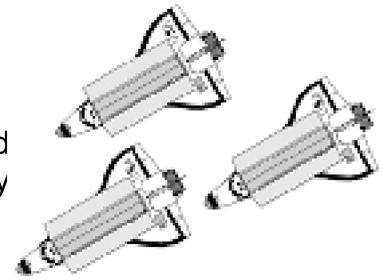
An empty bus has a mass of 12,000 kg. How many empty buses, *in terms of mass*, are equal to your mission's survival payload?

48,520 kg ÷ 12,000 kg ≈ 4.0433

Survival payload for a mission to Venus ≈ 4.04 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. Answers will vary.

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

48,520 kg	21,000 kg
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 X no

   Exception: *The survival payload for missions to Mercury and the Moon will fit inside 1 crew vehicle.*

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

   $$\frac{1 \text{ vehicle}}{21{,}000 \text{ kg}} \quad \text{or} \quad \frac{21{,}000 \text{ kg}}{1 \text{ vehicle}}$$

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 = survival payload in kg • 1 vehicle per 21,000 kg

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.) Venus example...

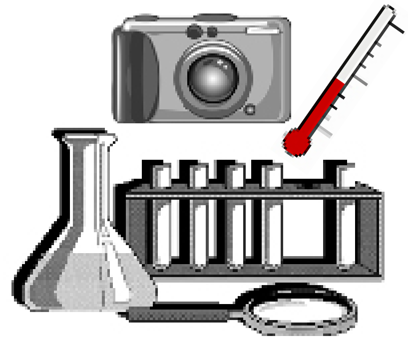
   $$\text{number of crew vehicles} = 48{,}520 \cancel{\text{kg}} \cdot \frac{1 \text{ vehicle}}{21{,}000 \cancel{\text{kg}}}$$

   ≈ 2.31 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.*)
   Students must round ***up*** their decimal value.

   A total of 3 crew vehicles are needed for a trip to Venus.

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 = total mission vehicles – survival 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.) This sample answer is for a mission to Venus.

science payload portion of vehicle = 3.00 vehicles – 2.31 vehicles

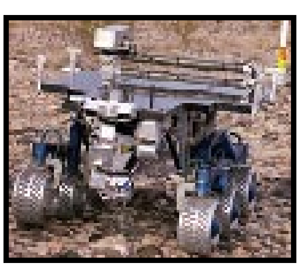
= 0.69 vehicle

The portion of a crew vehicle available for science payload is: 0.69 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 = science payload portion of vehicle • vehicle capacity in kg/vehicle

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.



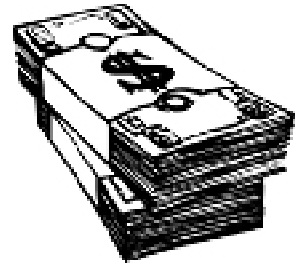
mass of science payload = 0.69 ~~vehicle~~ • 21,000 kg / 1 ~~vehicle~~

= 14,490 kg

The science payload can have a mass up to 14,490 kg.

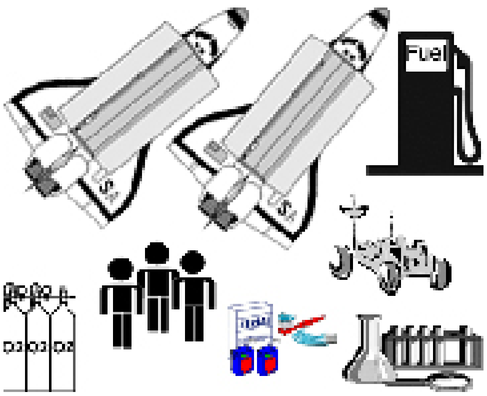
Name: Date: .

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

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? __3__ vehicles (for a mission to Venus)

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 = 85,000 kilograms • 3

= 255,000 kilograms

The total mass of the crew vehicles needed for my mission is 255,000 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: Venus

Total astronaut mass: 245 kg

Total crew vehicle mass (p.7): 255,000 kg

Total survival mass (p.4): 48,520 kg

Total science mass (p.6): 14,490 kg

SUM (mission mass without fuel)**:** 318,255 kg

IV. Now that you know the total mass of your crew, the vehicle fleet, 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 = mission mass before fuel ÷ 1.79

= 318,255 kilograms ÷ 1.79

= 177,796.09 kilograms

The mass of fuel needed for a mission to Venus ≈ 177,796 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. (The answer below is for Venus.)

