A mathematical tour of American Museum of Natural History

Getting to know the city through a mathematical walk

Welcome to the Math for America Math Trail at the American Museum of Natural History! The idea behind a Math Trail is quite simple. Students follow a planned route and answer mathematical questions related to what they encounter along the path. Through the experience students are given the opportunity to connect mathematics to many subjects including art, design, architecture, science, geography, and history.

This Math Trail was prepared by Ron Lancaster, a Lecturer in K-12 Mathematics Education at the University of Toronto. Prior to his position at the University of Toronto, Ron taught middle and high school mathematics for over 20 years. Ron used Math Trails in his own teaching to make the study of mathematics more attractive and engaging.

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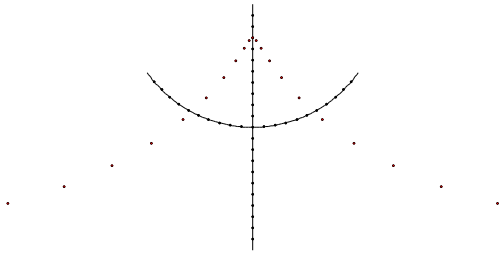


Name that graph...

The Trail

The Trail begins at the entrance to the Gottesman Hall of Planet Earth. One way of locating this area is by entering the museum from Central Park West. As soon as you enter the building you will be in the Theodore Roosevelt Memorial Hall. Turn right and you will see the entrance to the Gottesman Hall of Planet Earth.

Question 1

As you enter the Gottesman Hall of Planet Earth, turn right and then look on your left side for the exhibit titled Forces that Affect Climate. Within this exhibit find the section titled Ice Ages and the Earth's Orbit. Estimate how many years have been used on the horizontal axes for each of the following Milankovic Cycles.

(a) wobble
(b) tilt
(c) elliptical shape of the orbit

Question 2

On the graph for the elliptical shape of the orbit, the y-axis is labeled as "more" or "less". What does this mean? For example, of the two ellipses shown in Figure 1, which one is more elliptical? How would you measure this notion of more or less?

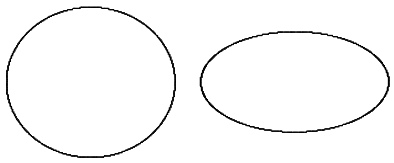


Figure 1

Question 3

On your left side locate the exhibit titled How Climate is Recorded in Ice (this is located in the area with the sliding graphical display on a long track).

Record the data in Table 1 for the three 1-meter lengths of ice from a core that penetrated through the entire 3,022 meter-thick Greenland Ice Sheet.

Table 1		
	depth (meters)	date (BC)
left core		
middle core		
right core		

Even though there is very little data in Table 1, provide one observation about the relationship between the depth and date.

Question 4

On the right side of this hallway, locate the exhibit titled The Atmosphere. Refer to the pie chart titled Composition of the Atmosphere and record the data in Table 2.

Table 2	
Nitrogen	
Oxygen	
Argon	
All other elements	

Without using a calculator, determine if the following statements are true or false.

(a) The amount of nitrogen is over five times the amount of oxygen.

(b) The ratio of oxygen to argon is about the same as the ratio of argon to all other elements

(c) The four percentages add up to 100%.

Question 5

Locate the graph in the section titled Global Warming.

(a) The scales on the vertical axis for the average temperature and atmospheric CO_2 concentration are very clear. The same cannot be said for the scale on the horizontal axis. Which tick marks correspond to the years 1870 and 1970? Has data been given on this graph for years before 1870 and after 1970?

(b) Has the atmospheric CO_2 concentration changed linearly for the time period shown? If not, suggest a function that could be used to model the level of CO_2.

(c) What does parts per million mean? What is a part and why is the number a million being used? Why is a billion not used?

Question 6

Walk a short distance to the circular exhibit on the right side titled Atmosphere on Earth and Venus.

(a) The statement is made that Venus and Earth are about the same size. If for example there is a 1% difference between the radii of these planets, can it be said that there is a 1% difference between their

(i) diameters?
(ii) surface areas?
(iii) volumes?

(b) If two spheres have the same volume, do they have the same surface area? Is the reverse true?

Question 7

Walk to the nearby display titled Dynamic Earth and sit in the circular shaped area below the semi-sphere on the ceiling that displays continuous images of the earth.

(a) Estimate the number of people that could sit or stand in this area.

(b) If the diameter of the circle that encloses this seating area (as measured from the outer edge of the steps on one side to the outer edge on the other side) were twice as large, how many people could now sit or stand in this area? Is the answer twice as many?

