

Engineering Activity: Marble Roller Coasters

NextGen Science Standards for Engineering: 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Docent Guidelines:

1. Schedule a date and time with your teacher. Estimated time for this activity: 60-75 minutes.
2. Input the day and time into the Science Lab Master Schedule. Please make sure you add set up and clean up time to the class time, and add your name.
3. This activity requires a lot of space. Ask about using the cafeteria or a second classroom or have some students work outside.

Supplies Needed:

1" foam pipe insulation (cut in half lengthwise ahead of time, about 4 half tubes per group)
Masking tape for each group (2-4 students per group)
Marbles (at least one per group)

The students will also use elements from around the classroom, like tables, chairs, yardsticks, boxes, etc.

Docent Instructions:

1. Give an introductory lesson and demonstration of building techniques (no more than 10 minutes). Be sure to give the instructions and review the 4 big mistakes and how to avoid them.
2. The task is to construct a roller coaster for a marble, working in a small group. They can add as many exciting elements as will work successfully (loops, hills, etc.) The marble should stay on the track until it reaches a barrier at the end of their track.
3. Near the end of the time period, let the groups try each other's roller coasters.
4. Have students disassemble the tubing carefully for re-use. Have them remove all tape pieces.

Background/Introduction:

(from

https://www.teachengineering.org/view_lesson.php?url=collection/duk_/lessons/duk_rollercoaster_music_less/duk_rollercoaster_music_less.xml)

Today's lesson is going to be all about roller coasters and the science and engineering behind them. Before we start talking about physics, though, I'd like for you to share some of your experiences with

roller coasters. [Listen to a few students describe their favorite roller coasters. Point out some of the unique features of each coaster, such as hills and loops, that relate to the lesson.]

Does anyone know how roller coasters work? You might think that the roller coaster cars have engines inside them that push them along the track like an automobile. While that is true of a few roller coasters, most roller coasters use gravity to move along the track. Do any of you remember riding a roller coaster that started out with a big hill? If you looked closely enough, you would see in the middle of the track on that first hill, a chain. You might have even felt it "catch" to the cars. That chain hooks on to the bottom of the cars and pulls them to the top of that first hill, which is always the highest point on a roller coaster. Once the cars are at the top of that hill, they are released from the chain and coast through the rest of the track, which is where the name roller coaster comes from.

Your task is to create a marble roller coaster. You can add as many interesting elements as you can that will work successfully. The marble should stay on the track until it reaches a barrier at the end. What kind of energy do roller coasters use?

Vocabulary/Definitions to Review

kinetic energy: The energy of an object in motion, which is directly related to its velocity and its mass. The marble has kinetic energy as it is moving along the track.

potential energy: The energy stored by an object ready to be used. (In this lesson, we use gravitational potential energy, which is directly related to the height of an object and its mass.) The marble has potential energy at the beginning high point of the track.

speed: How fast an object moves.

velocity: A combination of speed and the direction in which an object travels.

critical velocity: The speed needed at the top of a loop for a car/marble to make it through the loop without falling off the track.

acceleration: How quickly an object speeds up, slows down or changes direction. The marbles will need to accelerate in order to go all the way over a hill or through a loop. The marbles will accelerate most at the bottom of a hill.

momentum: momentum is the force that keeps an object going in the direction it's currently moving. Sudden turns or drops that do not account for the marble's momentum may result in the marble flying off of the track.

friction: A force caused by a rubbing motion between two objects. Friction will slow the marble down.

Instructions for Students: (from <http://www.instructables.com/id/Marble-Roller-Coaster/>)

1. Begin by placing a strip of tape on the end of a piece of tubing and affixing it to a smooth, flat surface. Then place another piece of tape across the first piece to secure the tubing in place. Let your students know that the higher the roller coaster is when it starts, the more energy your marble will have when it begins rolling. More energy means that the students' marble will be able to travel farther and faster. Students may stand on chairs, but not tables.