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

= 245 kg + 255,000 kg + 177,796 kg + 48,520 kg + 14,490 kg

= **496,051 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?

Pluto

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

Moon

$ 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.)

Cost of mission = 496,051 ~~kg~~ • $10,000.00 / 1 ~~kg~~

= $4,960,510,000

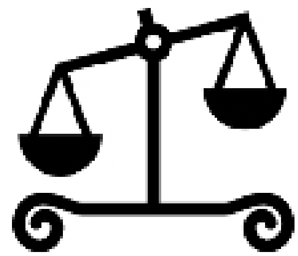
≈ 4.9 billion dollars

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

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:

$$\frac{\text{science payload mass}}{\text{total mission mass}}$$

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 = 14,490 ~~kg~~ / 496,051 ~~kg~~ (fraction)

≈ 0.029 (decimal)

≈ 2.9% (or 3%) (percent)

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

> The cost of the mission is $ 4,960,510,000, and the science payload represents about 3 % of the total mission mass.

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

Answer Key: Student Workbook pp.2-6

Destination	Mercury	Venus	Moon	Mars	Io/Europa	Titan	Triton	Pluto
answers from Lesson 3								
Mission Length in Years	1.02 yrs	2.46 yrs	0.08 yrs	3.40 yrs	4.19 yrs	6.30 yrs	16.53 yrs	21.16 yrs
= mission length in years • 365.25 days								
Mission Length in Days	372.56 days	898.52 days	29.22 days	1,241.85 days	1,530.40 days	2,301.08 days	6,037.58 days	7,728.69 days
= 18 kg per day • 3 astronauts								
Daily Survival Mass	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day
= mission length in days • daily survival mass for 3 astronauts in kg per day (rounded to nearest whole kg)								
Total Survival Payload	20,118 kg	48,520 kg	1,578 kg	67,060 kg	82,642 kg	124,258 kg	326,029 kg	417,349 kg
= survival payload in kg ÷ 12,000 kg (rounded to nearest hundredth)								
Survival Payload in Buses	1.68 buses	4.04 buses	0.13 bus	5.59 buses	6.89 buses	10.35 buses	27.17 buses	34.78 buses
= survival payload in kg ÷ 21,000 kg per vehicle (rounded to nearest hundredth)								
# Vehicles for Survival Payload	0.96 vehicle	2.31 vehicles	0.08 vehicle	3.19 vehicles	3.94 vehicles	5.92 vehicles	15.53 vehicles	19.87 vehicles
= number of crew vehicles for survival payload rounded up to the next whole number								
Total Crew Vehicles	1 vehicle	3 vehicles	1 vehicle	4 vehicles	4 vehicles	6 vehicles	16 vehicles	20 vehicles
= total crew vehicles - portion of vehicles for survival payload								
Portion of Vehicle for Sci Payload	0.04 vehicle	0.69 vehicle	0.92 vehicle	0.81 vehicle	0.06 vehicle	0.08 vehicle	0.47 vehicle	0.13 vehicle
= portion of vehicle for science payload • 21,000 kg per vehicle								
Total Science Payload	840 kg	14,490 kg	19,320 kg	17,010 kg	1,260 kg	1,680 kg	9,870 kg	2,730 kg