(c) Estimate the diameter of a circular shaped area that would provide enough room for the population of the entire world (approximately 6.6 billion people) to sit or stand in.

Question 8

Walk to the nearby exhibit titled Forming the Planets.

(a) How many hours did it take for the planets to form? How many years did it take the moon to form?

(b) Compare the time it took for the planets to form to the time for the moon to form.

Question 9

Locate the nearby bronze model of the earth named after Wallace Gilroy.

(a) Estimate the radius of this sphere. Use a piece of string to measure the circumference of the sphere and then calculate the radius. Compare your calculated value to your estimated one. How else could you determine the radius?

(b) Given that the radius of the earth at the equator is approximately 6378 km, how tall would you be if this model were the actual size of the earth?

Question 10

Walk into the room behind the bronze model, turn right and walk to the back of the room to locate the exhibit titled Measuring an Earthquake's Intensity.

(a) Use the text that accompanies this exhibit to fill in the missing numbers.

The scale is calibrated logarithmically, meaning that a _____ is _____ times greater than a _____. Measured in terms of actual energy release, each step on the Richter scale represents _____ times more energy.

(b) Use the information contained in the text to determine the comparisons in Table 3.

Table 3

Richter Scale Magnitude Comparison	Ratio of Ground Motion Effect	Ratio of Energy Released
5 versus a 4	10:1	33:1
6 versus a 4		
7 versus a 4		
8 versus a 4		
9 versus a 4		
3 versus a 4		
5.5 versus a 4		

(c) Fill in the data in Table 4 for the average number of earthquakes per year for each of the following cases. What patterns do you notice between the average number and the magnitude?

Table 4	
magnitude	average number of earthquakes per year
2	
3	
4	
5	
6	
7	
8	

(d) The data in Table 5 appears in this area of the exhibit. Is this data consistent with the claim made that each step on the Richter Scale represents 33 times more energy?

Table 5	
magnitude	energy release
2	56
3	1,800
4	56,000
5	1,800,000
6	56,000,000
7	1,800,000,000
8	56,000,000,000
9	1,800,000,000,000
10	56,000,000,000,000

Question 11

Around the corner from your present location, you will find an exhibit titled How Rocks Form. Locate the section titled Deforming Rocks in the Laboratory.

(a) Use the information contained in the exhibit to fill in the missing information in Table 6.

Table 6	
d depth (kilometers)	P pressure (atm)
0	
0.1	
0.3	
0.7	
1.2	
1.7	
3.3	
6.7	

(b) Graph P versus d and determine the relationship between these variables. After the Trail research this topic and look for scientific reasons that explain this relationship.

(c) Take a digital photo of the 8 rocks in the glass display. After the Trail print a hard copy of the photo and measure the height of each rock as it appears in the photo. How do these heights change from one rock to the next?

Table 7	
rock	height in digital photo
1	
2	
3	
4	
5	
6	
7	
8	

Question 12

Leave this room and enter the Planetarium through the nearby entrance.

When you enter the room you will encounter a scale that shows your weight on the moon. Choose a member of your group who is willing to divulge their weight and have this person stand on the scale. Record the weight that appears on the scale and the weight of this person on earth.

Table 8	
location	weight
Moon	
Earth	

(a) How are these weights related?

(b) Based on these two weights, would you weigh more or less on a planet that is bigger than the earth?

Question 13

Go down one level and locate the exhibit titled The Universe.

(a) Use the text that accompanies this exhibit to fill in the missing numbers.

In New York City, we revolve around Earth's axis at a speed of _____ kilometers an hour. Earth orbits the Sun at an average speed of _____ km/h.

(b) Is the speed in Jakarta the same as in New York City? How do you know?

(c) For the case of the Earth orbiting the Sun, the speed is described as being an average. Why is the word average used here?

Question 14

Locate the exhibit titled Interacting Galaxies. The statement given below appears in the section titled A Tabletop Galaxy Collision.

The intensity of light and the force of gravity decrease with distance in the same manner

(a) How did Holmberg take advantage of the similarity in the behavior of light and gravity to build a model to study gravity?

(b) Based solely on the above statement, which functions could be used to model the relationship between the intensity of light (represented by y) or the force of gravity (represented by y) and the distance from the source (represented by x).

$y = kx$ $\quad y = kx^2$ $\quad y = kx^3$

$y = \frac{k}{x}$ $\quad y = \frac{k}{x^2}$ $\quad y = \frac{k}{x^3}$

$y = k\sin(x)$ $\quad y = k\cos(x)$

(c) After the Trail, research which model is correct (depending on what you know, you might already know the answer). Use this function to answer these questions.

