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Curriculum topics:

- Velocity and Speed
- Slope
- Rates
- Ratios
- Algebraic Formulas
- Roller Coasters

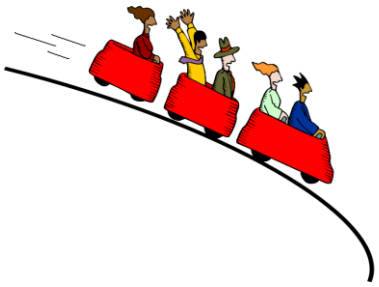
Subjects:

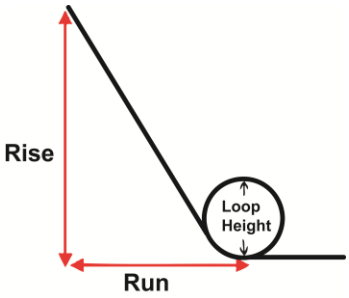
Mathematics, Physical Science

Grade range: 6 – 12

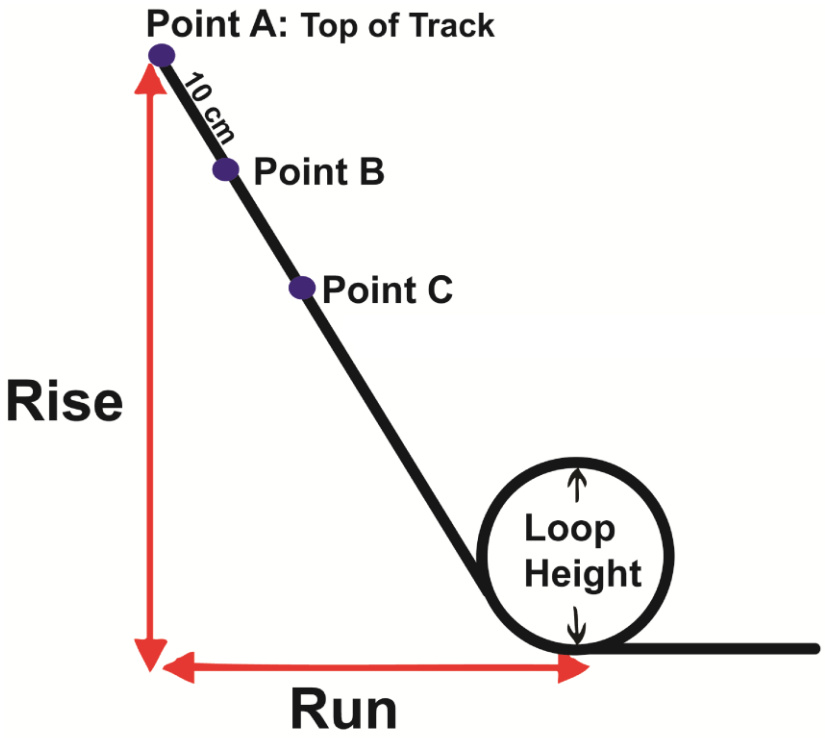
ROLLER COASTER MATH

Use math to design roller coasters





What does math have to do with thrilling roller coaster rides? How high does a coaster need to be to successfully navigate through a loop and on to the end of the track? How is the speed of the coaster related to the height of the coaster's starting position?



Who we are:

Resource Area for Teaching (RAFT) helps educators transform the learning experience through affordable "hands-on" activities that engage students and inspire the joy and discovery of learning.

For more ideas and to see RAFT Locations

www.raft.net/visit-raft-locations

http://www.raft.net/raft-idea?isid=659

Materials required

For each activity station:

- Marble, 1 per team
- Foam pipe insulation (not self-sealing type), for ~1.5 to 2.5 cm pipe (½" to 1"), 2 to 2.5 meters (6 to 8 ft) in length, sliced in half lengthwise, 1 half for each team
- Masking tape
- Stopwatch, or other timing device
- Metric tape measure
- Calculator
- Table or desk
- Roller Coaster Recording sheet, 1 or more per team

Design Challenge Introduction

Before going to the **How to build it** section, challenge students to use their ingenuity to see if they can create a roller coaster using the foam pipe insulation without any directions. Don't show them any pictures or give them any hints.