Answer Key: Student Workbook pp.7-10

Destination	Mercury	Venus	Moon	Mars	Io/Europa	Titan	Triton	Pluto
= number of crew vehicles • 85,000 kg								
Total Crew Vehicle Mass in kg	85,000 kg	255,000 kg	85,000 kg	340,000 kg	340,000 kg	510,000 kg	1,360,000 kg	1,700,000 kg
= astronaut mass + crew vehicle mass + survival payload mass + science payload mass								
Mission Mass w/o fuel in kg	106,203 kg	318,255 kg	106,143 kg	424,315 kg	424,147 kg	636,183 kg	1,696,144 kg	2,120,324 kg
= sum of mission mass in kg without fuel ÷ 1.79 (rounded to nearest whole number)								
Total Fuel Mass in kg	59,331 kg	177,796 kg	59,298 kg	237,047 kg	236,954 kg	355,409 kg	947,566 kg	1,184,539 kg
= astronaut mass + crew vehicle mass + survival payload mass + science payload mass + fuel mass								
Total Mission Mass in kg	165,534 kg	496,051 kg	165,441 kg	661,362 kg	661,101 kg	991,592 kg	2,643,710 kg	3,304,863 kg
= total mission mass in kg • $10,000.00 per kg								
Total Mission Cost in $	$1,655,340,000 ($1.6 billion)	$4,960,510,000 ($4.9 billion)	$1,654,410,000 ($1.6 billion)	$6,613,620,000 ($6.6 billion)	$6,611,010,000 ($6.6 billion)	$9,915,920,000 ($9.9 billion)	$26,437,100,000 ($26.4 billion)	$33,048,630,000 ($33 billion)
= science payload mass in kg ÷ total mission mass in kg (rounded to 3 decimal places)								
Sci Mass : Missn Mass (decimal)	0.005	0.029	0.117	0.026	0.002	0.002	0.004	0.001
= ratio of science payload mass to total mission mass written as a percent								
Percent of Science Payload	0.5%	2.9%	11.7%	2.6%	0.2%	0.2%	0.4%	0.1%

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.

Name: Date: .

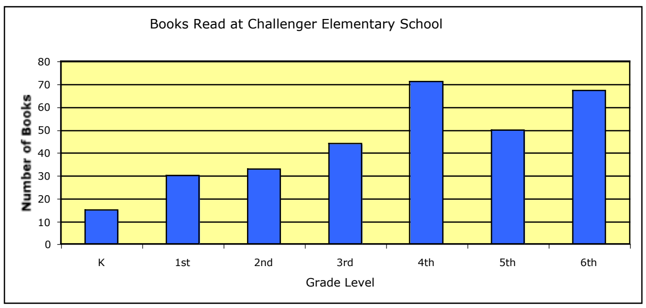
Graphing Resource

Student Guide

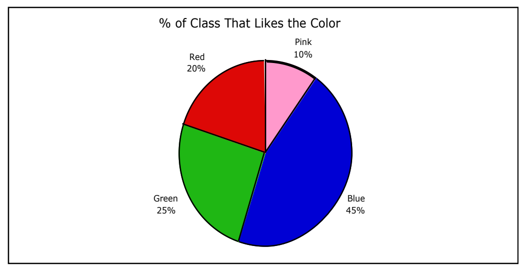
Types of Graphs

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

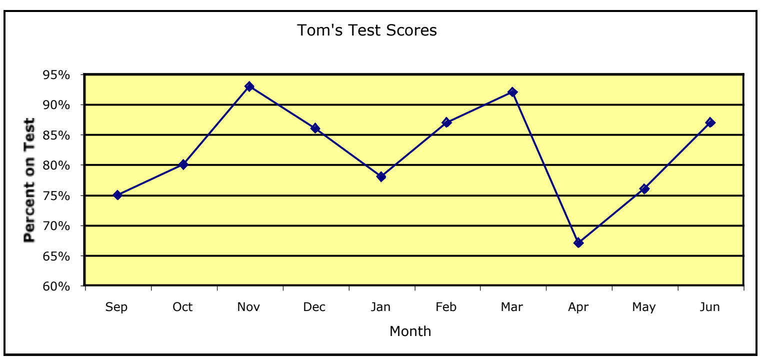
Bar graphs are often used to compare values.



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: .