(i) If the value of x is doubled, what happens to the value of y? What does this mean in terms of the intensity of light and the force of gravity?

(ii) What type of change in the value of x would cause the value of y to become twice as small? What about twice as large?

Question 15

Locate the nearby circular seating area. Note that the top is covered with small blue square tiles.

(a) Estimate the total number of blue square tiles.

(b) Measure the side of a tile and the diameter of the circle. If the tiles covered the entire surface, calculate the total number of tiles that would appear on the surface. Compare this calculated result to your estimate from part (a).

Question 16

Scattered around this area, you will find at least four different scales that display your weight on places other than the earth. Locate these scales and find the weight of the same person who was weighed in Question 12. Record these weights in Table 9.

Table 9	
location	weight
Earth	
Mars	
Neutron Star	
Red Giant Star	
Halley's Comet	

(a) How are these weights related?

(b) Based on these weights and the weight on the moon from Question 12, would you weigh more or less on a planet that is bigger than the earth?

Question 17

Locate the nearby exhibit titled Stars.

(a) Record the definitions of Low Mass Stars, Intermediate Mass Stars, High Mass Stars and Very High Mass Stars.

(b) Only the first definition expresses the size of the star as a percentage of the mass of the Sun. Rewrite the other three definitions using percentages.

Question 18

Locate the section of this exhibit titled Lives of Stars.

(a) Rewrite the text that contains comparisons of the lives of the four different types of stars using powers of ten.

Low mass stars live _____ times longer than Intermediate Mass Stars. Intermediate Mass Stars live _____ times longer than High Mass Stars. High Mass Stars live _____ times longer than Very High Mass Stars.

(b) Make a ratio comparing the

(i) the life of a Low Mass Star with that of a Very High Mass Star

(ii) life of a Very High Mass Star with that of a Low Mass Star

Does the use of powers of ten in part (a) make these comparisons easier to state?

Question 19

In this section locate four vertical lines similar to those shown in Figure 2.

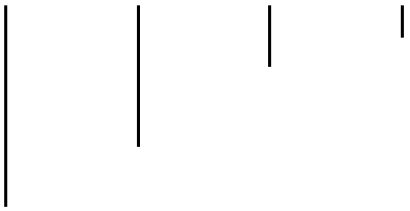


Figure 2

(a) What information is being conveyed by these lines? Are they drawn to scale?

(b) Each vertical line contains a small light that runs down the line. Time how long each light takes to go from top to bottom. How are these times related to the information being conveyed?

(c) Note how line segments have been joined from the bottoms of the second and third line segments to the tops of the first and second line segments (Figure 3). Oddly, the bottom of the last line segment has been joined to a point slightly down from the top of the third line segment (that point is marked with a 1). Why is there a difference?

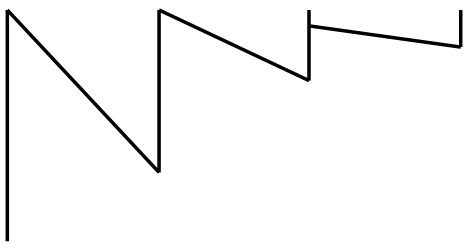


Figure 3

Question 20

Walk to the exhibit that is located directly under the bottom of the Planetarium.

(a) Use the text that accompanies this exhibit to fill in the missing numbers. Then use the numbers to answer the questions in parts (b) to (e).

The sun's volume is so large that it could hold a _____ earths. Light takes over _____ minutes to travel from the sun to the earth. All other stars are more than _____ times farther away from earth than the sun. The surface of the sun glows white hot at _____ degrees Celsius, hot enough to vaporize all known substances.

(b) Calculate the ratio of the radius of the sun to that of the earth.

(c) Given that the speed of light is 299,792,458 meters per second, calculate the distance from the sun to the earth.

(d) How long would it take light to get from our closest star to the earth?

(e) Given that 100^0 Celsius is the equivalent of 212^0 Fahrenheit, is it true that the temperature at the surface of the sun is 10600^0 ?

Question 21

Walk to the nearby exhibit titled Supernova and locate the section titled Energy of a Supernova. Stop and admire the clever and fascinating manner in which a graph has been presented in order to fit in with the design of the exhibit. For many of you, this might be the first time in which you have seen a graph with a horizontal axis that is curved. In this question you are going to have an opportunity to see what other standard graphs look like when presented on this type of coordinate system.

Graph each of the functions on the grid provided in Figure 4. Extra grids have been provided in Appendix A.

(a) $y = x$

(b) $y = x^2$

(c) $y = 2^x$

(d) $y = \sin x$

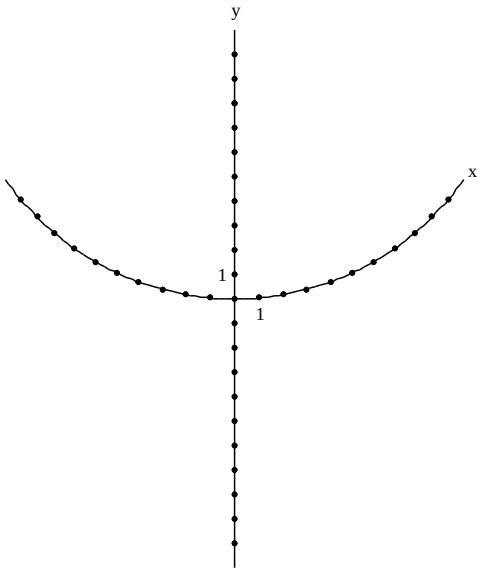


Figure 4

Question 22

If the graph discussed in Question 21 had been drawn on a standard set of axes it would be similar to one shown in Figure 5. Which of the following functions could be used to create this graph? What other functions could be used to produce graphs of this form?

(a) $y = \dfrac{8x^2}{2^x}$

(b) $y = 2^x \; y = \dfrac{2^x}{8x^2}$

(c) $y = 0.06x(10 - x)^2$

(d) $y = 0.06x^2(10 - x)$

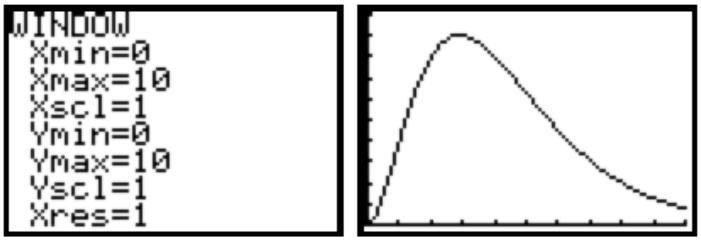


Figure 5

Question 23

Locate the exhibit titled Planets. Check that the data in Tables 10 and 11 has been entered correctly.

Table 10			
	diameter relative to Earth (km)	mass relative to Earth (grams)	temperature range (Celsius)
Mercury	0.382	0.055	-180^0 to 470^0
Earth	12,800	5.97×10^{27}	-15^0 to 40^0
Uranus	4.01	14.5	-210^0
Jupiter	11.2	318	-150^0
Venus	0.949	0.815	480^0
Mars	0.532	0.107	-120^0 to 20^0
Saturn	9.45	95.2	-180^0
Neptune	3.88	17.1	-210^0

Table 11			
	period of rotation	period of revolution	mean distance to the sun relative to the Earth
Mercury	58.6 days	88.0 days	0.387
Earth	23 h 56 m	365.25 days	150 million km
Uranus	17 h 14 m	83.7 years	19.2
Jupiter	9 h 56 m	11.9 years	5.20
Venus	243 days	225 days	0.723
Mars	24 h 37 m	1.88 years	1.52
Saturn	10 h 39 m	29.4 years	9.54
Neptune	16 h 7 m	164 years	30.1

By graphing one set of data versus another, search for relationships between the quantities in Tables 10 and 11. For example, is there a relationship between the period of revolution and the mean distance to the sun or this there a connection between the mass and diameters of the planets?

Question 24

Make your way to the second level using the escalators or the Roosevelt elevators and locate the exhibit titled The Scales of The Universe. Go for a power walk around this 400-foot-long walkway. Develop 10 questions of your own related to the information that appears in the Powers of Ten material, to the 87-foot Hayden Sphere, to the 9-foot model of Jupiter and to the 17-foot rings of Saturn.

Question 25

Enter the Big Bang Theater and go through the exit at the opposite end. Walk down the ramp and follow the Harriet and Robert Heilbrunn Cosmic Pathway. Develop questions of your own related to the 13 billion year journey that you will take as you follow the 360-foot walkway. For example, at the start of the path, you can measure the length of your stride and calculate how many millions of years pass with every step. What questions come to mind related to this activity?

Question 26

The next few questions require you to go outside. Exit the building using the Columbus Street entrance.

When you leave the building you will encounter The Times Capsule designed by Santiago Calatrava and created by the New York Times.

(a) What is the earliest date on which this time capsule can be opened? What day of the week will this be?

(b) Exactly how many days remain until the first day that the time capsule can be opened?

Question 27

Walk a short distance in the direction of Columbus Avenue, turn to the right and locate the nearby Alfred Nobel Sculpture.