Encourage them to play with the foam pipe insulation tubing and the marble and see if any ideas come to mind. Eventually, one or more students will get the idea of making at least one loop for the marble to travel on. As soon as that happens, focus the attention of the other students on that idea. Soon, everyone will be trying to add a loop to their tracks. At this moment, the students are experiencing the same creative "challenges" that roller coaster engineers experience!

Now show them pictures of real roller coasters and give them instructions on how to assemble theirs using this RAFT Idea Sheet.

How to build it

1. Measure and record the length of the piece of the foam pipe insulation. Tape one end of a half-tube "track" to the top edge of a table or desk.

2. Configure the rest of the track, going toward the floor, with one vertical loop-de-loop (see figure 1) so that a marble released at the top of the track will successfully navigate the loop-de-loop and reach the end of the track. (Practice releasing the marble along several track configurations until the team chooses one configuration that seems the best).

3. Tape underneath the bottom of the loop, and then tape this connection onto the floor (be careful not to put tape on the inside of the U-channel which might block the path of the marble.)

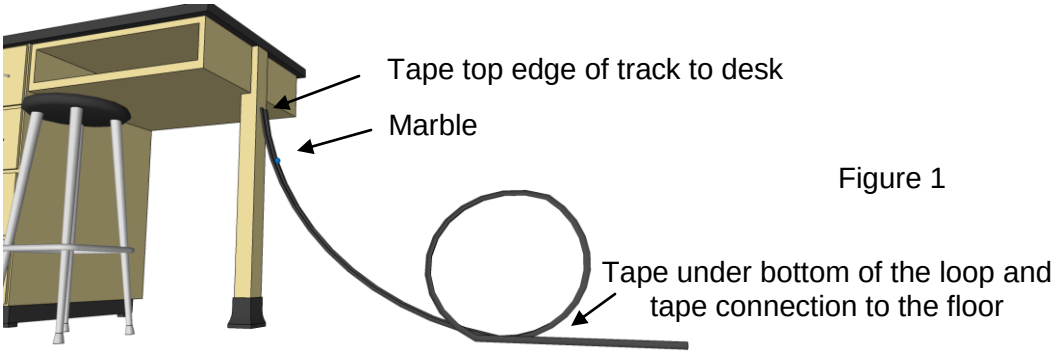
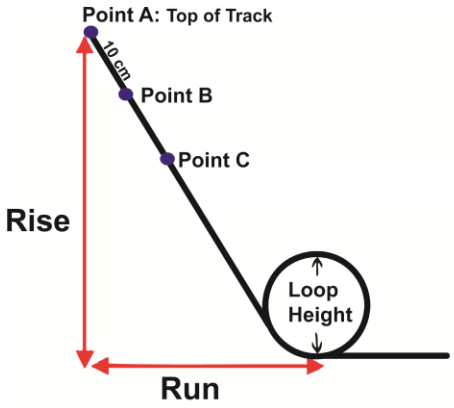


Figure 1

To do and notice (for teams of 4)

1 For the chosen track configuration, measure and record the height of the loop (in cm), the *rise* (the height of the top of the track above the floor), and the *run* (the horizontal distance from the top of the track to the beginning of the loop), see illustration. Compute the slope (rise divided by the run) of the track on the recording sheet.



2 Test the chosen configuration:
Note: Place the marble on the track at the starting point, release, and let gravity take over. Be careful not to push the marble.
Starting at the top of the track **(Point A)**, conduct 3 trials. For each trial:

a. Measure (in seconds) and record the time it takes for a marble to traverse the track. (Start the timer once the marble is released at the top of the track. Stop the timer once the marble exits the track.)
b. Calculate the average speed for each trial (track length/trial time). Note: the velocity (speed and direction) of the marble is changing throughout the run; this calculation gives the average speed (not the instantaneous velocity) for each run.
c. Add the 3 average speeds and divide by 3 to calculate the average of the average speeds for trials starting at **Point A**.

3 Pick a second starting point, **Point B**, 10 cm from Point A, measured along the length of the track.

4 For the new starting point, conduct 3 trials as in step 4. Remember to calculate the average speed using the new distance that the marble is traveling (track length minus 10 cm).

5 Pick a third starting point, **Point C**, on the incline before the loop, above or below Point B.

6 For the new starting point, conduct 3 trials as in step 4. Remember to calculate the average speed using the new distance that the marble is traveling (track length minus distance from Point A to Point C).