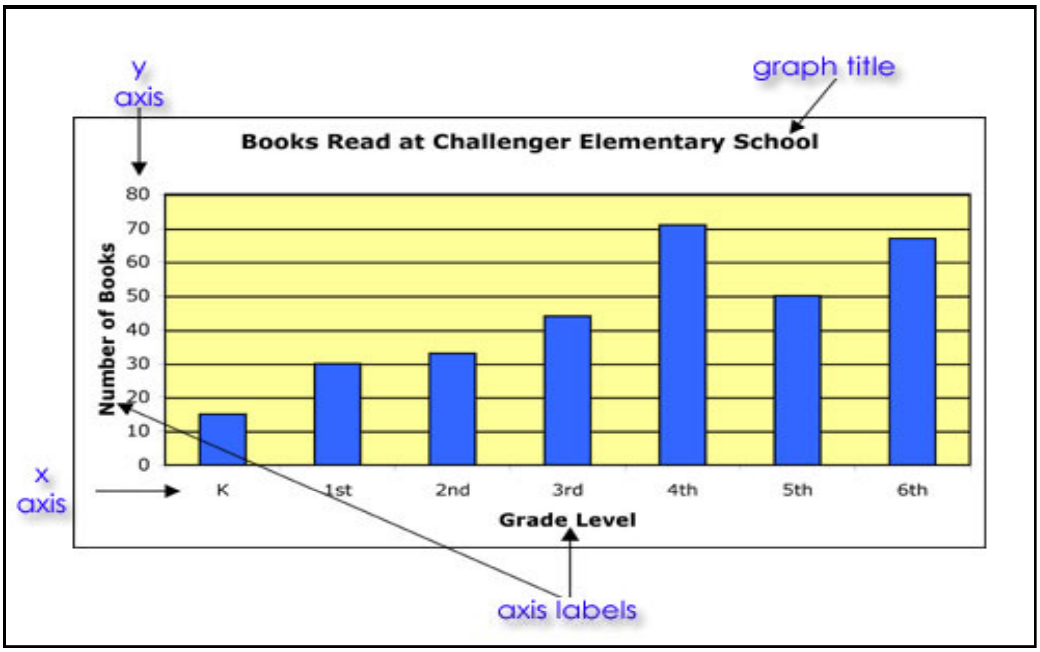
Before You Begin

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.

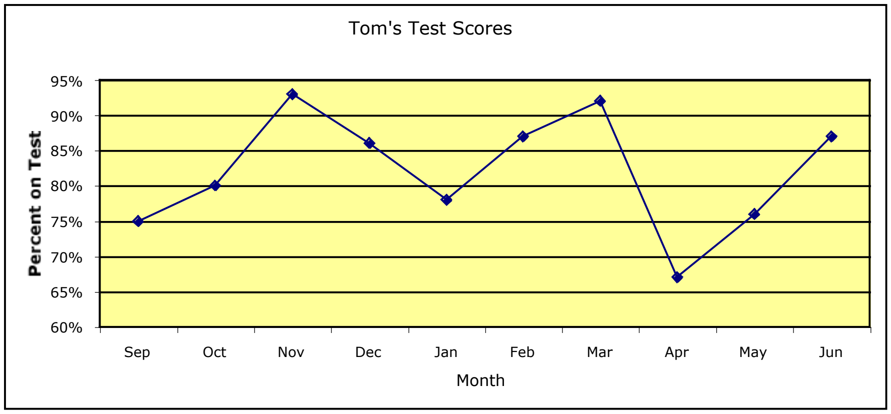
You also must choose a **scale** for your vertical y-axis. The vertical scale on the bar graph above goes from 0 to 80 in increments of 10.

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%.

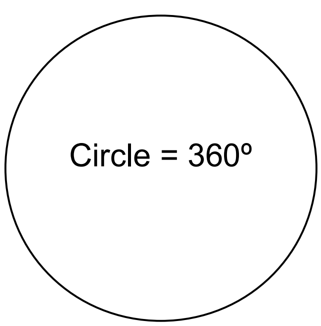
The unit of measurement for this graph is "percent." (%)



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%**

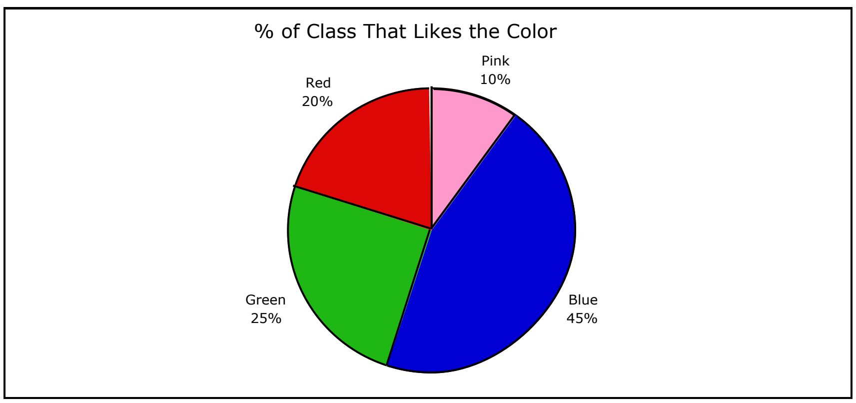
The sum of your fractions should total to 100%.