(a) Estimate or measure where possible, the height and the sides of the squares at the base and top of the sculpture. Calculate the volume and surface area of the structure. Which one of these quantities would be important in determining the cost of the materials used to make this sculpture?

(b) Two sides are almost filled with the names of American recipients. Estimate how many years it will take before the third side will be filled (it is presently blank).

Question 28

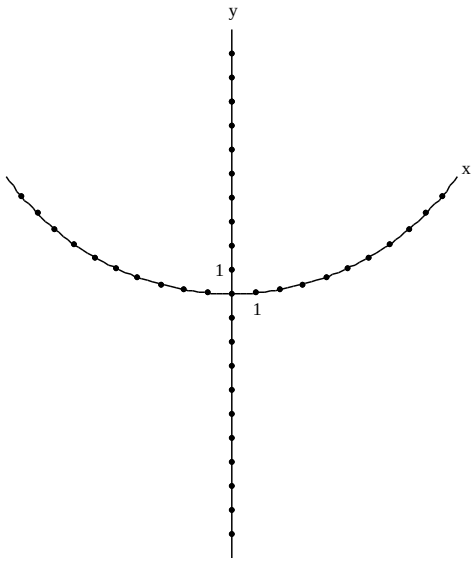
This marks the end of the Trail. I hope that you have enjoyed it and that it has provided you with a good overview for what a Trail might look like. Before you stop, here is a puzzle for you to work on.

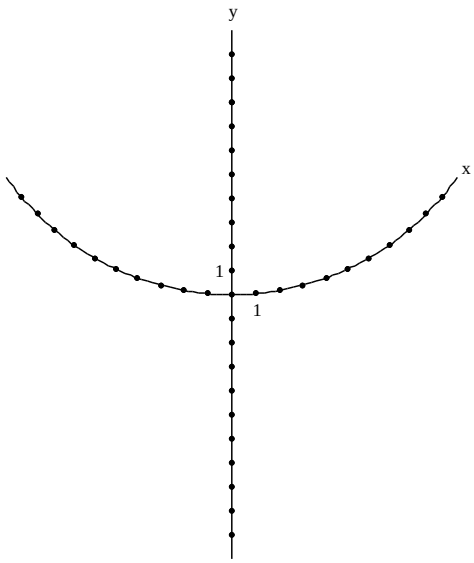
In the addition puzzle given below (ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE + ROSE = CENTER), each letter represents a digit from 0 to 9. Any given letter stands for just one digit (in other words the value of R cannot be say 3 and 9 at the same time) and two different letters cannot stand for the same digit (so O and S can't both be say 7). Also the first letter of any word cannot be 0. There is only way of assigning digits to these letters so that the rows of ROSE add up to CENTER. Good luck finding the solution!

		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
		R	O	S	E
+		R	O	S	E
C	E	N	T	E	R

Appendix A

Extra grids for Question 21.

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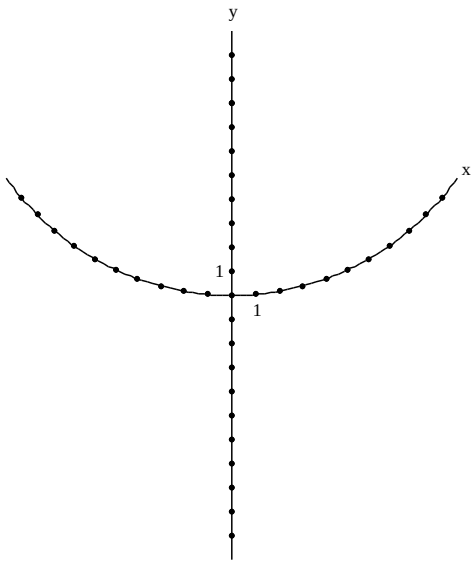
x
1
1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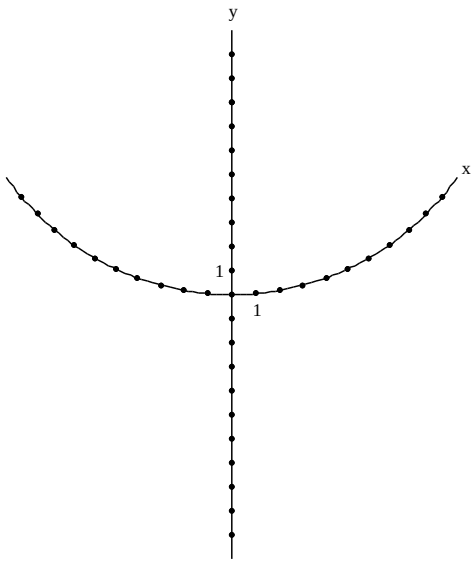
y
x
1
1

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