Marble Roller Coasters!

Target Grade: Elementary/Middle
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Brief Overview

This physics-based lesson will introduce several key physics topics to the students, including kinetic vs. potential energy, energy conservation, friction, and centripetal force. This will all be taught throughout an extensive building process that allows the students to build with creativity while they apply the engineering design process to improve their roller coasters.

Main Teaching Goals

- Introduce gravitational potential energy and kinetic energy
    - **Gravitational Potential Energy**: The potential energy an object has if dropped from a specific height
    - **Kinetic Energy**: The energy of an object in motion (dependent on the object's speed and mass)
- Consider how the two are related and how one can be changed into another
- Introduce and demonstrate the concept of centripetal force
    - **Centripetal Force**: Force that pulls an object centrally as it follows a circular path
- Illustrate how energy can be "lost" to frictional forces
    - **Friction**: A force that resists movement of an object in relation to another object (often works in opposite direction of movement)
- Emphasize the **engineering design process**!
    - Process of planning, designing, building, experimenting, and redesigning that engineers frequently use to improve their products

Careers and Applications

Any design engineer must go through the tough task of considering, building, and improving—what we call the engineering design process. This lesson builds up those skills of persisting through obstacles and teaches students to consider physics as they build and make improvements. Also, a lesson like this can apply to non-engineering careers. An urban

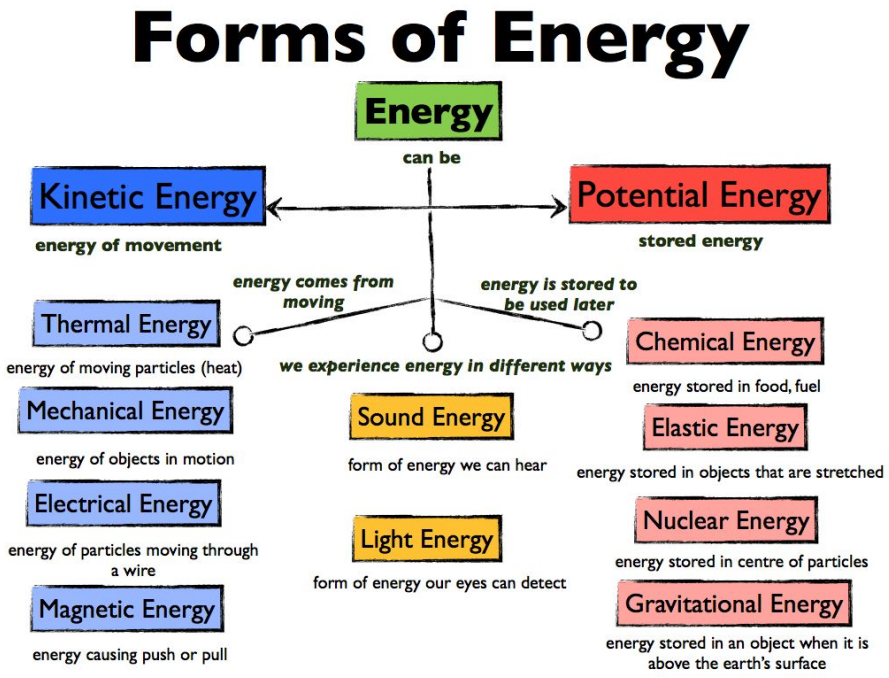
designer must take into consideration gravitational potential energy when deciding where (and where not) to lay out roads!

Agenda

- Introduction (5 min)
- Module 1: Bouncing Balls (5-10 min)
- Module 2: Centripetal Forces (5 min)
- Module 3: Overcoming the Hill (15-20 min)
- Module 4: Loop-de-Loop (15-20 min)
- Conclusion (<5 min)

Introduction

Energy, in its most basic sense, is the ability to do work. This means that energy is an object's ability to counteract an existing force, such as chemical bonding, friction, or gravity. To introduce this, mentors should introduce kinetic energy and potential energy, creating two lists. Ask students what they consider energy to be and have them try to put their suggestions into the lists! Be sure to consistently reinforce the difference between the two.



Tell the students that today's objective will be to create a roller coaster! The way we are going to do this is by converting potential energy into kinetic energy!

Module 1: Bouncing Balls

Introduction

This module is essentially an extension of the introduction that introduces the concept of potential and kinetic energy through the simplest example, gravity! It teaches conservation of energy and exemplifies how potential energy is converted into kinetic energy.

Teaching Goals

1. **Kinetic Energy:** the energy of an object in motion (dependent on the object's and speedmass)
2. **Gravitational Potential Energy:** the potential energy an object has if dropped from a specific height
3. **Friction:** A force that resists movement of an object in relation to another object (often works in opposite direction of movement)
4. ***Conservation of Energy:** Energy is never lost nor gained. Any energy that is "lost" in one system is simply transferred in another manner to a different system.