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.

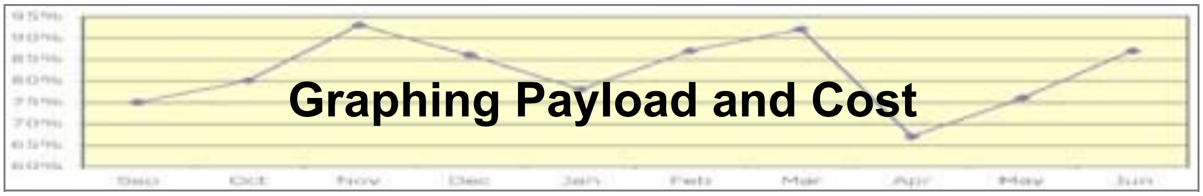
Pink	=	36º
Blue	=	162º
Green	=	90º
Red	=	72º
Total	**=**	**360º**



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.

Responses to the following questions will vary based on the item(s) selected above.

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.

Answers will depend on how much weight the student thinks he or she can carry. An adult backpacker can carry between 30 to 40 pounds (≈ 13.6 to 18 kg). This would be approximately 13 to 18 days worth of water.

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?

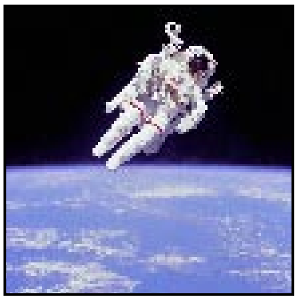
D. If you drank 1 liter of water a day, then how many day's worth of water could you carry?

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? = total survival payload (p.4) ÷ 3

B. Calculate the number of vehicles a solo mission would need to transport the survival payload for one crew member. = survival payload ÷ 21,000 kg
= answer rounded up to whole number

C. Calculate the mass of a science payload that a one-person mission would be able to support. = portion of vehicle for science payload • 21,000 kg

D. Calculate the difference in mass of the science payload for a solo mission versus for a three-person mission.
= science payload for 1 person - science payload for 3 people

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

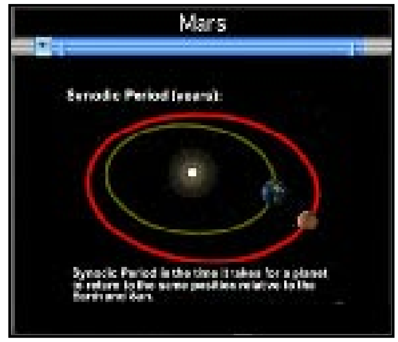
F. Why do you think NASA sends multiple astronauts on missions?

		A	B	C		D
Destination	**Survival Payld 3 people (kg)**	**Survival Payld 1 person (kg)**	**# of vehicles solo mission**	**Science Payld 1 person (kg)**	**Science Payld 3 people (kg)**	**Difference in Sci Pylds (kg)**
Mercury	20,118 kg	6,706 kg	1 vehicle	14,280 kg	840 kg	+ 13,440 kg
Moon	1,578 kg	526 kg	1 vehicle	20,370 kg	19,320 kg	+ 1,050 kg
Mars	67,060 kg	22,353 kg	2 vehicles	19,740 kg	17,010 kg	+ 2,730 kg
Io/Europa	82,642 kg	27,547 kg	2 vehicles	14,490 kg	1,260 kg	+ 13,230kg
Titan	124,258 kg	41,419 kg	2 vehicles	630 kg	1,680 kg	- 1,050 kg
Triton	326,029 kg	108,676 kg	6 vehicles	17,220 kg	9,870 kg	+ 7,350 kg
Pluto	417,349 kg	139,116 kg	7 vehicles	7,980 kg	2,730 kg	+ 5,250 kg

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.

See table of answers on the following page.

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: .