7 If the marble does not have enough speed to make it around the loop, make a note on the recording sheet and choose a starting point closer to the top of the track.

8 Compare the different teams' roller coasters, data, and observations.

9 Note how the slope of the roller coaster affects the speed of the marble.

10 Discuss design strategies: what worked, what could have been done better, how math was used in the designs and evaluations.

11 Optional: Repeat steps 1 and 2 with new configurations and/or materials, e.g., longer track lengths, extra loops, marbles of different weights and sizes, and compare findings.

Curriculum Standards:

Ratios and Proportions (Common Core Math Standards: Ratios and Proportions, Grade 6, 1, 2, & 3; Grade 7, 1 & 2)

Write, read, & evaluate expressions (Common Core Math Standards: Expressions & Equations, Grade 6, 2)

Forces & Motion (Next Generation Science Standards: Physical Science, Middle School 2-2; High School 2-1)

Kinetic & Potential Energy (Next Generation Science Standards: Middle School, Physical Science 3-2 & 3-5,)

Gravity (Next Generation Science Standards: Middle School, Physical Science 2-4)

Compare Multiple solutions & combine (Next Generation Science Standards: Middle School, Engineering Design, 1-2, 1-3, & 1-4)

Test variables (Next Generation Science Standards: Grades 3-5, Engineering Design 1-3)

Design criteria (Next Generation Science Standards: Engineering Design, Middle School, 1-1; High School, 1-2 & 1-3)

Additional standards at: http://www.raft.net/raft-idea?isid=659

Learn more

- Discuss other ways math could be used to help construct a safe and fun roller coaster ride (e.g., cost of materials, types of brakes.)
- Create a longer roller coaster by connecting more than one tube to another, then adding some loops. Test the marble (and then a heavier "steely" marble) on the track and compare findings.
- Can one track be designed for both a regular and a steely marble to run through where both marbles finish with the same ending time?
- Investigate older roller coasters made primarily out of wood, and newer types made from steel and other materials.
- Read about the history of roller coasters: how were the first types made and what changes were made to their design over the years?

Extend this activity with the following suggestions:

- Create a Design Challenge with this activity. See the RAFT Idea Sheet ***Designing Design Challenges*** for ideas.

Related activities: See RAFT Idea Sheets:

Ratios, Rates, and Proportions:
Star Distances on a Map -
http://www.raft.net/ideas/Star Distances on a Map.pdf

Velocity:
Marble Rollercoaster -
http://www.raft.net/ideas/Marble Rollercoaster.pdf

Scaling the "g's" -
http://www.raft.net/ideas/Scaling the g's.pdf

Slope on a Rope -
http://www.raft.net/ideas/Slope on a Rope.pdf

Slippery Slopes -
http://www.raft.net/ideas/Slippery Slopes.pdf

Resources

Visit www.raft.net/raft-idea?isid=659 for "how-to" video demos & more ideas!
See these websites for more information on the following topics:

- **The effect of the change in slope in roller coasters** – http://www.myphysicslab.com/RollerSimple.html
- **NCTM lesson on roller coaster math** – http://illuminations.nctm.org/LessonDetail.aspx?id=L241
- **Animation showing potential vs. kinetic energy on a roller coaster** – http://search.eb.com/coasters/ride.html
- **Physics involved** – http://www.learner.org/exhibits/parkphysics/coaster.html
- **History and physics** – http://science.howstuffworks.com/roller-coaster.htm
- **Physics of loops** – http://www.physicsclassroom.com/class/circles/u6l2b.cfm
- **Videos on Balanced and unbalanced forces from the Khan Academy:** https://www.khanacademy.org/science/physics/forces-newtons-laws/balanced-unbalanced-forces/v/balanced-and-unbalanced-forces

The content behind the activity

To keep roller coasters on the track, make sure to do the math! This activity gives students hands-on experience with several mathematical and physical concepts in the development of a safe roller coaster. The roller coaster starts with an initial drop, usually a very high hill, so the coaster gains enough speed to keep itself on the track and to successfully navigate a loop. The coaster reaches its greatest speed at the bottom of the track.

In this activity, the students gain experience taking data on track length and run time and then using the data collected to calculate the average speed for each run. The progression of construction, testing, observation, and evaluation reinforces the integration of math and science in the real world challenge of roller coaster design.