****Elaborate on this concept if your students seem to have an understanding of the first three. If not, don't spend too much time on it!***

Background for Mentors

Kinetic Energy is the energy an object in motion has. This means that it takes a certain amount of energy to accelerate an object from rest to a certain velocity. At the same time, every object in motion has a certain amount of energy to work against a counteracting force, such as gravity is this project. The equation for Kinetic Energy is:

$$KE = \frac{1}{2}mv^2$$

Potential Energy, on the other hand, is an energy an object has due to its position in in comparison to a set zero position. "Zero position" can mean several different things, depending on the type of potential energy. For elastic potential energy, zero position is the natural state of a material such as a rubber band. Therefore, a rubber band that is stretched is always inclined to (and thus has an energy to) go back to its natural state. For exothermic chemical potential energy, zero position is the state after a reaction because that is the more stable configuration. For gravitational potential energy, zero position is often the ground or some point below the object. What matters for marble roller coasters is this gravitational potential energy, whose equation is:

$$PE = mgh$$

Conservation of Energy means that, in an isolated system (**disregarding** non-conservative forces like friction or the transfer of energy to another system):

$$Total\ Energy = KE + PE$$

Therefore, total energy stays the same always while Potential and Kinetic Energy can be changed into one or the other, which is what this module demonstrates. However, this being said; in reality, energy can be lost to frictional forces.

Friction is a non-conservative force, meaning that energy is "lost" to friction and an isolated system cannot recover this energy. Our system's energy (the marble) in this module is lost to friction by converting to many different types of energy, including light energy, sound energy,

and heat energy. This energy is not recovered by the system; however, it is important to recognize that universal energy is never lost!

Materials

- 1 Tennis Ball

Procedure

1. Ask the students what kind of energy a tennis ball has when you hold it up slightly above a surface [**Potential]**. Then, drop it to the floor and ask what kind of energy it has right before hitting the floor [**Kinetic**].
2. Talk about how potential energy was *converted* to kinetic energy!
3. Drop the tennis ball again, letting it bounce until it stops. Ask the students why the ball stopped and why the ball didn't continue bouncing forever.
4. Explain how energy in the system was "lost" to heat and sound energy.
5. Repeat this, but this time, roll the ball (or any other object you find) very slowly on a surface with friction. Ask the students why it eventually stopped. Hopefully, they can tell you it's a similar reason to what you did before (energy was primarily "lost" to different types of energy)!
6. Introduce the concept of friction and how energy can be transferred from one object (the ball) to another (the ground).

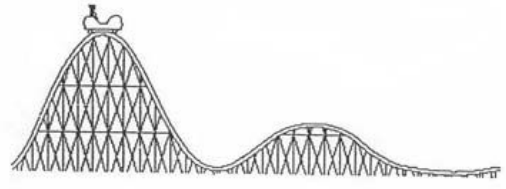
Module 2: Centripetal Forces

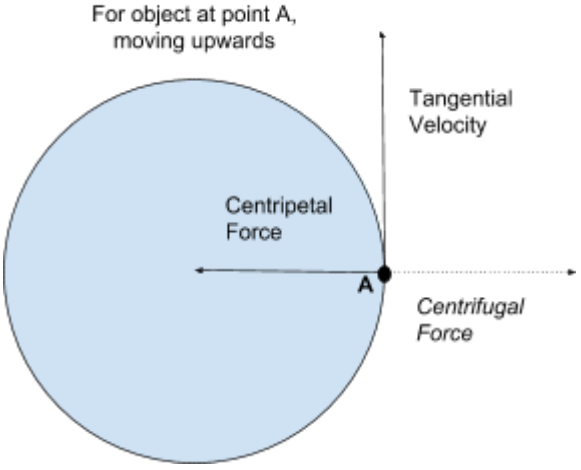
Introduction

This is a very quick introduction to centripetal force. The goal is to have students have a basic understanding of why the marble doesn't just fall off the track when it goes around in the loop!

Teaching Goals

1. Introduce the basics of centripetal forces!
    a. **Centripetal Force**: Force that pulls an object centrally as it follows a circular path





Background for Mentors

Centripetal force is the force that pulls an object centrally as it follows a circular path. The magnitude of centripetal force is always consistent as long as the

object retains its mass and travels at the same speed. The equation for the strength of the force is:

$$F_{cp} = \frac{mv^2}{r}$$

Materials

- 1 ping pong ball
- String
- Tape
- A half cup of water

Procedure

1. Introduce centripetal motion in its most basic sense. Draw a free body diagram if you're feeling ambitious!
    a. String and Ping Pong Ball Demo
        i. Hold onto the free end of the string and spin the ping pong ball over your head and in front of you, all in a circular pattern.
        ii. Ask the students why the ball follows a circular motion.
        iii. If they say it is because of the string, they are absolutely right. The string is creating the centripetal force!
        iv. You can have students try themselves, just **be careful** they don't hit anyone with the ball
    b. Cup of Water Demo
        i. Thread a string through the two holes in the cup, creating a sort of bucket mechanism that you can spin by holding onto the string
        ii. Ask the whole class what they think will happen when the cup filled with water is spun horizontally or vertically in a circle.
        iii. Fill the cups a little less than halfway with water.
        iv. Spin the cup in a loop.
            1. Make sure that the cup is spun fast enough so water does not leave the cup.
            2. **Stand far back** from the students so no one is hit by the cup if it flies off the string.
        v. Ask the students what they saw and why the water did not leave the cup.