2. To connect two pieces of tubing together, lay a piece of tape along the middle of the tube with about half of it hanging off of the end. Pick up the second piece of track and use your finger to press the tape onto it. Use your fingers to smooth out the tape. And finally, tape the underside of the tubes together, too. If students are working together, then one person can hold the track pieces in place while the other tapes them together. It's important to have nice smooth connections. You should definitely emphasize this with students because no matter how awesome the roller coaster looks, if the connections are sloppy, it won't work well.
3. Most of the time, your students' roller coasters will need to touch down onto a flat surface like the floor. To secure the tubing to the floor, use two smaller pieces of tape and secure the sides of the roller coaster. Do not tape across the entire tube. Leaving the track clear of tape helps ensure that the marble will roll smoothly.
4. And finally, show your students how to make turns. The track must be turned on its side if the marble is travelling even moderately fast. In roller coaster construction, this is called 'track banking.' This is a good opportunity to explain the negative effects of momentum. A marble travelling forward will continue moving in that direction because of its momentum. If a curved track is not banked, the marble may fly off of the edge of the track. However banking the track allows the marble to run along the 'bottom' of the track. Once the turn is complete, the track should be straightened out.
5. Now for the fun stuff! A roller coaster that just goes in a straight line can be fun, but I find it much more satisfying to include exciting elements. Loops can be created by securing the track to a flat surface, then bending the track upside down and securing the other end. You can explain that loops work because of centripetal force. Centripetal force is like momentum: it's when an object wants to keep moving forward, except that it's forced into a circular path. Hills can be made by securing the track to a flat surface, then lifting the middle of the track up and securing the other end. This is another good opportunity to illustrate the negative effects of momentum. If the hill is too small and the marble is travelling too fast, the marble's momentum will carry it up the hill and then continue its trajectory off the track.
6. **4 big mistakes and how to avoid them**
 1. Bad connections. Remind the students that the tape needs to be smoothly applied.
 2. Not enough energy. Marbles have a limited amount of energy, so encourage the students to plan their roller coaster according to how much energy the marble has. I often see students wistfully creating awesome-looking features that don't work because they do not account for how much energy the marble has. Start the coaster high and test regularly.
 3. Too much momentum. Remember, momentum is the force that keeps the marble going in the direction it's currently moving. Sudden turns or drops that do not account for the marble's momentum may result in the marble flying off of the track.
 4. Not enough testing. This is the biggest mistake. I've seen students make awesome looking roller coasters, but because of a lack of testing, it fails right at the start. Emphasize the importance of constant testing. Always test a new addition. Always test before adding onto the roller coaster. If the marble is falling off of the track halfway through, then everything that is built after that point won't matter until the problem is fixed. Experiment, observe, and make corrections!

Safety, tips, and troubleshooting

- Keep an eye on your students if you allow them to stand on chairs. Make sure they do not overextend themselves to reach the start of their roller coaster or they may lose their balance and fall.
- Do not allow your students to run. It's easy to get hurt while diving for a runaway marble or tripping over a low-lying track piece. It's also easy to disrupt a precisely configured roller coaster, and running students may bump into tables/chairs/etc that are connected to a roller coaster.
- Toward the end of class, make an announcement: everyone has permission to try anyone's roller coaster. It's fun!
- When it comes time to clean up, do not allow your students to frenetically demolish their own roller coasters. Track pieces can be ruined, and it leads to other reckless behavior. Instead, tell them to carefully take the tape off of the track pieces from *their own roller coaster* and turn it into a giant tape ball. For whatever reason, kids love making tape balls.

More Lesson Background and Concepts for Docent Reference

- In roller coasters, the two forms of energy that are most important are gravitational potential energy and kinetic energy. Gravitational potential energy is greatest at the highest point of a roller coaster and least at the lowest point. Kinetic energy is energy an object has because of its motion.
- The first hill of a roller coaster is always the highest point of the roller coaster because friction and drag immediately begin robbing the car of energy. At the top of the first hill, a car's energy is almost entirely gravitational potential energy (because its velocity is zero or almost zero). This is the maximum energy that the car will ever have during the ride. That energy can become kinetic energy.
- Friction exists in all roller coasters, and it takes away from the useful energy provided by roller coaster. Friction is caused in roller coasters by the rubbing of the car wheels on the track and by the rubbing of air (and sometimes water!) against the cars. Friction turns the useful energy of the roller coaster (gravitational potential energy and kinetic energy) into heat energy, which serves no purpose associated with propelling cars along the track. Friction is the reason roller coasters cannot go on forever, so minimizing friction is one of the biggest challenges for roller coaster engineers. Friction is also the reason that roller coasters can never regain their maximum height after the initial hill unless a second chain lift is incorporated somewhere on the track.
- Cars can only make it through loops if they have enough speed at the top of the loop. This minimum speed is referred to as the critical velocity.
- Most roller coaster loops are not perfectly circular in shape, but have a teardrop shape called a clothoid. Roller coaster designers discovered that if a loop is circular, the rider experiences the greatest force at the bottom of the loop when the cars are moving fastest. After many riders sustained neck injuries, the looping roller coaster was abandoned in 1901 and revived only in 1976 when Revolution at Six Flags Magic Mountain became the first modern looping roller coaster using a clothoid shape. In a clothoid, the radius of curvature of the loop is widest at the bottom, reducing the force on the riders when the cars move fastest, and smallest at the top when the cars are moving relatively slowly. This allowed for a smoother, safer ride and the teardrop shape is now in use in roller coasters around the world.