Destination	Mercury	Moon	Mars	Io/Europa	Titan	Triton	Pluto
Synodic Prd	0.32 yrs	0.08 yrs	2.14 yrs	1.09 yrs	1.04 yrs	1.01 yrs	1.00 yrs
Mssn Length (1 synd prd)	1.02 yrs	0.08 yrs	3.40 yrs	4.19 yrs	6.30 yrs	16.53 yrs	21.16 yrs
= mission length for 1 synodic period + additional synodic period							
Mssn Length (2 synd prd)	1.34 yrs	0.16 yrs	5.54 yrs	5.28 yrs	7.34 yrs	17.54 yrs	22.16 yrs
= mission length for two synodic periods in years • 365.25 days							
Mssn Length in days	489.44 days	58.44 days	2,023.49 dys	1,928.52 dys	2,680.94 dys	6,406.49 dys	8,093.94 dys
Daily Survivl Mass for 3	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day	54 kg/day
= mission length in days • daily survival mass for 3 astronauts in kg per day (rounded to nearest whole kg)							
Survival Payload for 3	26,430 kg	3,156 kg	109,268 kg	104,140 kg	144,771 kg	345,950 kg	437,073 kg
= survival payload in kg ÷ 21,000 kg per vehicle (rounded to nearest hundredth)							
# of Vehicles (survivl pyld)	1.26 vehicle	0.15 vehicle	5.20 vehicle	4.96 vehicle	6.89 vehicle	16.47 vehicl	20.81 vehicl
# of Vehicles for totl missn	2 vehicles	1 vehicle	6 vehicles	5 vehicles	7 vehicles	17 vehicles	21 vehicles
= total number of crew vehicles - portion of vehicles for survival payload							
# of Vehicles (for science)	0.74 vehicle	0.85 vehicle	0.80 vehicle	0.04 vehicle	0.11 vehicle	0.53 vehicle	0.19 vehicle
= portion of vehicle for science payload • 21,000 kg per vehicle							
Science Payload	15,540 kg	17,850 kg	16,800 kg	840 kg	2,310 kg	11,130 kg	3,990 kg
= number of crew vehicles • 85,000 kg							
Vehicle Mass	170,000 kg	85,000 kg	510,000 kg	425,000 kg	595,000 kg	1,445,000kg	1,785,000kg
Missn Mass w/o Fuel	212,215 kg	106,251 kg	636,313 kg	530,225 kg	742,326 kg	1,802,325kg	2,226,308kg
= sum of mission mass without fuel ÷ 1.79 (rounded to nearest whole number)							
Fuel Mass	118,556 kg	59,358 kg	355,482 kg	296,215 kg	414,707 kg	1,006,885kg	1,243,747kg
Total Mission Mass	330,771 kg	165,609 kg	991,795 kg	826,440 kg	1,157,033kg	2,809,210kg	3,470,055kg
New Mission Cost	$3.3 billion	$1.7 billion	$9.9 billion	$8.3 billion	$11.6 billion	$28.1 billion	$34.7 billion
Original Mission Cost	$1.6 billion	$1.6 billion	$6.6 billion	$6.6 billion	$9.9 billion	$26.4 billion	$33.0 billion
Difference in Mission Cost	+ $1.7 billion	+ $0.1 billion	+ $3.3 billion	+ $1.7 billion	+ $1.7 billion	+ $1.7 billion	+ $1.7 billion

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?

Answers will vary depending on the room sizes.

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?

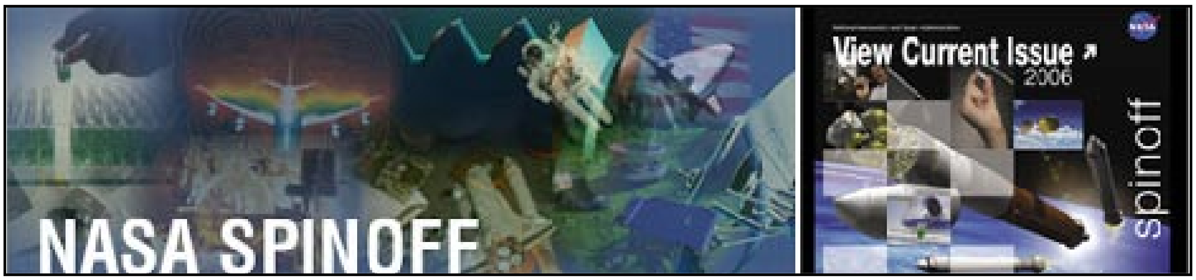
D. What is different about living in a crew vehicle? How can astronauts use space more efficiently than we can on Earth?

(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.)