Additional Note to Mentors

Try doing a very simple free body diagram (no matter how much you may despise them) if you don't know how to teach centripetal force otherwise. Also, your site gets to choose whichever demonstration you like more!

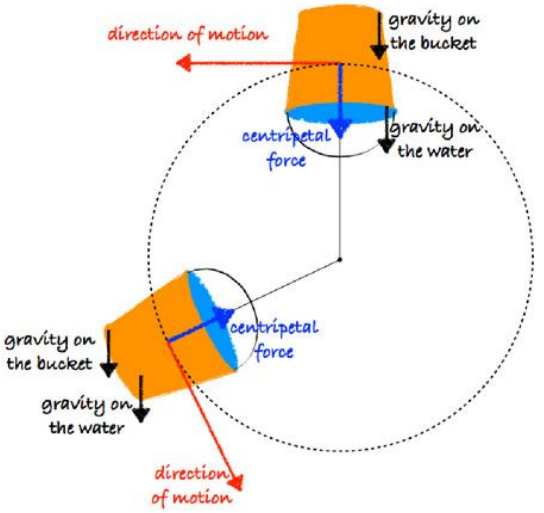


Figure: http://www.physicscentral.com

Module 3: Overcoming the Hill

Introduction

This module is the initiation of your engineering design process! The goal at the end of this module is to have students build a roller coaster with a hill.

Teaching Goals

1. Emphasize how this design requires the conversion of first potential to kinetic energy, then kinetic back to potential, and finally potential back to kinetic.
2. Frictional forces don't allow the marble to reach the same height that it started at.
3. Testing your design while building is essential. This is a key part of the Engineering Design Process!

Materials

- Foam Tubing already cut in half
- Masking Tape
- Marbles

Procedure:

1. Have students begin by taping their foam tubing to a smooth, flat wall. Remind them that the higher they start their roller coaster, the more energy the marble will have at the bottom. That being said, **do not allow** students to put themselves in dangerous situations putting up the first part of the tubing
2. Connect the tubing stuck to the wall with more tubing with tape until it reaches the floor. Be sure to have the students secure the tubing on the floor.
3. To create the hill, secure the track on the surface and bend the track upwards, creating a downward facing parabola. Now, secure the other side.
4. Continuously have the students test their designs!

Additional Notes for Mentors

A lot of these steps are intuitive! Give the kids a lot of freedom with how they approach this. The steps are simply for your use if they are having difficulty. Also, as you walk around, ask the kids questions to relate back to the first two modules, such as:

1. Why did/didn't the marble get over the hill?
2. How could you make sure that the marble has more speed at the bottom of the hill?
3. When the marble is at the top of the hill, what kind of energies does it have?
4. Anything else you can think of!

Module 4: Loop-de-Loop

Introduction

This is the final step of our project! The goal is to create a coaster with a loop integrated into it, implementing the idea of centripetal force just introduced.

Teaching Goals

1. Witness how centripetal force works with a real example!

Materials

- Foam Tubing already cut in half
- Masking Tape
- Marbles

Procedure:

1. Secure the track to a flat surface as was done with the hills
2. Bend the track upside-down to create the loop you desire of whatever height and secure the other end
3. If any problems in terms of balance arise, simply try again or try to use reinforcements of tape
4. Remind students of the importance of a high starting position [Potential Energy] and the problems friction may cause!

Additional Note to Mentors

Free time? Have the students be as creative as they want. Maybe try to create curves in the track, multiple loops, or even a jump. Let them be creative!

Conclusion

As the student's prepare to leave, have them reflect on what worked and why. Reinforce the concepts of potential energy and kinetic energy, and ask them what they would do differently if they had to do it again!

References

- Marble Roller Coaster, LanceMakes, Instructables. http://www.instructables.com/id/Marble-Roller-Coaster/
- What is Centripetal Force? KhanAcademy https://www.khanacademy.org/science/physics/centripetal-force-and-gravitation/centripetal-forces/a/what-is-centripetal-force
- What is Conservation of Energy? KhanAcademy https://www.khanacademy.org/science/physics/work-and-energy/work-and-energy-tutorial/a/what-is-conservation-of-energy

Summary Materials Table

Material	**Amount per Group**	**Expected $$**	**Vendor (or online link)**
Masking Tape	1 roll per site	~$16	Amazon
String	1 string per site	~<$10	Amazon
Tennis Ball	1 per site		
1/2 inch x 6 foot Pipe Insulation, cut into half-pipes	3-4 half-pipe tubes per 2 students	$0.78 per tube	ToolWorkshop.com
Marbles	~1 per student	~$10	Amazon