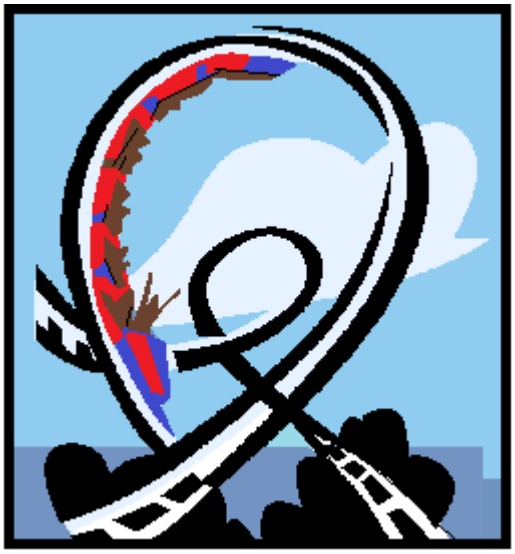
In a roller coaster the **potential energy** (PE) (energy due to position) that the car has at the top of the track is converted into **kinetic energy** (KE) (the energy of motion). Before the car starts moving all of its energy is potential; when it reaches the lowest point all of the energy has become kinetic.

The equations are:

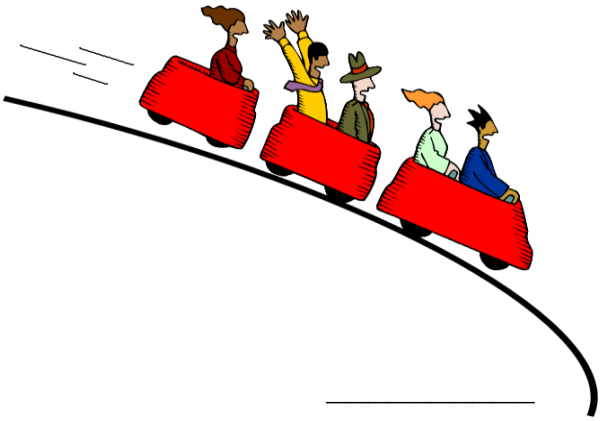
PE = **(m) (g) (h)** =
(**m**ass of object) (acceleration due to **g**ravity) (**h**eight of the starting point of the object)

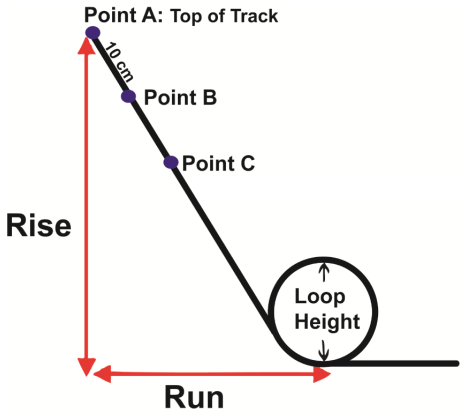
KE = (½ **m)** (**v**^{2})=
½ (**m**ass of the object) (**v**elocity of object) (**v**elocity of object)

Velocity is the rate at which an object changes its position and includes the speed and direction of the object; *acceleration* is the rate of change of velocity; *mass* is the amount of matter contained in an object. The average acceleration due to gravity on Earth is 9.81 meters/(second)^2.



Roller Coaster Recording Sheet





Rise = _____
Run = _____
Slope = Rise / Run = _____
Loop Height (cm) = _____
Total length of the track (cm) = _____

Starting Point	**Distance of starting point from top of track (cm)**	**Distance marble travels along track**	**Trial**	**Time for marble to run track (sec)**	**Average speed of marble (cm/sec) (distance traveled/ travel time)**
Point A: Top of Track	0 cm	(Track length)	**1**		
			2		
			3		
Average of the 3 average speeds for trials starting at Top of Track					
Point B: Second starting point	10 cm	(Track length 10 cm)	**1**		
			2		
			3		
Average of the 3 average speeds for trials starting at Point B					
Point C: Third starting point (on incline before loop)	_____ cm	(Track length _____ cm)	**1**		
			2		
			3		
Average of the 3 average speeds for trials starting at Point C					

Compare different roller coasters. Record observations: