Scream Machines!

For many people, there is only one reason to go to an amusement park. The roller coaster. Some people call it the "scream machine," with good reason.

Have students explain their roller coaster experiences. Encourage students to describe

- **How fast they went**
- **How high they went**
- **How far they went**
- **How long the ride lasted**

Ask questions, such as the ones below, to stimulate discussion. Write a list of phrases that describe students' experiences and responses on the board.

- **What do you remember most about your first roller coaster ride?**
  What do you like (dislike) about roller coaster rides? (*Give students time to share their personal experiences. You may wish to list student responses in two columns on the board labeled Likes and Dislikes*.)
- **How fast do you think roller coasters go? Why would one roller coaster go faster than another? (Help students see that the coaster's height, especially the height of the first drop, is the main factor affecting maximum speed.)**
- **About how long do you think a roller coaster ride lasts? Why would some roller coaster rides last longer than others? (*Guide students to see that the height of the coaster and the length and steepness of the track may all influence the duration of the ride*.)**

For students who have never ridden one, give them a first person point of view by watching one or more videos (*ex.** Cyclone Front Seat on-ride POV Coney Island Astroland Cyclone Front Seat on-ride POV Coney Island Astroland, or Leviathan Front Seat on-ride HD POV Canada's Wonderland**,).** ***Please review any videos before showing them to your class for appropriateness of content. Riders on rollercoasters sometimes tend to use colorful language! The history of roller coasters reflects a constant search for greater and more death-defying thrills. But really, the inspiration for the modern roller coaster is a very simple ride found in any playground: the slide. ***Ask students how many of them have ever been sledding, or gone down a giant slide, like those sometimes at a county fair. What do they think it would be like riding a giant ice cube down one?***

The Russian ice slides were tall wooden structures with ice frozen over a long sloping ramp. These slides would often rise up seventy or eighty feet and the ramps stretched for hundreds. A staircase led up to the launch area where riders mounted a sled made of either wood or ice. The ice sleds were simply a block of ice with a straw mat adding some protection between the freezing ice and the riders' bottoms. ***Have students ever sat down on snow or ice? What happens after a bit?*** A length of rope was looped through a hole drilled in the block so that sliders had something to hold onto. Once riders were positioned on their blocks, all it took was a little shove and off they went! Occasionally bumps were added at the end of the slide to introduce a little more excitement. At the very end, riders plowed into a pile of sand which slowed them down, a technique based on the principle of friction. Slides were built in parallel pairs but facing opposite directions. One ramp ended near the stairs of the second slide, so riders could spend the day going back and forth down the slides. Later, more elaborate wooden sleds were built with iron runners to increase the speed and intensity of the ride. ***Why do students think that they kept trying to make the rides faster? What other ways could they have used? Grease? Steeper hills? Would students pay to go down these slides?***

While the ice slides were thoroughly enjoyed all over Russia, there were some safety issues. Sliding down an ice ramp on a block of ice offered very little in the way of control. ***How would students have made it so that people wouldn't fall off? Could you freeze a rope onto the block to hang on to?***

One solution slide owners came up with was to offer guides familiar with the wily ways of the sleds to help riders navigate safely to bottom: for a small fee of course. However, it wasn't until the French picked up on the ice slides and tried building their own that a safer system was invented.

The French businessman that brought the ice slides to France must've thought he had hit the entertainment jackpot, but he quickly found out that his country was not quite cold enough to keep the slides totally frozen. The resultant mushy and wet ride inspired the next step in the evolution of the roller coaster, which was to put wheels on the sleds, and thus, no more ice.

However, accidents were still just as much of a problem as they were with the ice slides. That's when the idea for a track was finally hit upon. ***Ask students, how might a track have made it any safer****?*

In 1817, Les Montagues Russes a Bellevilles (The Russian Mountains of Bellevilee), a ride that locked the sleds' wheels into a track, became the world's first roller coaster. In that same year, The Aerial Walk, a coaster ride that featured a heart-shaped track was also unveiled. The two tracks of this ride would fan out from the launch tower and meet again at the lift hill. It was these two rides, with their cars firmly locked into a guiding track, which set the stage for all roller coasters to come. The next move toward today's modern roller coasters would be made across the Atlantic in the United States.

Rushing Ice Riders

Ice cubes are small enough to hold and pass, yet slippery enough to slide easily. That makes them naturally fun when used as sleds on a simple roller coaster. Get several boards or stiff sheets of cardboard, ex. from a box and create separate sections on it so that you can put multiple different racers on the same board. Have students create their ice cube sleds and slide them down the board at different times. Record the time of how long it took each team's ice cube to slide down the board and whether or not they lost their passenger.

Materials:

- Ice Cubes
- Paper plates
- Salt
- Other available construction materials (ex. craft foam, cloth, etc)
- Cardboard covered in wax paper, outside slide, or other ramp materials to form a ramp.
- Stopwatch
- Small plastic figurines, ex. the size that would be on cupcakes
- Optional: Sand for the end of the ramp

Present the problems to the students: **What size of sled and what materials will make an ice cube slide down the ramp or slide the fastest possible, without losing its passengers?**

Divide students into groups, pairs, or have them work individually. Give each group some of the available materials to work with. **What solutions can they come up with? Do they discover the connection between salt and ice?**

For younger students: If students want to build bigger sleds, demonstrate that shaking a little salt on the ice to act as glue as the salt melts the ice a little to help the cold cubes stick to one another.

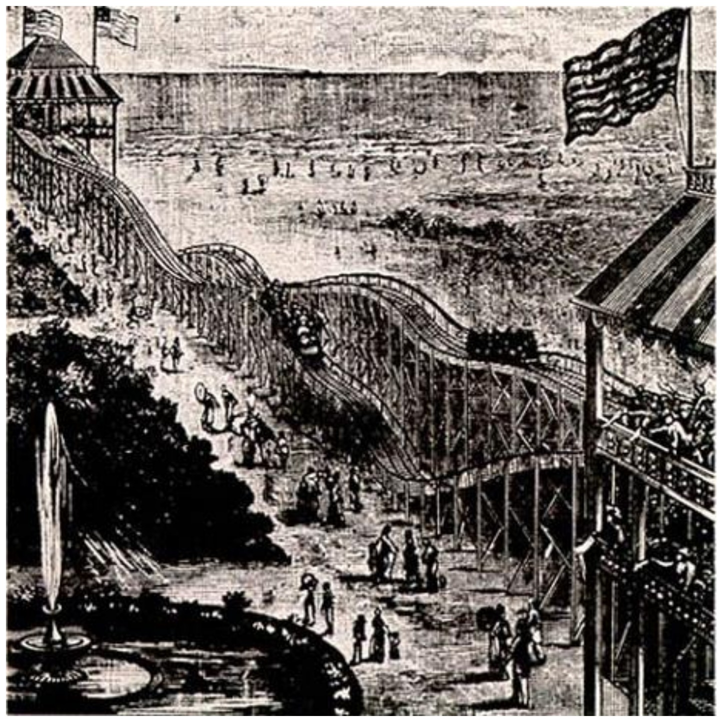
To test: If using a flat surface tilt it at an angle on a table. Line the ice cube sleds up, keeping them in place with a yard stick and then let them loose all at once for a fun and crazy race. The ice sleds melt, turn, spin and slide at the whimsy of the weather and heat, your room probably won't be as cold as Russia! Some zoom by and knock others out of the way.

Retest: Whose method was most effective, thus far? What did students learn from their first efforts? What ideas do they have for improvements? Does salt help things stick together? Have students rebuild and retest.

Use caution to not slip on puddles of melted water or dropped ice cubes!

Man-made Mountains

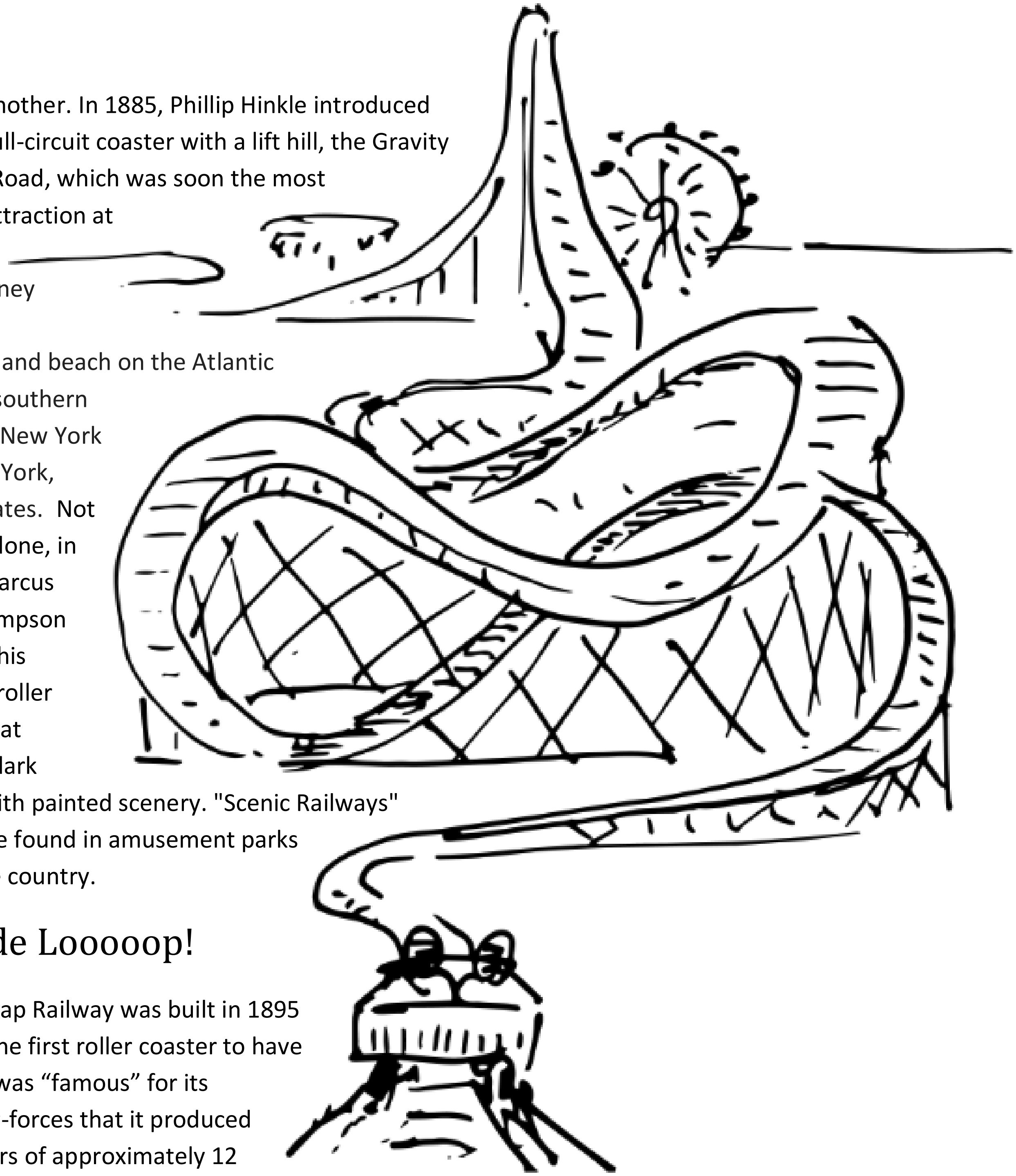
The name *Russian Mountains* to designate a roller coaster is preserved in most Latin languages. Ironically, the Russian term for roller coasters is американские горки("amerikanskie gorki") "American Mountains".



In 1827, a mining company in Summit Hill, Pennsylvania constructed the Mauch Chunk gravity railroad, an 8.7 mile long (14 km) downhill track used to deliver coal to Mauch Chunk (now known as Jim Thorpe), Pennsylvania. By the 1850s, the "Gravity Road" (as it became known) was providing rides to thrill-seekers for 50 cents a ride. [Today it’s $110 per person for a one-day pass into DisneyLand. The most expensive US amusement park is Universal Studios at $129 per person for one day. The average ticket price of other parks hovers around $55 per person. And modern rides only last about 1-4 minutes]

Railway companies used similar tracks to provide amusement on days when ridership on the train was low. Railway companies, in search of ways to keep passenger usage up on the weekends, set up parks here at the end of the rail lines and introduced weekend and summer activities. The first rides at these parks were carousels, but in 1884, the first gravity switchback train was introduced. This was the first true roller coaster in America.

Using this idea as a basis, LaMarcus Adna Thompson began work on a gravity Switchback Railway that opened at Coney Island in Brooklyn, New York in 1884. Charging only 5 cents per ride, he made hundreds of dollars every day. Passengers climbed to the top of a platform and rode a bench-like car down the 600 ft (180 m) track up to the top of another tower where the vehicle was switched to a return track and the passengers took the return trip. This track design was soon replaced with an oval complete circuit, so they didn’t have to haul the cars from one track to another. In 1885, Phillip Hinkle introduced the first full-circuit coaster with a lift hill, the Gravity Pleasure Road, which was soon the most popular attraction at Coney Island. Coney Island is a peninsula and beach on the Atlantic Ocean in southern Brooklyn, New York City, New York, United States. Not to be outdone, in 1886 LaMarcus Adna Thompson patented his design of roller coaster that included dark tunnels with painted scenery. "Scenic Railways" were to be found in amusement parks across the country.



Loop de Looooop!

The Flip Flap Railway was built in 1895 and was the first roller coaster to have a loop. It was “famous” for its extreme g-forces that it produced on its riders of approximately 12 gs. The circular nature of the coaster’s loop along with its small diameter of 25 feet caused riders to experience neck injuries from whiplash.

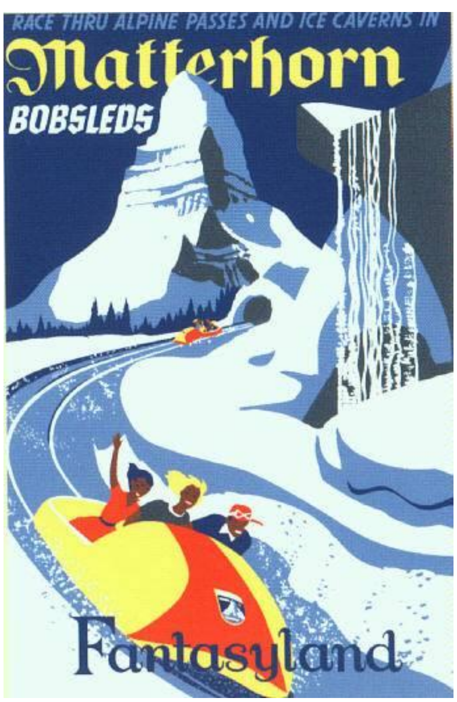
There are some interesting accounts where riders are hanging on for dear life in a death grip on the sides of the railcar and surviving a 12g ride which is absolutely crazy and incredibly dangerous! Modern looping roller coasters all use teardrop-shaped loops to reduce the g-forces. The Flip Flap Railway was the last coaster to use a truly circular loop.[1]

[1] https://www.arborsci.com/cool/pocketlab-voyager-2/

Moving Forward

Soon, roller coasters spread to amusement parks all around the world. In the 1920's there were between 1,500 and 2,000 roller coasters. Perhaps the best-known historical roller coaster, The Cyclone, was opened at Coney Island in 1927. Leap the Dips is one of the few roller coasters that exist from this time, and is actually the oldest coaster still running in the world. It was built in 1902 by E. Joy Morris and is located at Lakemont Park, Pennsylvania.

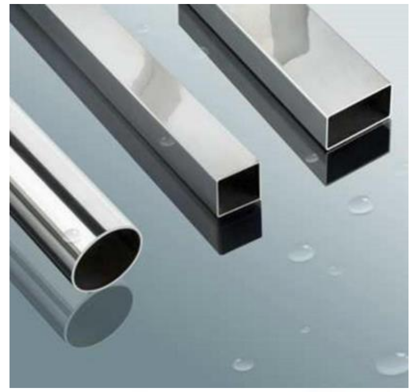
The Great Depression marked the end of the first golden age of roller coasters, and amusement parks in general went into decline. Because of the depression, the amount of coasters went from between 1,800 and 2,000 in 1930 to 245 in 1939. In the 1940s to 1960s many rides had to close down due to "white only" rules. They ran out of money having only a section of the public permitted in.



The Birth of DisneyLand

In the 1950s roller coasters for children grew in popularity. In 1955, the nation's first theme park opened: Disneyland. Not only did Disneyland usher in a new era for amusement parks, it also helped bring about some radical changes in roller coaster design. Up until this time, coasters were built out of wood, which limited the way loops could be handled. In 1959 Disney introduced the Matterhorn, the first tubular steel coaster. This was the first roller coaster to use a tubular steel track. Unlike wooden coaster rails, which are generally formed using steel strips mounted on laminated wood, tubular steel can be easily bent in any direction, which allows designers to incorporate loops, corkscrews, and many other maneuvers into their designs. Most modern roller coasters are made of steel, although wooden coasters are still being built.

The exciting features we expect from today's coasters--loops, a corkscrew track, and stability--can be traced back to that first steel coaster. In the 60s, many of the small family-owned amusement parks were bought and replaced by large theme parks like Six Flags. In 1972, when The Racer was built at Kings Island in Mason, Ohio (near Cincinnati and designed by John Allen), the instant success of The Racer began a second golden age, which has continued to this day.

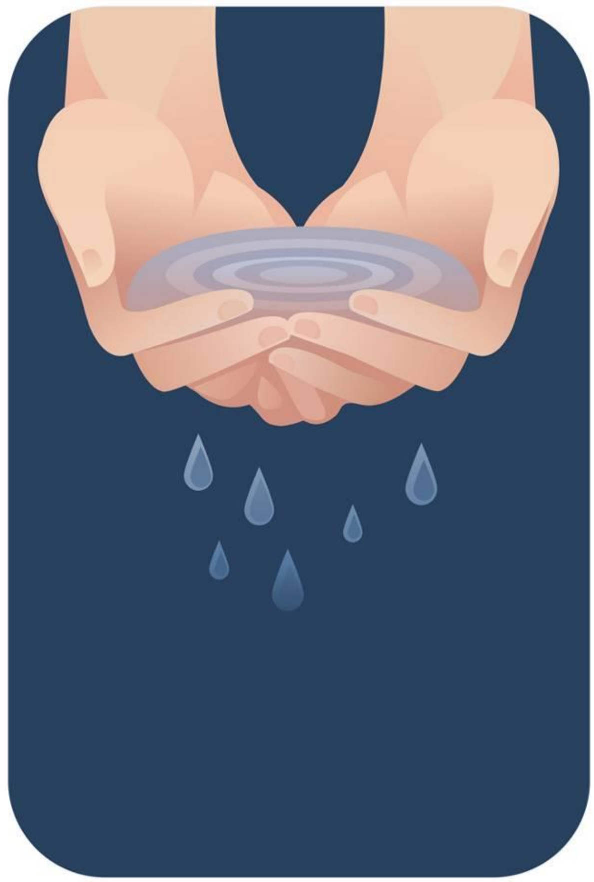


The first successful inverted (upside down) coaster was introduced in 1992, and now you can find passengers riding in coasters with their feet dangling freely below them (and occasionally above them) as they travel the track. In 1997, a coaster opened at Six Flags Magic Mountain whose design would have been considered impossible even a few years before. This scream machine is 415 feet tall and can reach a speed of 100 miles per hour. Technology, working with the laws of physics, continues to push what is possible in ride design.

Up until the late 1970s, roller coasters were fairly standard. Whether the tracks were made of wood or steel, a slow lift chain, powered by a motor, click-clack-clicked and pulled coaster trains slowly up a lift hill. At the top of the hill, the chain unhooked and gravity took over. Most new coasters still use the tried-and-true approach, but attraction designers have been experimenting with a number of launch systems to ratchet up the acceleration, speeds, heights, and (of course) the thrills, as well as create a different kind of ride experience. Some use a catapult style launch and others use a hydraulic push. Either way, or regardless of the method, screaming out of the loading station the new breed of coasters eliminates the anticipation of the lift hill and deliver non-stop action from beginning to end.

Two Pieces of the Puzzle

In order to understand how roller coasters work we need to understand a bit about two basic elements used in our modern day roller coasters. The launch and the stop. In some coasters, that’s done through Hydraulics and Magnetic Brakes**. In order to give students a better understanding of these two elements, conduct the following experiments and discuss with students what part they might play in roller coaster construction.**



When it debuted in 2005, Kingda Ka at New Jersey's Six Flags Great Adventure laid claim to the twin titles of the world's tallest and fastest roller coaster. Its 50.6-second adrenaline rush of a ride sends coaster freaks up a 456-foot top hat tower and reaches a maximum speed of 128 mph in 3.5 seconds. Yikes!
What gives Kingda Ka its incredible record-breaking oomph? Hydraulics.
If that pithy explanation has you scratching your head, let's dive into some of the details. Up until the late 1970s, nearly all modern roller coasters were fairly standard. Whether the tracks were made of wood or steel, a poky lift chain powered by a motor click-clack-clicked a coaster train slowly up a lift hill. At the top of the hill, the chain disengaged, and gravity took over.
Most coasters built from the late 1970s on still use the tried-and-true approach, but some ride designers have been replacing conventional lift hills with a number of launch systems. They can ratchet up the acceleration, speeds, heights, and (of course) the thrills, as well as create different kinds of ride experiences. Screaming out of the loading station, launched coasters like Kingda Ka eliminate the anticipation of the lift hill and deliver non-stop action from beginning to end.

To send coaster trains and their fearless passengers screaming from the get-go, ride designers have developed a variety of launch methods including magnetic propulsion, compressed air, and jazzed-up electric motors. But hydraulics offer a relatively simple and efficient way to quickly get coaster cars moving quickly—VERY quickly.[2]

Water? Power!

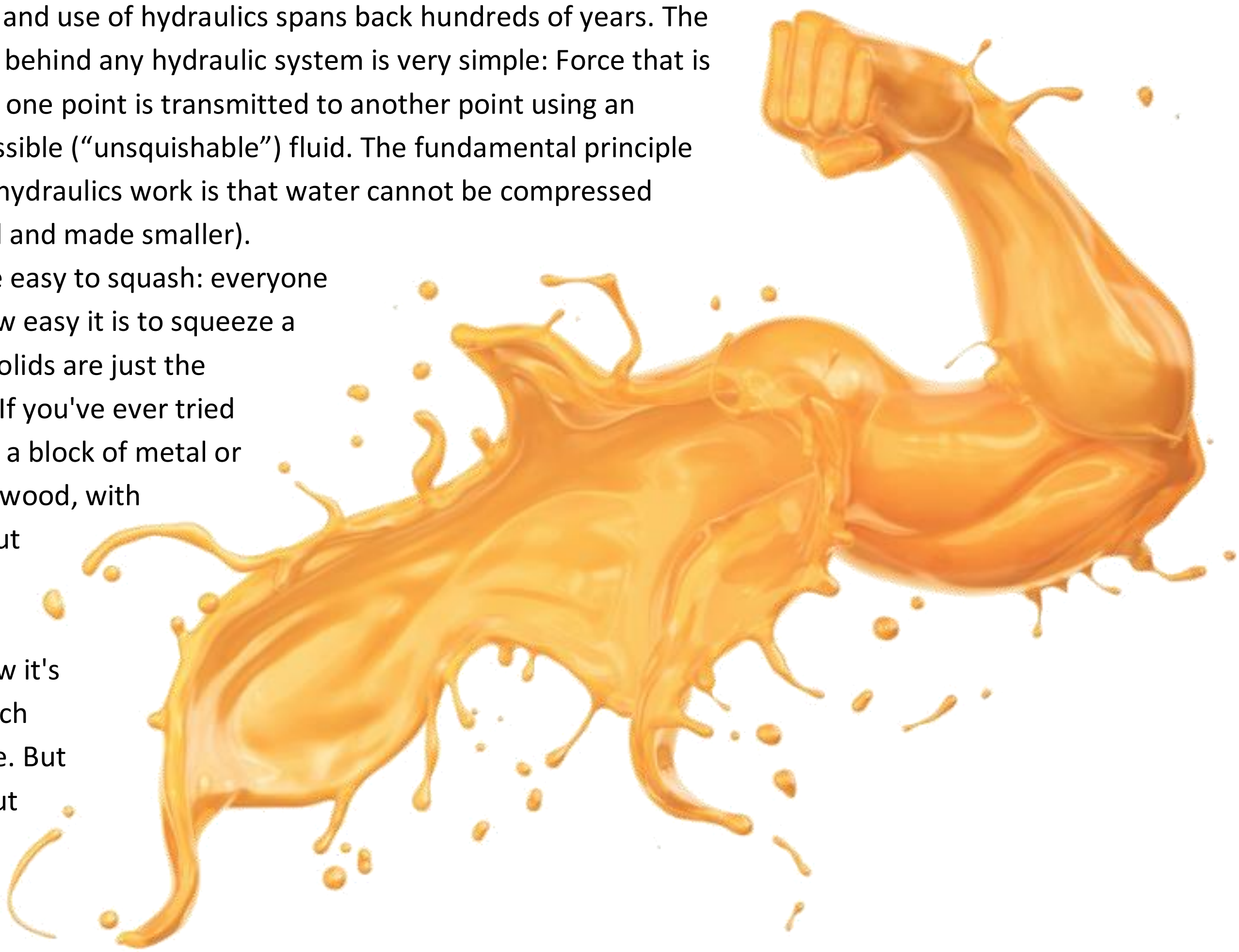
A Simple Demonstration of Fluid Mechanics, a.k.a. Hydraulics

Often force must be transferred from one part of a machine to another in order to control a moving part. Fluids (liquids) squeezed in high pressure tubing are often used to transmit a large force, like in roller coasters, where hydraulic systems provide enormous amounts of power to launch those carts along the track.

A roller coaster engineer likens the hydraulic launch process to blowing up balloons. *Blow up a balloon to demonstrate.* "They store huge amounts of energy, then at the precise moment, poof, they release it."

Discovery and use of hydraulics spans back hundreds of years. The basic idea behind any hydraulic system is very simple: Force that is applied at one point is transmitted to another point using an incompressible ("unsquishable") fluid. The fundamental principle on which hydraulics work is that water cannot be compressed (squeezed and made smaller).

Gases are easy to squash: everyone knows how easy it is to squeeze a balloon. Solids are just the opposite. If you've ever tried squeezing a block of metal or a lump of wood, with nothing but your fingers, you'll know it's pretty much impossible. But what about liquids?

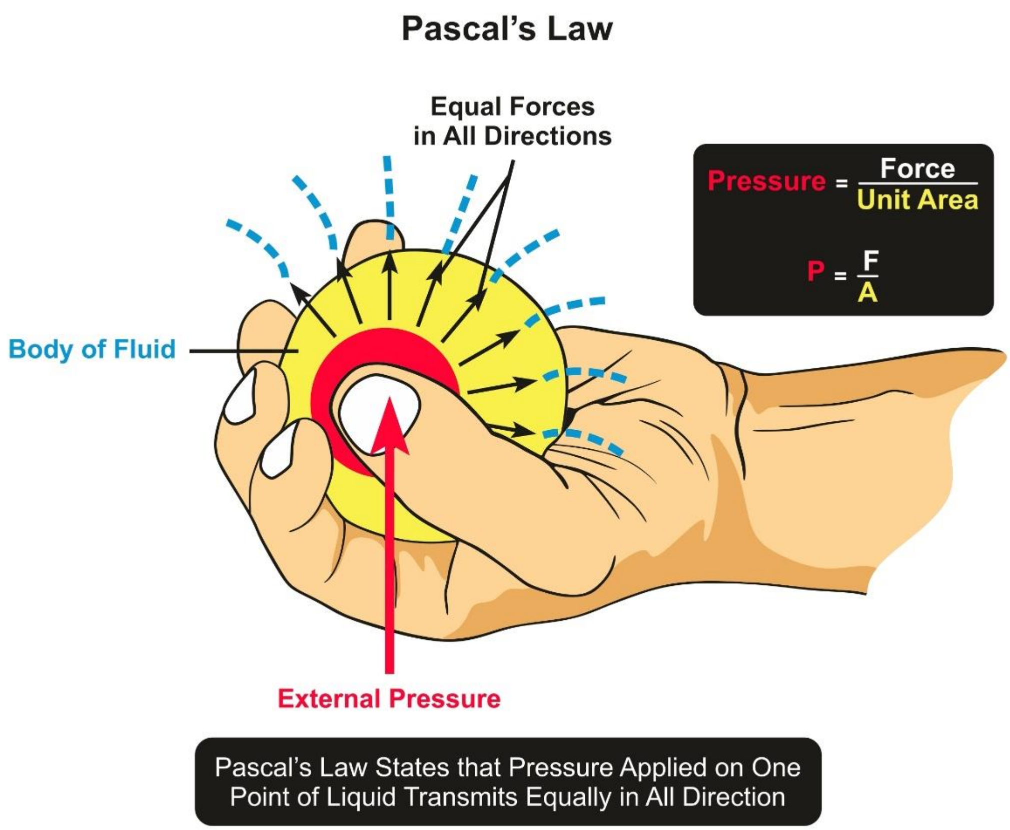


[2] https://www.tripsavvy.com/how-kingda-ka-works-3226405

Where do they fit in?
You probably know that liquids are an in-between state, a bit like solids in some ways and a bit like gases in others. Now, since liquids easily flow from place to place, you might think they'd behave like gases when you try to squeeze them. In fact, liquids are, for all practical purposes, virtually incompressible—much like solids.
Therefore, fluid is perfect for transmitting force because when you push on it and squeeze it, it applies that force on whatever point you want the force delivered. A hydraulic system uses force that is applied at one point and is transmitted to another point using a fluid. Water is ideal for uncomplicated demonstrations like the one student will do; however in industrial applications; specialized hydraulic fluid is more often used.

The basic rule of using hydraulic power is called Pascal's Principle or Pascal’s Law.

Pascal's Principle: Pressure exerted on a fluid is distributed equally throughout the fluid.



Of course, as Prof. Newman says, "there is no free lunch," In order to move the larger area, the smaller area has to move a lot in order to move the larger area a little.

In our picture, the larger area is nine times greater than the smaller area. In order to move the larger piston one inch, the smaller piston has to move nine inches.

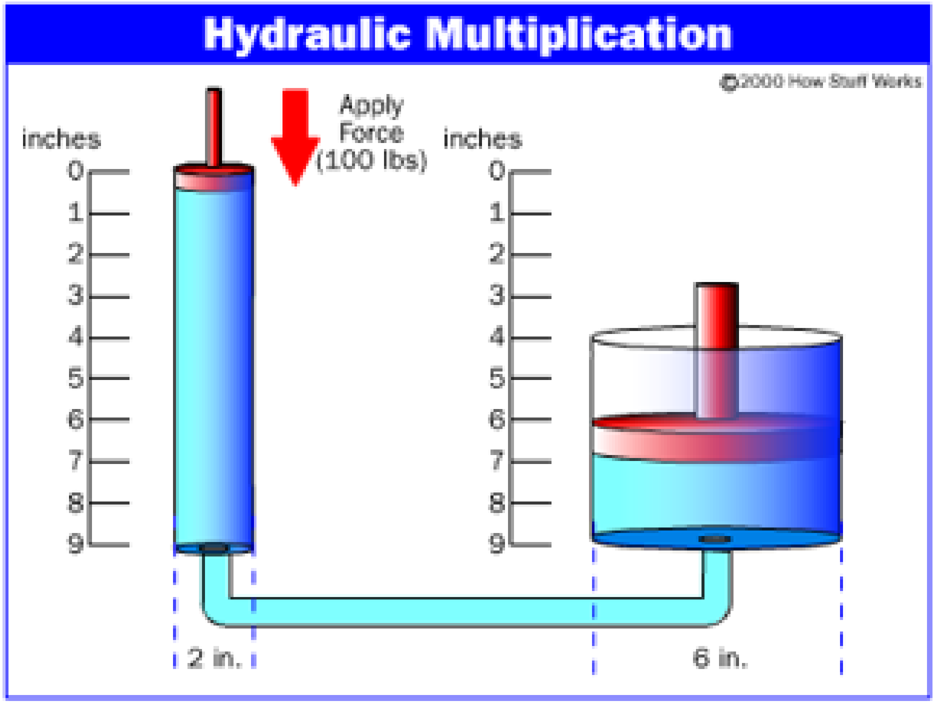
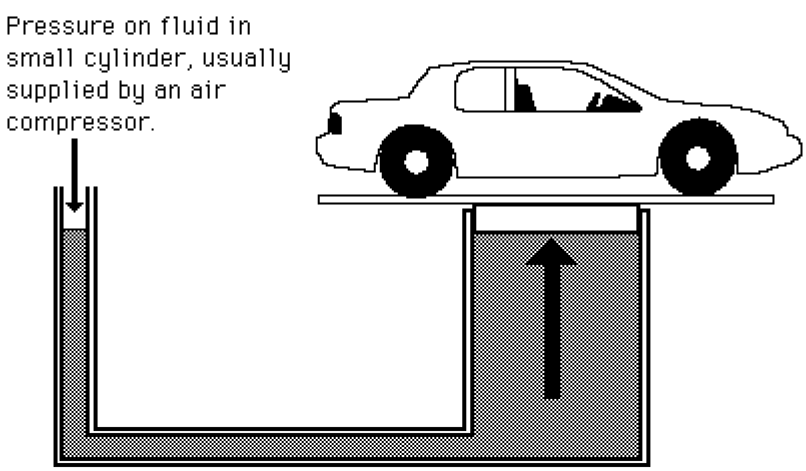


Image via www.howstuffworks.com

The great thing about hydraulic systems is that the pipe connecting the two cylinders can be any length and shape, allowing it to snake through all sorts of things separating the two pistons. The pipe can also fork, so that one master cylinder can drive more than one slave cylinder if desired.

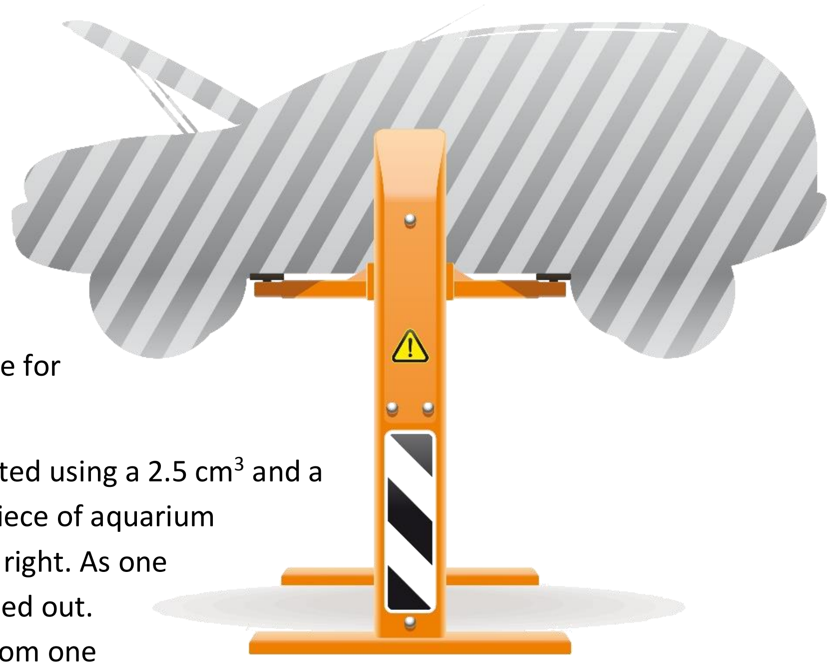
Now, students get to become hydromechanics and try it for themselves.



www.allstar.fiu.edu/aero/Hydr01.htm

Can you give me a lift?

Materials:



- Water
- Aquarium Tubing
- 2.5 cm^3 syringes
- 10 cm^3 syringes
- Books, bricks, or other heavy objects
- Option: sealant or waterproof tape for security

A simple hydraulic activity can be conducted using a 2.5 cm^3 and a 10 cm^3 syringe connected by a 1m long piece of aquarium tubing filled with water, as shown on the right. As one plunger is pushed down the other is pushed out. Force is transmitted through the water from one syringe to the other. ***Have students follow precisely a multistep procedure to put together their hydraulic system and when carrying out their own experiments, taking measurements, or performing technical tasks.***

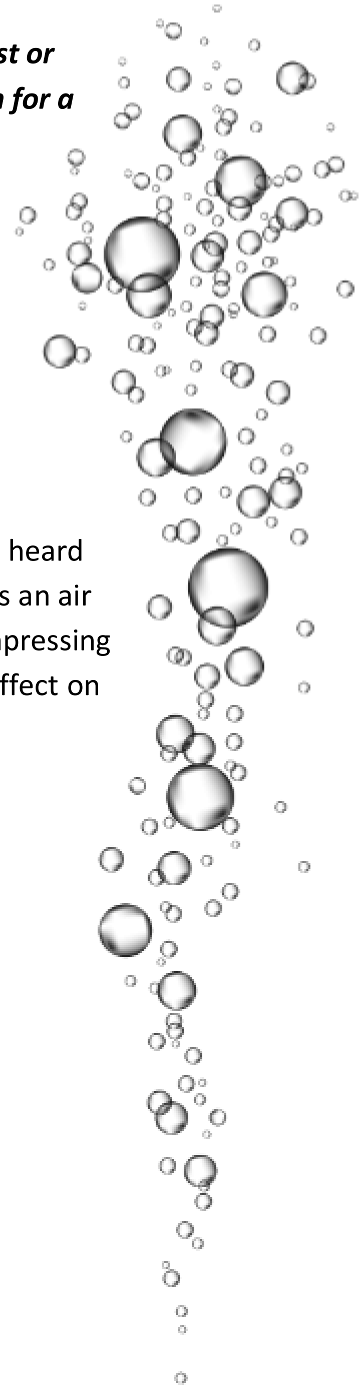
Once the set up is put together, how far does the plunger of the big syringe move out when students push in the small syringe 4 cms?

Ask your students to place their thumb over one of the plungers and try to stop it from moving outwards while their partner presses down on the other. Which syringe, the 2.5 cm3 or 10 cm3, will they use to push their partner's thumb upwards?

Now, have students set up their own experiment, ex. they may try to lift a heavy object like a book, or a brick, or try to use more than two syringes. ***When lifting objects is it best to***

put the small syringe under the heavy object, as shown in the picture, or is it best to put the bigger syringe under the heavy object?

Extension: ***Can students come up with any other experiments or ideas to test or areas to possibly apply this system? What about a hydraulic braking system for a rollercoaster?*** Ex: Some students have constructed models that transfer the force of one syringe to a small brake. The brake pad can simply be an eraser glued to the end of the other syringe plunger. Students will also need to set up a positioning apparatus; however this should not prove particularly difficult. For example one set up may have a student press one plunger into the syringe, and the other syringe plunger applying brake pressure to a spinning model wheel.



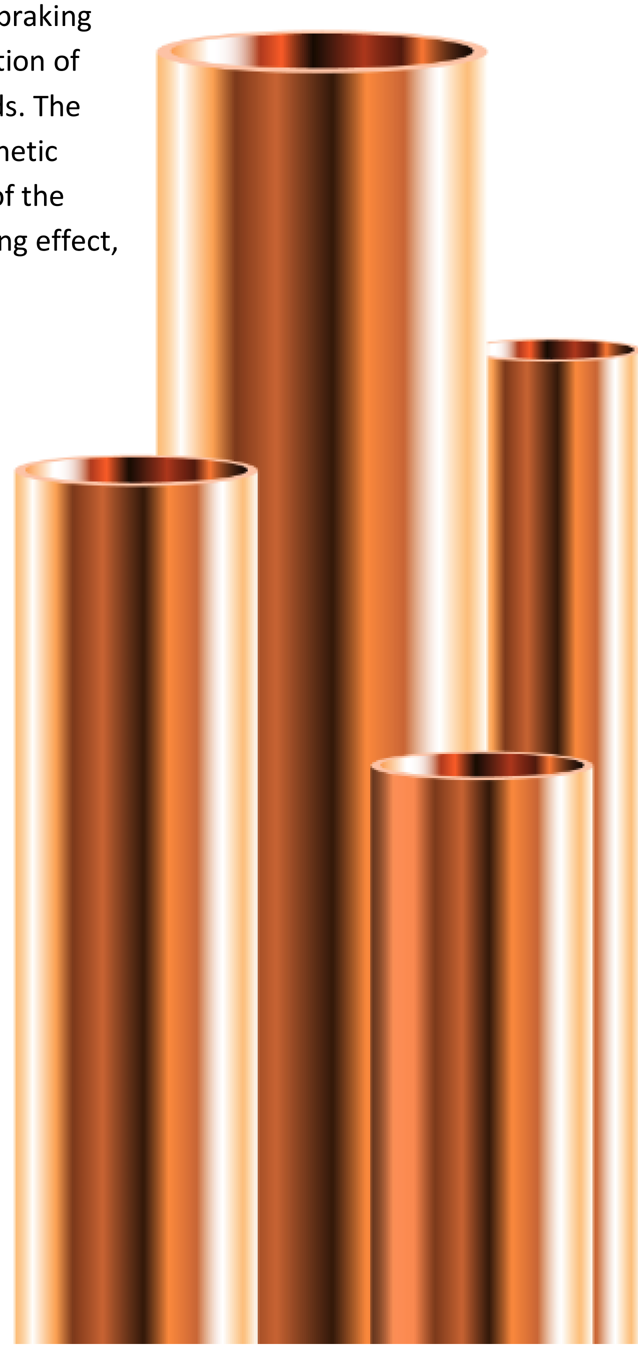
Note: Air in the System?

It is important that a hydraulic system contains no air bubbles. You may have heard about the need to "bleed the air out of the brake lines" of your car. If there is an air bubble in the system, then the force applied to the first piston gets used compressing the air in the bubble rather than moving the second piston, which has a big effect on the efficiency of the system, as your students may notice.

The Stop: Magnetic Braking Systems

Like any train, a roller coaster needs a brake system so it can stop precisely at the end of the ride or in an emergency. In roller coasters, the brakes aren't built into the train itself; they're built into the track. Many times the system is very simple; a series of clamps is positioned at the end of the track and at a few other braking points. A central computer operates a hydraulic system that closes these clamps when the train needs to stop. The clamps close in on vertical metal fins running under the train, and this friction [rubbing] gradually slows the train down.

Another system has grown in popularity, magnetic braking systems using Lenz's law. Lenz's law gives the direction of electric currents created by changing magnetic fields. The electric currents will be in a direction in which magnetic fields caused by the current will oppose the cause of the change. One result of this law is the magnetic braking effect, which makes a memorable physics demonstration experiment for students.



Materials:

- A copper or aluminum pipe
- A fairly powerful neodymium magnet (or several small ones stacked together) that are small enough to fit inside the pipe.
- Option: PVC pipe to match the size of your copper pipe, for comparison
- Option: Non-magnetic pizza cutter
- Option: Powerful horseshoe magnet

Note: The size and shape of the magnet does not matter as long as it can fit easily into the pipe. The exact length of the pipe is also unimportant, but the **type** of pipe does matter. It must be a metal that conducts electricity but is nonmagnetic. Copper or aluminum will work. Iron, steel, or any type of PVC will not work.

Demonstrate with the PVC pipe, if you have one. ***After*, h*ave students predict how fast they think the magnet will fall through the pipe, record their predictions. Have them make predictions***

about whether and how the pipe may be affected by a magnet. Now simply drop the magnet down the pipe and have students watch what happens. It will take much longer than one would expect. Option: For a similar experiment working on the same principle, find a pizza cutter, or similar spinning disk, made of a nonmagnetic metal. Taking care not to cut your hands, get the disk spinning as fast as possible. Then place the spinning disk inside a fairly powerful horseshoe shaped magnet. Watch it quickly stop spinning.

What's happening?

Ask students: Have students identify how magnets attract or repel one another. ***Have them give their ideas on why the magnet falls so slowly. Why does the pizza cutter disk stop spinning? Discuss their theories.*** Faraday's law and Lenz's law provide the keys to understanding these demonstration experiments and the magnetic braking effect used by roller coasters.

Draw a diagram for students as you discuss how the experiment works. Have students work to fill in the parts they can with their ideas. In this case, while the magnet is entering the pipe, it creates a magnetic current and multiple magnetic fields (eddy currents) in the pipe. The pipe tries to resist the change by repelling (pushing against) the falling magnet. The opposing force on the magnet slows the magnet down (N to N). Then, when the magnet is leaving the coil, the pipe creates a magnetic current to, again, slow the magnet, this time, from leaving it (S to N). We can think of the pipe itself as a magnet which repels the entering magnet and attracts the departing magnet. The moving magnet is repelled in front and attracted in rear.

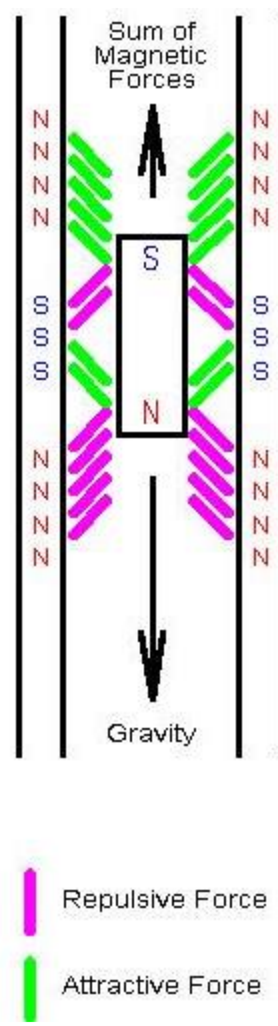
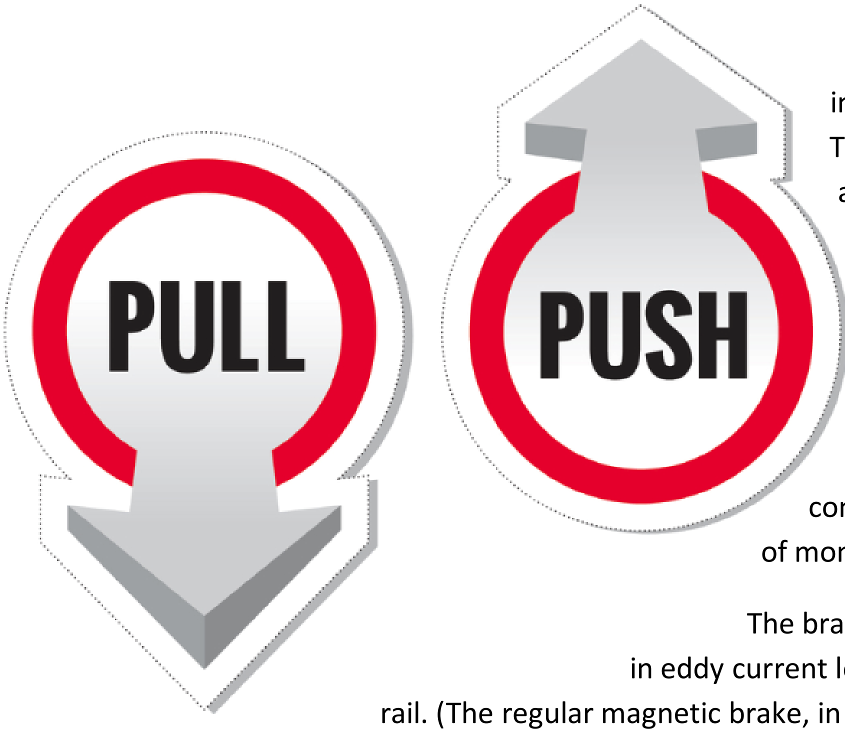


Image Credit: http://www.coolmagnetman.com/magpipes.htm.

Similarly the spinning pizza cutter disk has caused eddy currents. The currents induce magnetic fields that oppose their cause, which is the spinning disk. The disk slows to a stop, rather like a roller coaster wheel.

In transportation systems, when the magnet is moved along the rail, it creates a moving magnetic field in the head of the rail, which then generates electrical tension (Faraday's



induction law) and causes eddy currents. These change the magnetic field in such a way that the magnetic force is changed to the opposite of the direction of the movement, (pulling backwards), thus creating a horizontal force, which works against the movement of the magnet. It's pulling it backwards while the magnet continues to try to move forward because of momentum.

The braking energy of the vehicle is converted in eddy current losses which lead to a warming of the rail. (The regular magnetic brake, in wide use in railways, exerts its braking force by friction with the rail, which also creates heat.)

The eddy current brake does not physically touch the rail, and thus it doesn't wear down (not like tires on your car that eventually grind down because of friction) even if it's used for a long time, and creates no noise (no big shrieks!) or odor (like the smell of burning breaks if you try to stop your car too fast). The eddy current brake is unusable at low speeds, but can be used at high speeds both for emergency braking and for regular braking. ***Why do students think it would be unusable at low speeds?***

Modern roller coasters use this type of braking, but in order to avoid the risk of potential power outages they use permanent magnets instead of electromagnets, thus not requiring any power supply. However, they lose the ability to adjust the braking strength as easily as they could if they used electromagnets. ***What could be potential dangers of depending on electricity to stop a roller coaster car? What if the power went out, what might happen to the riders?***

Record Holders:

The best thing, for riders, about record-breaking roller coasters is that those records never last for long. We know it won't be long before another ride comes along and blows the previous record out of the water. In 2012, the following held the records.

Height: Kingda Ka Six Flags Great Adventure, Jackson Township, New Jersey, USA 128 mph Kingda Ka is only the second fastest, but also the tallest roller coaster in the world, with a $25 million-dollar price tag for its construction. A hydraulic launch mechanism rockets the train from 0 to 128 miles per hour (206 km/h) in 3.5 seconds, pulling about 1.67 g's.

At the end of the Kingda Ka launch track, the train climbs the main tower, twisting 90 degrees to the right before reaching a height of 456 feet (139.5 m). The train then descends 418 feet (127 m) straight down through a 270-degree spiral. Finally, the train climbs the second, 129-foot hill, producing a moment of weightlessness before being smoothly brought to a stop by the magnetic brakes. Due to the high speed and open nature of the trains, this ride will not operate in even light rain, as rider contact with rain drops can cause pain. ***Discuss with students: Why would raindrops cause pain on a roller coaster? Have you ever stuck your hand outside the car when you were driving when it was raining? Or ridden your bike really fast downhill when it was raining? What did it feel like?***

Want to go behind the scenes and see what Kingda Ka's hydraulic building looks like? Check out the "How Kingda Ka Works photo gallery" at http://themeparks.about.com/od/photoandvideogallery/ss/KingdaHydraulic.htm.

"With its ultra-high, ultra-fast specs, Kingda Ka begs the question: How much taller and faster could designers make coasters? "The challenge is not 'Can we do it?' " one engineer says, alluding to coaster brinkmanship. "The question is 'At what cost?' "

Parks can count on coaster fans lining up to test their mettle on bigger, faster thrill machines, but bragging rights only go so far when bean counters look at the return on investment. The sky, apparently, is the limit (as is the speedometer), but how many parks would be willing to shell out the tens of millions of dollars it would cost to build coasters that pierce the sky?[3]"

Top Speed: Formula Rossa: Kingda Ka lost the title of being the world's fastest when Formula Rossa at Ferrari World opened in November 2010 in Abu Dhabi, United Arab Emirates. Manufactured by Intamin, and taking over $45 million dollars to build, Formula Rossa is the world's fastest roller coaster with a top speed of 240 km/h (150 mph). The coaster train accelerates to its top speed in approximately 4.9 seconds Immediately following the launch, the train ascends a 53 m (174 ft) hill, where its speed is significantly reduced via magnetic brakes. The train completes the course with a maximum speed of 105 km/h (65 mph) after this point around the 1.4-mile-long track. Due to the high air speeds and thus risk of an impact with airborne particulates or insects, riders in the front are required to wear protective glasses similar to those used during skydiving.

Longest: Steel Dragon 2000 Nagashima Spa Land Nagashima, Mie, Japan: 8,133 feet. A skyscraper itself, Steel Dragon 2000 rises up 318 feet and begins with a 306-foot drop that accelerates the trains to 95 mph. Two more hills in excess of twenty stories each (252 feet and 210 feet respectively) follow the first. The total ride experience lasts about three minutes in which time thrill-seekers will have covered over a mile and a half of steel track. The building of Steel Dragon 2000 required far more steel than other coasters for earthquake protection. This put the cost of the coaster at over $50 million. This coaster's name was chosen because it debuted in 2000 - in the Far East, the "Year of the Dragon."

3 https://www.tripsavvy.com/how-kingda-ka-works-3226405

And We're Off!

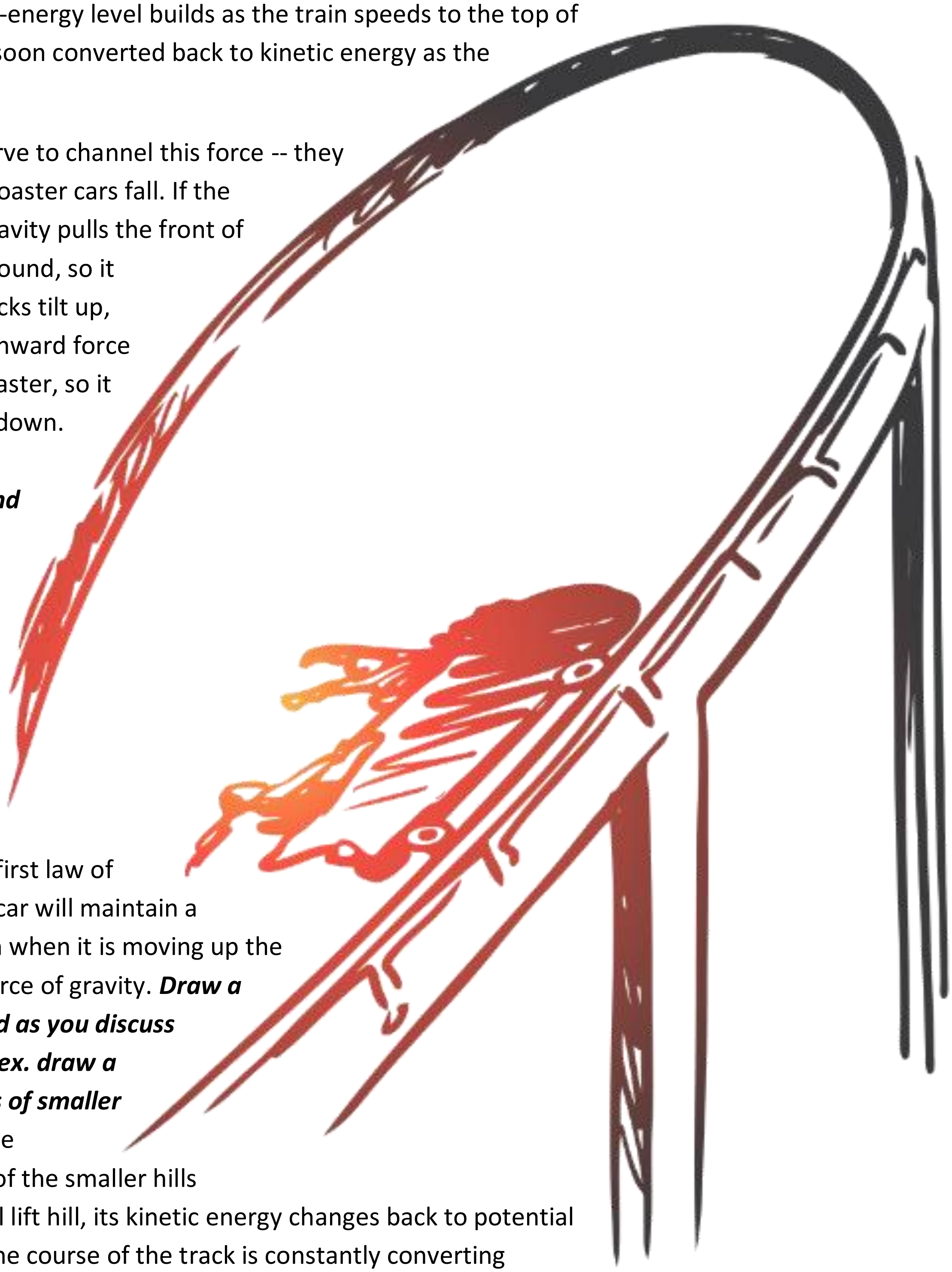
What riders may not realize as they're cruising down the track at 95 miles an hour is that the coaster has no engine. The car is pulled to the top of the first hill at the beginning of the ride, but after that the coaster must complete the ride on its own. It isn't being propelled around the track by a motor or pulled by a hitch. The conversion of potential energy to kinetic energy is what drives the roller coaster, and all of the kinetic energy you need for the ride is present once the coaster descends the first hill. Those high hills give your coaster the maximum possible energy for the rest of the ride. ***Have students heard of potential and kinetic energy? Can energy really be transformed from one type to another? If something "loses energy" where does it go?***

The purpose of the coaster's initial ascent is to build up a sort of reservoir of potential energy. The concept of potential energy, often referred to as energy of position, is very simple: As the coaster gets higher in the air, gravity can pull it down a greater distance. ***Discuss with students: You experience this phenomenon all the time, when? Can they think of examples?*** **--** think about driving your car, riding your bike or pulling your sled to the top of a big hill. The potential energy you build going up the hill can be released as kinetic energy -- the energy of motion that takes you down the hill.

Once you start cruising down that first hill, gravity takes over and all the built-up potential e-nergy changes to kinetic energy. Gravity applies a constant downward force on the cars.

A roller coasters energy is constantly changing between potential and kinetic energy.

Draw a diagram of a large lift hill (a), followed by a dip (b), a second hill (c), and a loop-the-loop (d & e) before the end of the ride. Then discuss with students, at the top of the first lift hill (a), there is maximum potential energy because the train is as high as it gets. As the train starts down the hill, this potential energy is converted into kinetic energy -- the train speeds up. At the bottom of the hill (b), there is maximum kinetic energy and little potential energy. The kinetic energy propels the train up the second hill (c), building up the potential-energy level. As the train enters the loop-the-loop (d), it has a lot of kinetic energy and not much potential energy. The potential-energy level builds as the train speeds to the top of the loop (e), but it is soon converted back to kinetic energy as the train leaves the loop.



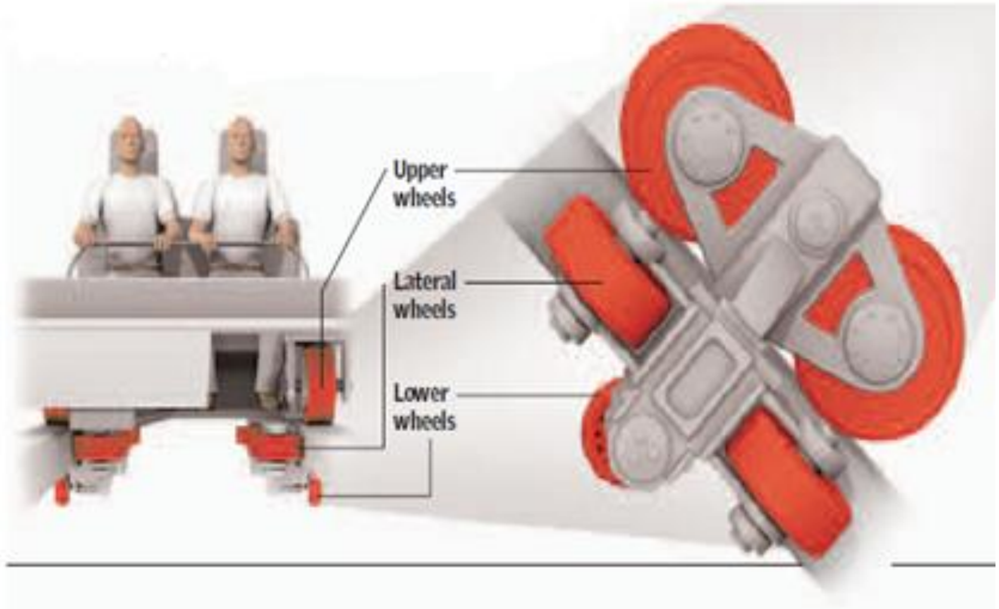
The coaster tracks serve to channel this force -- they control the way the coaster cars fall. If the tracks slope down, gravity pulls the front of the car toward the ground, so it accelerates. If the tracks tilt up, gravity applies a downward force on the back of the coaster, so it decelerates or slows down. ***How would students compare potential and kinetic energy? Have students give their interpretation of the relationship between potential and kinetic energy.***

Since an object in motion tends to stay in motion (Newton's first law of motion), the coaster car will maintain a forward velocity even when it is moving up the track, opposite the force of gravity. ***Draw a diagram on the board as you discuss the hills and energy, ex. draw a large hill and a series of smaller hills after it.*** When the coaster ascends one of the smaller hills that follows the initial lift hill, its kinetic energy changes back to potential energy. In this way, the course of the track is constantly converting energy from kinetic to potential and back again.

This fluctuation in acceleration is what makes roller coasters so much fun. In most roller coasters, the hills decrease in height as you move along the track. This is necessary because the total energy reservoir built up in the lift hill is gradually lost to friction between the train and the track, as well as between the train and the air. When the train coasts to the end of the track, the energy reservoir is almost completely empty. At this point, the train either comes to a complete stop or is sent up the lift hill for another ride.

At its most basic level, this is all a roller coaster is -- a machine that uses gravity, momentum, and inertia to send a train along a winding track.

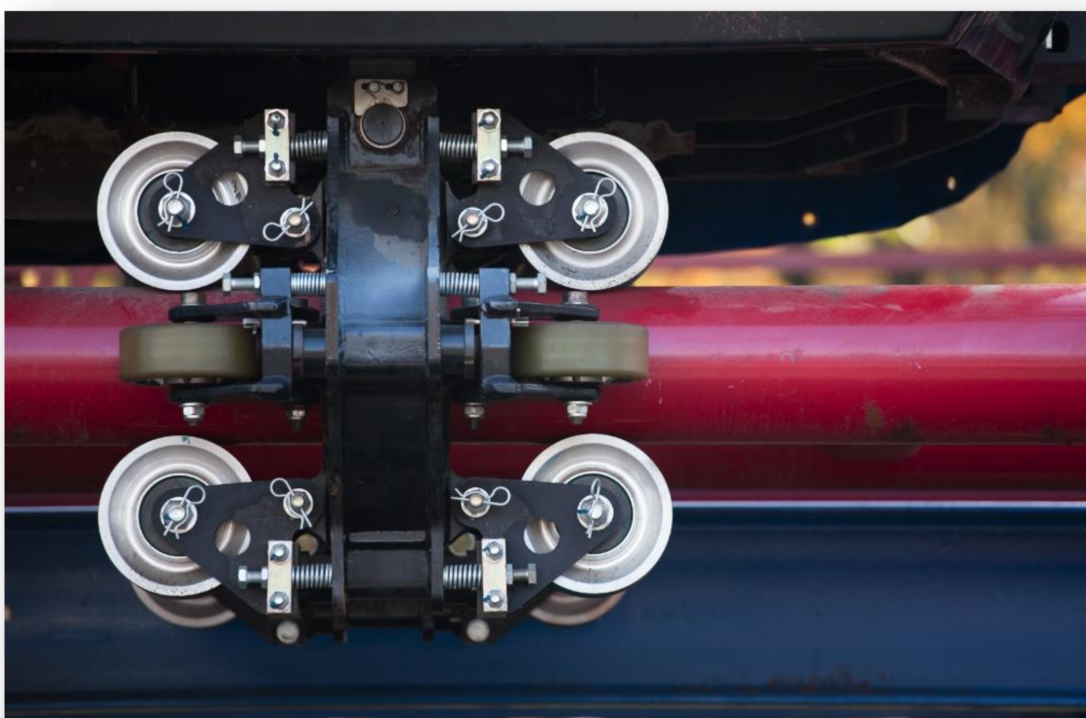
Once you're underway, different types of wheels help keep the ride smooth. Running wheels guide the coaster on the track. Friction wheels control lateral motion (movement to either side of the track). A final set of wheels keeps the coaster on the track even if it's upside down. And brakes stop the car as the ride ends.



Wheels of Motion

As coasters have evolved, they have become safer, more advanced and more thrilling. On the original wooden coasters, the wheels would sometimes fall off or the car might fail to stop at the end of the track. Today's coasters are built with many safety features to keep riders safe while still allowing a thrilling ride.

Running Wheels



These wheels are the primary wheels of the coaster. They're used to guide the coaster down the track. Positioned on top of the tracks, like the wheels of a train, they are made of metal and grooved on one side with a lip on the other to limit side-to-side movement.

Friction Wheels

On the side of the track, friction wheels control the lateral, or sideways, motion of the roller coaster. This allows the coaster to handle extremely sharp turns without skipping or flying off the track. When you feel the coaster whiplash as it comes out of a turn, the friction wheels are holding the coaster in place.

Upstop Wheels

When a coaster flips upside down, it needs to be attached to the track by something. ***Ask students what would happen if there wasn't something holding it on when the car went around the loop. Have students identify the force that causes objects to fall to the earth. How might they keep the cart from falling off but still allow it to move around the track?*** Positioned underneath the track, the upstop wheels hug the bottom of the rail and prevent the cars from becoming airborne and hold the coaster down, even when inverted (upside down). Without these wheels, the coaster would not be able to handle the extreme loops common in today's amusement parks.

Wooden or steel coaster: Does it really make a difference?

Roller coasters can be wooden or steel, and can be looping or non-looping. Riders notice a big difference in the ride depending on the type of material used. In general, wooden coasters are non-looping. Many times, they're also not as tall and not as fast, and they don't feature quiet as extremely steep hills (though they can seem quite steep when you're flying up and down them) or as long a track as steel ones do.

Wooden coasters do offer one advantage over steel coasters, assuming you're looking for palm-sweating thrills: they sway a lot more. Tubular steel coasters allow more looping, higher and steeper hills, greater drops and rolls, and faster speeds.

Ask students what might be some advantages of wooden roller coasters over steel?

Wooden roller coasters are amusement park staples. They offer a rickety ride that preceded the steel variety in theme parks across the country. Wooden coaster enthusiasts enjoy the rough ride and the feeling of being jostled around on the tracks. To many, these coasters represent a part of theme park history that can still be enjoyed by today's coaster enthusiasts. Many wooden coasters in today's theme parks have been around since the 1950s. In fact, the "Leap-the-Dips" coaster at Lakemont Park in Pennsylvania has been operating since 1902.

One advantage of wooden roller coasters over steel coasters is the cost to build them. Wood is cheaper than steel, thereby making it a cheaper way to create a thrill ride. However, wooden coasters typically require more maintenance. According to ThemedAttraction.com, all roller coasters are subject to daily inspections. But on wooden roller coasters, technicians are able to walk the entire track, checking for loose nuts and bolts and any other irregularities, attending to the ride with a more hands-on approach. This differs from steel coasters, as technicians cannot walk the entire track and must use binoculars to check for potential hazards.

While, in general, steel roller coasters are taller, longer, faster, smoother and more thrilling than wooden roller coasters, wooden roller coasters can also be engineered with similar intensity. For instance, Cedar Point's "Mean Streak" in Ohio features a 161-foot drop and 5,400 feet of track. The "El Toro" coaster at Six Flags Great Adventure in New Jersey is a 181-foot tall wooden coaster that reaches speeds of 70 mph. It's the only wood coaster in the world to feature a 76-degree angle drop. Wooden coasters are one of the oldest means of theme park entertainment and continue to be enjoyed today's riders[4]

[4] *Information gathered from http://www.learner.org/interactives/parkphysics/coaster.html © Annenberg Foundation 2012. All rights reserved. And, from Tom Harris at, "How Roller Coasters Work" HowStuffWorks.com. http://science.howstuffworks.com/engineering/structural/roller-coaster3.htm. All rights reserved.*

Coaster Challenge!

Using forces of nature (and quite a bit of cardstock) students will make a marble 'rider' loop-de-loop on a track that they design.

The Project

The students are designers of roller coasters for a company that sells coasters and rides to amusement parks all over the world. They have just developed a new roller coaster and need to prepare a portfolio of materials for the potential buyers. This portfolio must include the roller coaster design (including their scale drawings and calculations of scale), the speed of the coaster, and the cost of the coaster.

Using the principles of potential and kinetic energy, the students should be able to design their investigation to demonstrate the difference between potential and kinetic energy through constructing a roller coaster. As the marble moves down, potential energy changes to kinetic energy. As the marble moves up, kinetic energy changes to potential energy.

Friction is also a factor because it uses up some of the potential energy so there is not as much kinetic energy available.

The potential energy at the top of the roller coaster must be enough to move the marble through all the loops and hills without stopping.

Note: You will want to set a length of time the ride must last as part of the challenge. Ex. 30 seconds.

Materials:

Materials:

- Cardstock, white and colored (six different colors)
- Marbles (for riders)
- Ball point pens, for scoring templates
- Pencils (for drawings, notes, and keeping track of costs, measurements, etc.)
- Notebook paper (for notes, keeping track of costs, measurements, putting together the portfolio, calculating speed, etc.)
- 12" rulers (1-2 per group)
- Magazine or catalog - used as a cushion, it helps to score the templates when tracing.
- Rolls of transparent tape (1-2 per group) Ex. One class may need six rolls of 3/4" x 600" transparent tape.
- Roller Coaster Element Standard & Advanced Templates from paperrollercoasters.com (an average class will need six times as many pre-printed sheets of card stock and marbles as found in an Individual Set):
    - Copy the structural pieces (i.e. columns, beams, diagonal supports, and shelves) on white paper. Then **copy each of the other pieces on different colored paper**. That makes it much easier for the students to find the desired piece and copy the template and use it to inspire a redesign or adjustment. It also helps you to see which pieces are getting low.
    - Cut the sheets into strips using a paper cutter or scissors. Tips: *Cut along every thin gray line.* ***Practice making each piece so you'll be able to explain it to your students***.
    - *Create a sample reference board with each stage of each piece (including a finalized one) for students to go to when confused. This saves the teacher being asked many many times "How does this one go?" You'll want to decide on a price for each piece to help students calculate how much their roller coasters would cost to 'build' for their portfolios.*

- The Booklet Step by Step Instructions for Building Incredible Roller Coasters by Andrew Gait, www.paperrollercoasters.com
- A Master Template reference board with each template at each stage from initial cuts to final construction as well as a price for that piece
- Scissors (1 per student)
- Graph paper (for scale drawings, multi-view drawings of each group's unique track element template, etc.)
- Stop watches (1-2 total that students can borrow)
- Optional: Foam board or cardboard for bases
- Optional: cup and/or other materials to add in
- Optional: mailing labels to identify areas and shifts of potential and kinetic energy on the roller coasters

Image Credit: Imagineering Disney. http://www.imagineeringdisney.com/blog/2010/7/25/matterhorn-for-magic-kingdom-fantasyland.html

Students will learn about common vision, team work, and division of labor. For example, Disney hires a team that includes a cross section of wildly different disciplines in order to handle the construction of a new ride. These people are called "Imagineers," a word that combines "engineers" and "imagination," like the concept map an Imagineer drew on a napkin.

To give your students some imaginative ideas for their roller coasters, you might want to show your students all of the roller coasters in the gallery on the website: www.PaperRollerCoasters.com and other sites. Have students [individually, in pairs, or in small teams] then build a roller coaster using a marble, cardstock, foam board or cardboard base, scissors, and tape. Build the support structure! Following the Roller Coaster specification guidelines the students are to design and construct a roller coaster while working in a group.

Staying on Track with the Budget!

In the real world, engineers do not have unlimited resources to build a rollercoaster. This activity incorporates calculating costs for materials and staying within a budget. part of the challenge is to construct the most cost-effective rollercoaster possible. During construction students must also calculate the cost of the materials they use to construct their rollercoaster, including any they wasted or broke.

Cost: Calculate the cost of their rollercoaster by using the following Cost Specifications:

Tailor the budgeting challenge to the age and capabilities of your students as well as what the standards expect them to understand.

$ _______ for 1 Roll of Tape (ex. $1,000)

$ _____ per beam

$ _____ per support

$______ per funnel

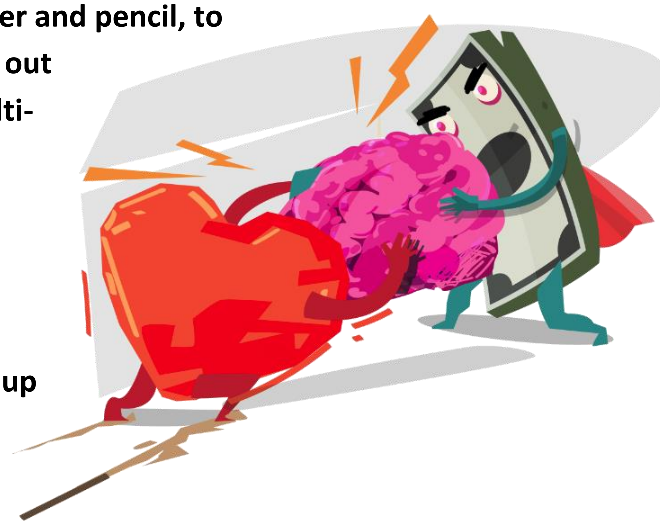
$ ______ per loop

$ ______ etc…

Put the cost of each part on your parts reference board.

Options & Ideas: You can also charge students for an ‘engineering consultation’ if they ask you to help them with a template or design element after the initial instruction is complete. Prebuilt templates could cost more. Have students have to calculate in a cost for time spent on construction. The possibilities are endless.

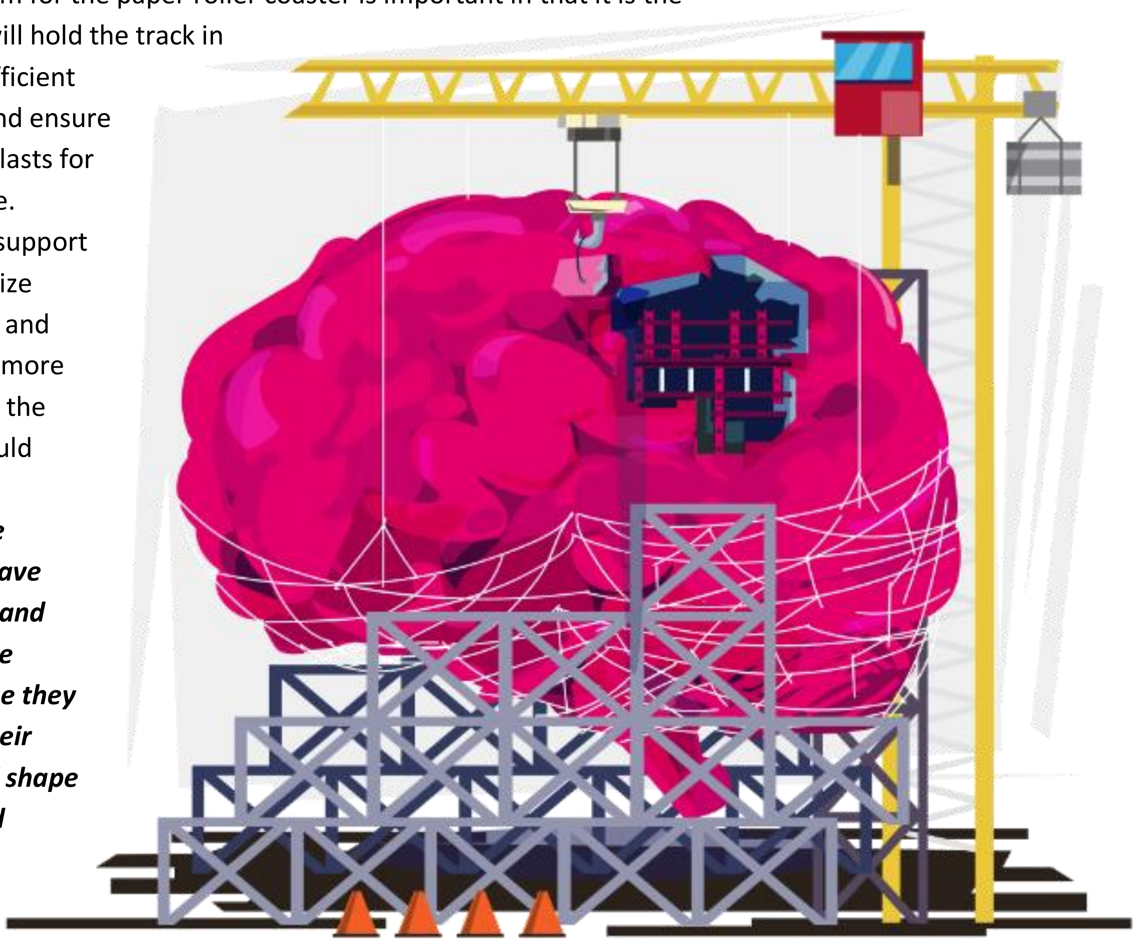
After reviewing and testing sample templates of track pieces, structural pieces, and other roller coaster elements (i.e. columns, beams, diagonal supports, and shelves), have students use their imaginations and engineering skills to construct their own templates for additional or unique track elements, using paper and pencil, to form and format the shapes on cardstock and test out their designs. Have students design a series of multi-view drawings that could be used by others to reconstruct their adaptive design and test its effectiveness.



Option: If other students want to use their unique element they could 'sell' them for a price and recoup some of their budget costs.

The Support System:

The support system for the paper roller coaster is important in that it is the framework that will hold the track in place, allow for efficient energy transfer and ensure the roller coaster lasts for as long as possible.



The intent of the support structure is to utilize geometric shapes and angles to provide more strength than just the material alone could provide. **[*While constructing have discussions and have students analyze and compare the three dimensional shape they are creating to their two- dimensional shape counterparts, and describe their similarities, differences, parts (e.g., number of sides and vertices/"corners") and other attributes (e.g., having sides of equal length), triangles are the strongest shape to build with, etc.*]**

Design Parameters

- More emphasis will be needed to be given to the overall design and quality of construction than just the simple "it needs to remain upright" goal.
- The columns and all supports must fit within the foundation (ex. foam board) provided if you are having them use a foundation.
  The structure must be rigid and not be moved or shifted while the marble is moving down the track. All columns must rise at a 90-degree angle from the foundation, older students may be required to measure the angles using a compass. Columns should not twist or be miss-shaped. All columns should be rectangular in shape. Note: They can be cut to different lengths!
- Diagonal supports will be affixed at 45-degree angles (measured using a compass) to the column and will be secured on both ends. Horizontal beams must travel at 90-degree angles from the column and must be rectangular in shape. No twisting or warping.

Measurement: Building it Up Inch by Inch

Image Credit: PaperRollerCoasters.com
http://www.paperrollercoasters.com/gallery.htm

- With younger students have them measure and record the length of each element or piece by selecting and using appropriate tools such as rulers, yardsticks, meter sticks and measuring tapes.
- Have students use length units of different lengths for the two measurements, ex. inches and centimeters.
- Have younger students order three components by length; and compare the lengths of two objects indirectly by using a third object ("See, this one is longer than those two, we should use it next.")
- Have older students measure using appropriate tools to determine how much longer one support is than another, expressing the length difference in terms of a standard-length unit and record it.
- Once students have a good understanding of the average piece sizes, they can then estimate what size element will be needed next, using units of inches, feet, centimeters, and/or meters.
- These measurements can also be used to determine a scale when their roller coaster is complete. They can include this scale as part of their portfolio. If their roller coaster is 24 inches tall, how tall would it be in real life if their scale was 1 inch for every ____ feet? What scale should they draw it at?

Note: Tape IS NOT to be used as a load bearing component. It is only to be used to secure or connect support systems. The less tape used the better, as long as all objects are secure.
Any column not serving a purpose should be trimmed or removed as necessary. Try to keep the visual clutter to a minimum. The roller coaster should be able to be moved, transported and used without any "normal" breakdown from use. Design the supports to last!
Option: If doing group competitions, the support system could be worth points, ex. 50 points.

The Track

Build the track! The roller coaster is to be built with the same quality in mind as the structure. Once again, the shapes students create, and the card stock itself should be doing the work and NOT the tape.

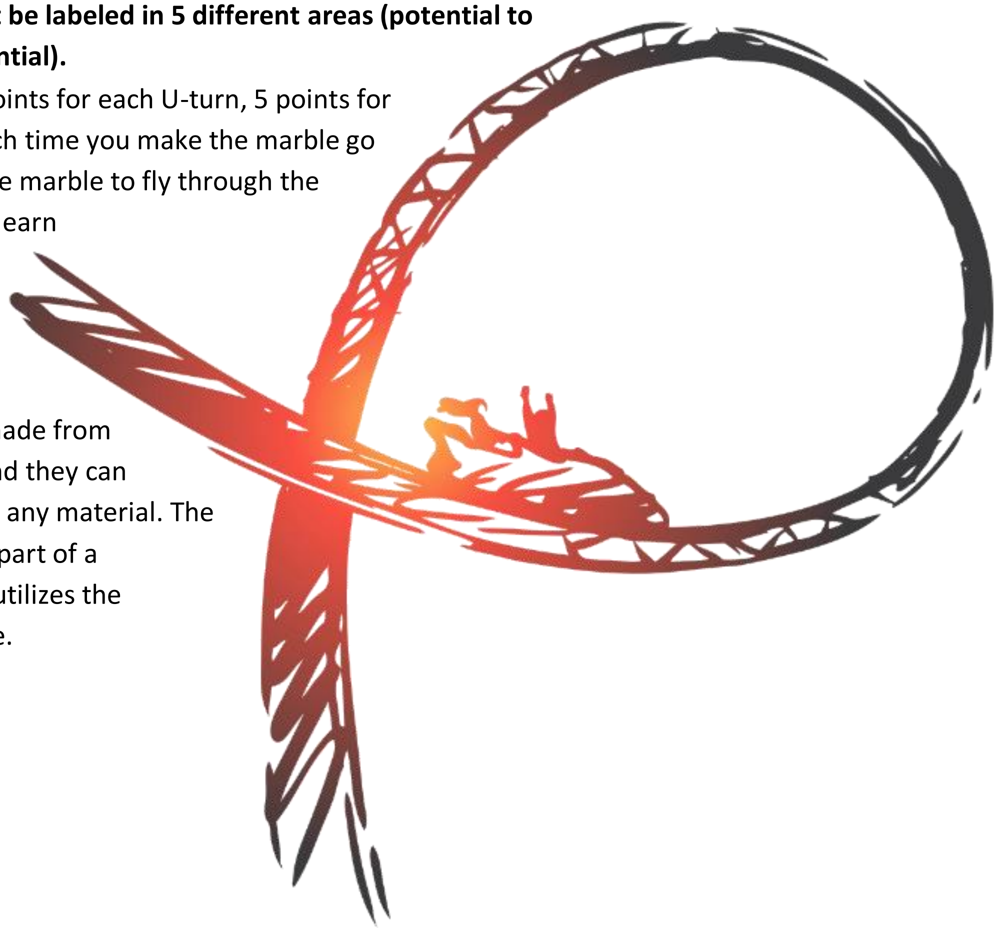
Share Tips for Success with Students:

- **Start small - You can always continue to build a structure taller later. Build a small structure and start attaching tracks. You might find out that you don't need a tall structure to make an interesting roller coaster.**

- **A slow marble can be impressive - If a marble takes 30 seconds to reach the bottom of the roller coaster, it will be more impressive than one that only takes 5 seconds. Keep the incline of your tracks gentle so the marble doesn't reach the end too fast.**
- **Only use steep tracks when necessary. If the marble flies off the track, make the slope gentler to keep the marble's speed under control.**

Track Specifications: *Adjust according to your students' abilities and grade-level standards if necessary.*

- Roller coaster must run for **at least _______** [ex. 30 seconds]
- Roller coaster marble "rider" must complete the track, from start to finish without any assistance and the marble must not fall out of the track under any circumstances
- All tracks must be supported, and they should not move while the marble is in motion.
- The roller coaster must have … [ex: six drops, six turns, 1 large funnel drop minimum, 2 maximum, a loop, and a minimum of 1 advanced element [the tipping switch, rotating arm, mini-funnel, switchbacks, zigzags, and/or the half-pipe.] Points are deducted for fewer drops, turns, or no loop.]
- Excessive tape is NOT allowed!
- If you use a "Y" intersection, the marble must be able to move in either direction randomly.
- **Energy transference must be labeled in 5 different areas (potential to kinetic, or kinetic to potential).**
- Options: Students get 3 points for each U-turn, 5 points for each loop, and 1 point each time you make the marble go up a hill. If they can get the marble to fly through the air and land in a cup, they earn an extra ten points.
- At least one track design piece that is not one of the supplied templates. But it can be made from them or pieces of them and they can add your own pieces from any material. The piece they add cannot be part of a commercial product that utilizes the transportation of a marble.



Using Logic & Pondering the Problems

As they build [and adjust] their design have the students consider the following questions. What forces are moving the ball around the track (Gravitational Potential Energy and Kinetic Energy)

1. Can all the hills be the same height? If not, why? Can they get bigger or must they get smaller? How will you determine how big or how small the hills can be?
2. Does the steepness of the hill count? Is it better to make the hills steep or not so steep? Why?
3. How curvy should the tops of the hills and the valleys be? Should you design sharp turns or smooth turns? Why?
4. What factors affect the speed and distance traveled by an object in motion?
5. What provides resistance on the roller coaster causing the ball to slow down? How can this resistance be reduced?

Time to Compare

Once their tracks are built (with any due adjustments to drawings and projected data as construction warrants them) have students test and compare their projected data to the real-world data they record using their models.

Note: ***Leave students with enough time to make revisions to their original design—an important factor in the process of design and engineering.***

- When their roller coasters are completed, have students solve unit rate problems including those involving unit pricing and constant speed, acceleration, and momentum, the average speed, speed at different points, and time for these tracks using a stopwatch and a timer. Have students record the data on a chart.
- Students can find the average speed of their coaster and compare it with the rest of the class.
- How does the projected data from their scale drawings compare to the data from the model? Are they comparable? What factors are different between the two?
- Students may alter the design of their coaster to come up with the optimum speed and time of ride and to allow the marble to move through the entire track without assistance. **(*Have students differentiate between potential and kinetic energy and determine where each is***

most effective. Is the potential energy at the top of the roller coaster enough to move the marble through all the loops and hills?) How do those adjustments affect the rest of their data? Have the students compare data with other groups.

Additional questions and ideas to have students consider while creating their portfolio/coaster.

1. How does changing the height or the length of a hill of a roller coaster affect the speed?
2. Is friction slowing their marble down? If not do they want it to in certain parts? How could they increase or reduce friction?
3. How does the rate of interest affect the payments that must be made on money that is borrowed? How does the length of time of the loan affect the total amount of interest paid when borrowing money?
4. How might students estimate the amount of money that can be generated by a roller coaster?

Bonus Additions for Competitions:

- Best scenery (+2 additional points] Lots of quality scenery covering the entire coaster and platform. Spending money on fancy scenery will not automatically make students a winner. Simple, but clever or well done, unique, designs show more creativity -especially when they support the name and theme of your coaster.
- Best Theme [+2 additional points] What's the name of their roller coaster? Does their scenery support this theme? Does the design support their theme? Is there a coolness or cleverness factor to their name?
- Most creative design element [+2 additional points] You're looking for something different. Students may use items not made from paper for this. They cannot use anything that was originally designed as a part of any kind of roller coaster toy.
- Most complex design. (+2 additional points] Wow. We're looking at the loops, twists, dips, turns, etc.

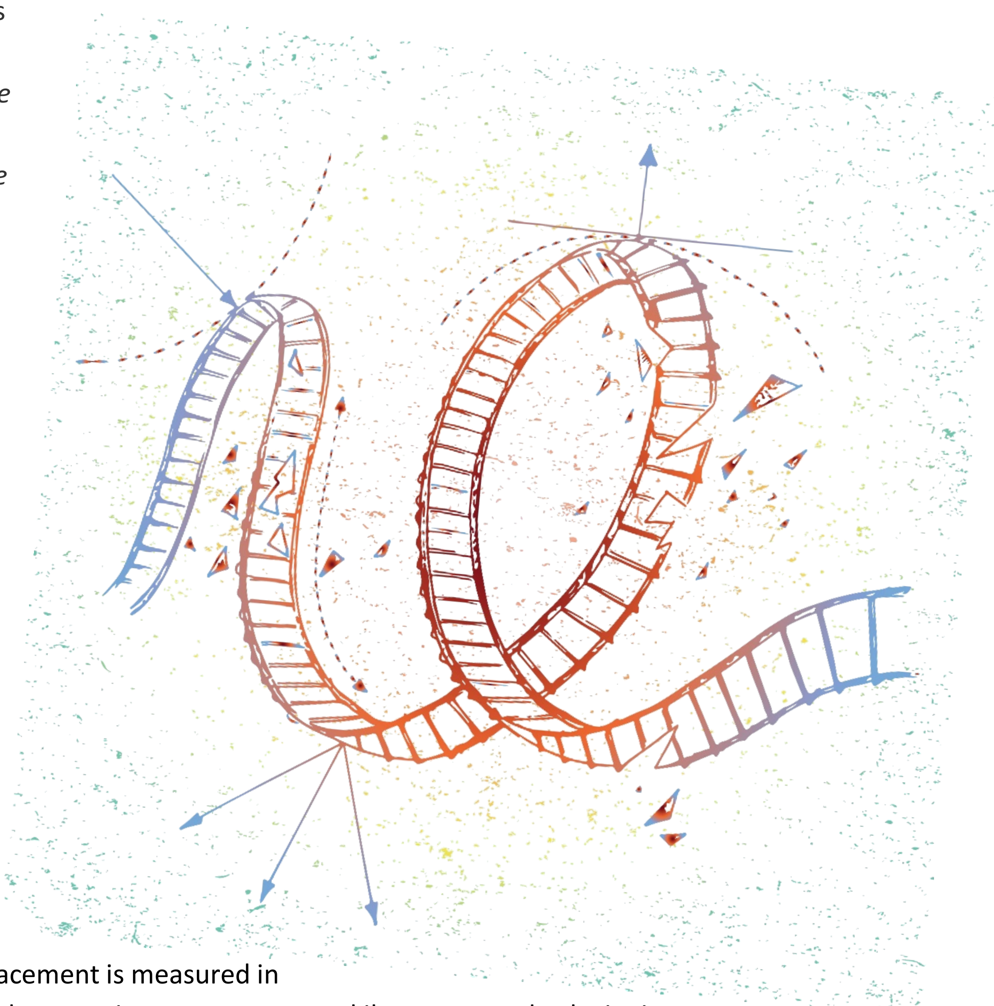
Calculations and Formulas:

Have students investigate and apply proper equations to solve basic problems pertaining to distance, time, speed, and velocity; track the data they measure; use equations and formulas; analyze the data using graphs and tables and relate these to the equation. For example: In order to calculate the speed of an object we must know how far it's gone and how long it took to get there. In determining motion at constant speed, have older students list and graph ordered pairs of distances and times, and plug the information into the speed formula to represent the relationship between distance and time and/or use the included worksheets.

During your discussion and class practice, work through discussion, demonstration, and practice to help students understand the concept that if they have any two pieces of the equation (ex. speed and distance), they can find the third (ex. time) by *transposing formulae*. Remind them that we must take care with the units, ex. If the speed is given in cm/second then time must be in seconds and distance will be given in centimeters.

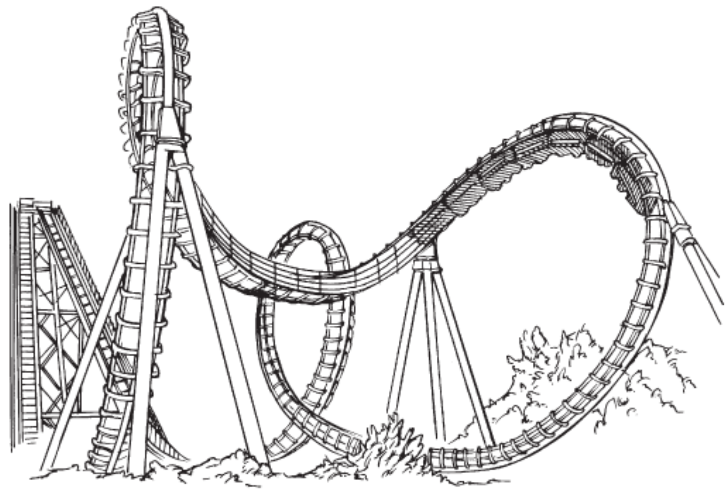
- **Average Speed:** Calculates average speed to ride a fixed distance in a given time. Formula: Speed = Distance ÷ Time
- **Time:** Calculates time required to ride a fixed distance in a given average speed. Formula: Time = Distance ÷ Speed
- **Distance:** Calculates distance covered from average speed and time elapsed. Formula: *Distance = Speed × Time*
- **Velocity:** Velocity equals displacement* (change in position) divided by time. v=d/t

Average velocity is mathematically defined as *average velocity = total displacement/time elapsed.*



*Note that displacement (distance from starting position) is not the same as distance traveled. If a car travels one mile east and then returns one mile west, to the exact same position, the total displacement is zero and so is the average velocity over this time period. Displacement is measured in units of length, such as centimeters, meters, or kilometers, and velocity is measured in units of length per time, such as meters/second (meters per second).

Option: Older students may calculate:



Speed at Specific Points: Have students prepare calculations to show the speed of their new roller coaster at several points along the track, for example they will want to show the speed at the top of each of the hills. Ex: Suppose their coaster reaches its maximum speed of 72 miles per hour at the bottom of their second hill, which is 200 feet tall. The formula for determining the speed of a coaster at the top of any hill is

$v_1 = \sqrt{(v_2)^2 + 2gh_2 - 2gh_1}$, where

v_1 = speed at the top of the hill in ft/sec,
v_2 = speed at the bottom of the hill in ft/sec,
h_1 = height at top of hill in feet,
h_2 = height at bottom of hill in feet, and
g = 32 ft/sec^2, the constant for gravity.
Assume that the bottom of the hill has height 0 ft.

1. What will be the value of $2gh_2$? Why?
2. The value of v_2 in the formula should be expressed in ft/sec since the value of g is in ft/sec^2. What is the maximum speed of the coaster at the bottom of the hill in ft/sec?
3. List the values for each variable to use in the expression on the right side of the formula.
4. What is the speed of the coaster at the top of the second hill?

A Need for Speed!

Calculating average speed student worksheet

In a most roller coasters, even paper ones, the speed of a cart or marble will increase and decrease many times as it rolls through. In this activity, you will find the speed of the marble in different portions of your paper roller coaster. You will also find the average speed of the marble during the entire trip down the paper roller coaster.

Materials:

Make sure you have each of these and check them off as you get them.

- ☐ completed Paper Roller Coaster
- ☐ yard stick
- ☐ pencil
- ☐ calculator
- ☐ string

Divide your paper roller coaster into three different sections by placing the following four marks on the tracks.

1. Start at the top and label the beginning of the roller coaster with an "A."

2. About 1/3 of the way down the roller coaster, label the track with a "B."

3. About 2/3 of the way down the roller coaster, label the track with a "C."

4. And finally, label the very end of the roller coaster with a "D."

Measuring Distances between points

1. We need to measure the distance that the marble must travel to get from Point A to Point B. To do this, lay one end of your string on the track at Point A.
2. Now, stretch the string exactly along the path that the marble will travel. When it reaches it, mark the string where it meets Point B on the track.
3. Remove the string from the track and measure the length of the string that reached from Point A to Point B when it was lying on the track. Record the distance in meters on the data table.
4. Do the exact same thing, again, to measure the distance from Point B to Point C and the distance from Point C to Point D. Record these distances in the data table.
5. Now we need to know how long it takes (the amount of time) for the marble to roll from Point A to Point B. To do this, put the marble at Point A, let go of it, and use a stopwatch to find how long it takes for the marble to reach Point B. Record this time in the data table.
6. Do this three times and record your results in the data table every time. Find the average for the three trials and enter that time in the data table. To do that take the three amounts of time (for this example 30 seconds, 32 seconds, and 28 seconds) and add them up. For example: 30 + 32 + 28 = 90. Then divide your answer by the amount of trials. In this time you did three, so in our example: 90/3 = 30. The average time is 30 seconds.

7. Now, measure the amount of time it takes for the marble to roll from Point B to Point C. Do not release the marble at Point B. Instead, release the marble at Point A again and start the stopwatch when it passes Point B. Stop the timer when the marble passes Point C. Repeat for three trials and calculate the average like you did before
8. Measure the amount of time it takes for the marble to roll from Point C to Point D. Do not start the marble at Point C. Instead, release the marble at Point A again and start the stopwatch when it passes Point C. Stop the timer when the marble reaches Point D. Repeat for three trials and calculate the average.
9. Calculate the average speed of the marble between Point A and Point B. In order to do it you need to divide the distance between Point A and Point B by the average amount of time that it took to get from Point A to Point B. For example, if your distance is 10 inches and it took, on average between the three trials, 5 seconds then you would divide 10 by 5.

$$\frac{10 \text{ inches}}{5 \text{ seconds}} = 2 \text{ inches per second}$$

10. Enter the speed of your marble in the data table. Use the correct units in the table.
11. Calculate the average speed of the marble between Point B and Point C. Record your result in the box on the table. Repeat the same steps to calculate the average speed of the marble between Point C and Point D.

	Test Trials			Results & Averages
	One	Two	Three	
Distance A to B				
Time from A to B				Average:
Speed b/w A and B				
Distance B to C				
Time from B to C				Average:
Speed b/w B and C				
Distance C to D				
Time from C to D				Average:
Speed b/w C and D				

1. Between which two points did the marble have the highest average speed? ____________________
2. Why do you think that the marble was moving the fastest on this part of your roller coaster?

____

____

3. Between which two points did the marble have the slowest average speed?

____

4. Why do you think that the marble was moving the slowest on this part of your roller coaster?

____

____ ____

6. If you wanted to make a roller coaster on which the marble would have the slowest average speed from the top to the bottom, how would you design it?

____

____

____

6. Calculate the average speed of the marble during the entire trip down the paper roller coaster.

	Test Trials			Averages & Results
	One	Two	Three	
Distance from A to D				
Time from A to D				Average:
Speed from A to D				

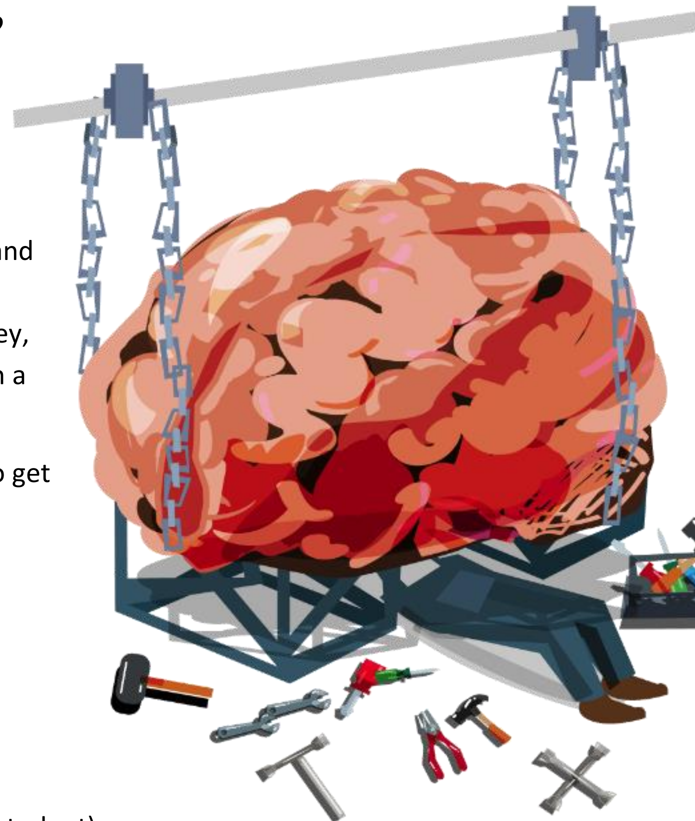
Challenge: Calculate the velocity of your roller coaster from start to finish and from start to midpoint. Velocity equals displacement* (change in position) divided by time. v=d/t *Note that displacement (distance from starting position) is not the same as distance traveled. If a car travels one mile east and then returns one mile west, to the exact same position, the total displacement is zero and so is the average velocity over this time period.

Distance marble traveled (in units of length)	Time it took (in units of time)	Velocity

Summarize the difference between the speed and velocity based on the distance and amount of time traveled. ____

____.

Imagineers: Design in Mind?



Each year, amusement park owners compete to earn some of the billions of dollars people spend on entertainment. In order to have customers come back year after year the parks need to have customers have fun the first time and newer, faster, more exciting rides the next time, especially roller coasters. But it takes time, money, work, and someone, or quite a few someones on a team, to build them.

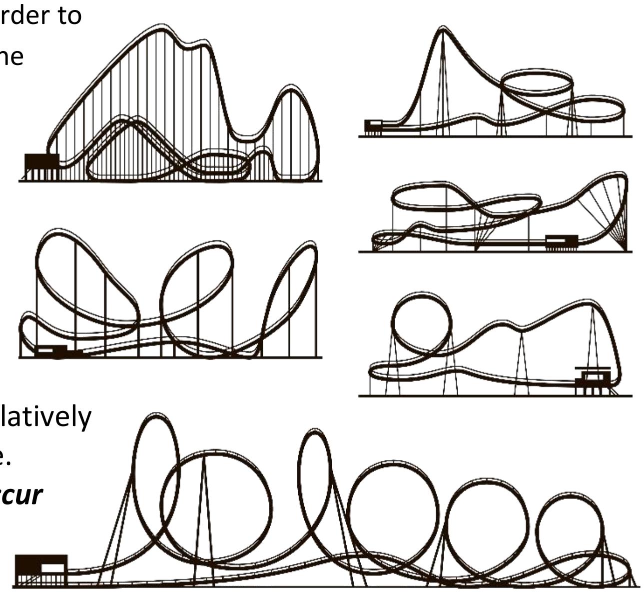
And before they can build them, someone has to get their new idea down on paper.

Materials:

Per group:

- completed Paper Roller Coaster
- 2 sheets of graph paper per student
- yard stick
- 12-inch rulers with centimeters (one per student)
- Protractors (one per student)
- Pencils (one per student)
- White board or large sheet of paper
- White board markers or regular markers

Have a student come to the front of the class and draw a 2-D (X-Y plane) roller coaster on the board. Discuss with the students what you would have to know in order to build this roller coaster. What it was made of, etc. Bring in the concepts of scale factor. You have to know how high the tallest point is, how big the loops are…before you can do anything you have to have some idea of scale.



Scaled drawings are a means of communication between the contractor and the designer of a product, such as a house, or in this case, a roller coaster. Scaled drawings are used because they allow the designer to put a large amount on information into a relatively small, portable, easily changed, and easily read package. ***Discuss with the students any difficulties that might occur with a designer trying to put a life size drawing of their roller coaster on to paper.***

One key part of every scale drawing is the scaling factor. This number represents the degree to which your scale drawing or scale model has been reduced in size when compared to the original. For example, a scaled drawing could show 1 inch for every 10 feet of the real object. That's a scale of 1/10, or 1 cm for every 32 ft, that's a scale of 1/32.

Practice

Have students practice by doing the following activity on graph paper:

Students will draw a 2-D model (a flat drawing on paper) of a roller coaster with the following dimensions. Their drawing should be a 1/32 scale (1 cm for every 32 ft) drawing on graph paper. Have students turn their graph paper sideways to allow enough room for their rollercoaster to fit. Use of a ruler and other measuring/drawing devices such as a compass is expected.

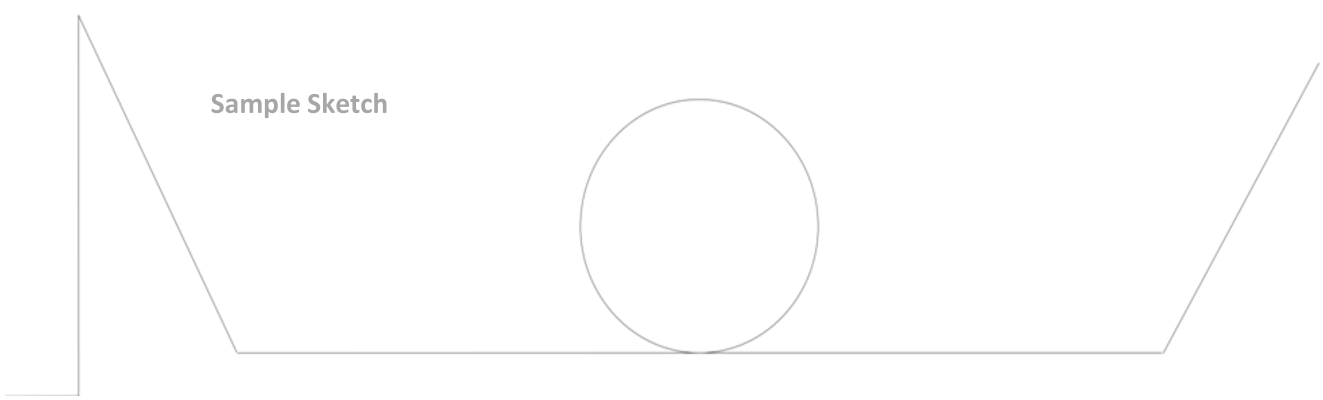
Start with a 20 cm level area

Then 96 cm vertical rise

After that an 80 cm 45 degree downward slope

Next a 360 cm level area with a 64 cm loop in the middle of the 360 cm length.

Finish with a 30-degree upward slope that is 75 cm long.

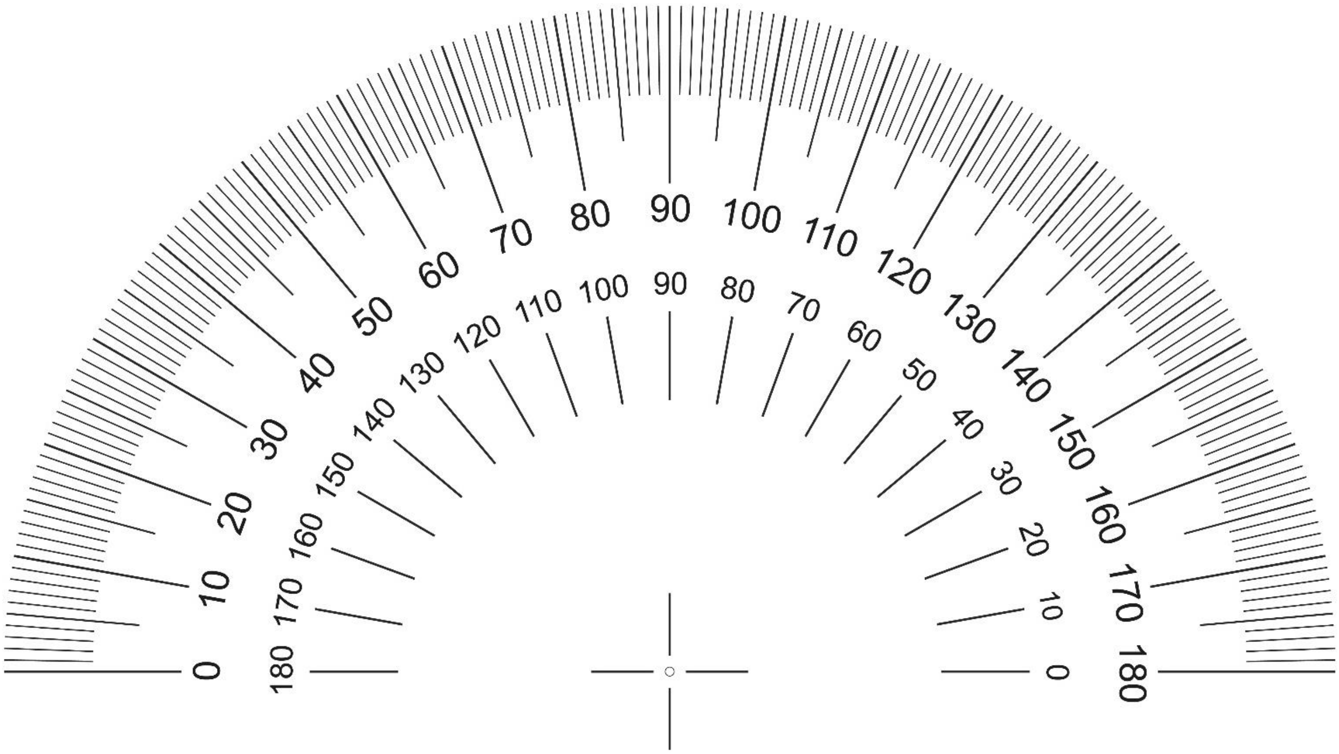


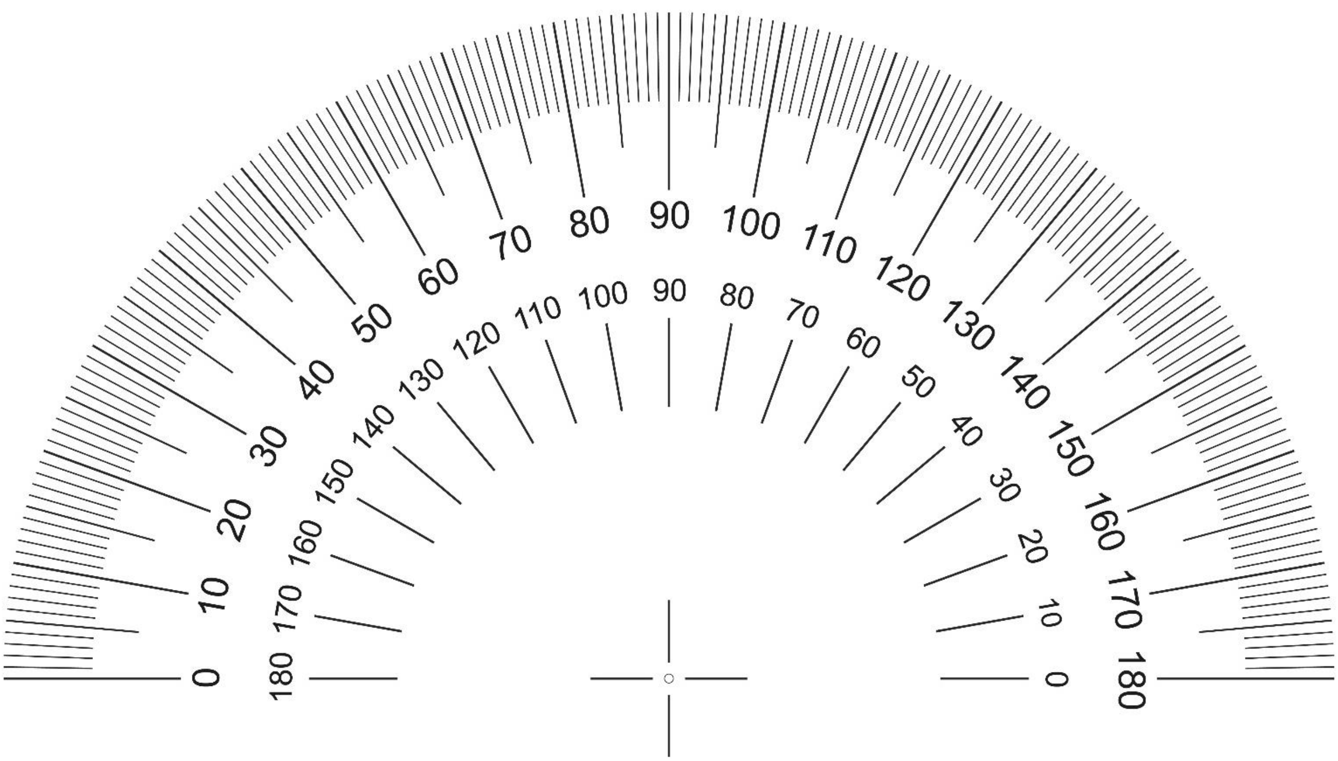
Younger students may copy the angles desired as demonstrated by the teacher and identify shapes as two-dimensional (lying in a plane, "flat") or three-dimensional ("solid"). For example, with younger students sizes may be compared directly or visually, not compared by measuring. With third graders, measure length by counting unit squares (square cm or improvised units, ex. graph paper squares). With middle students the teacher may show them how to use a compass and have them copy the angles.

Have students express measurements in a larger unit in terms of a smaller unit and determine the full scale (real world) dimensions of this roller coaster if the model is a 1/100 scale of a full scale roller coaster, meaning 1 cm for every 100 feet.

Next, have students alter their drawing and draw it again at 1/16, 1 cm for every 16 feet. How does that change the appearance of their coaster? Why? What do they note about the slope of the angled lines when they scale up and scale down? Have students consider both accuracy of drawing and capacity to draw the model in a reasonable overall size of graph paper.

Now, have students create scaled drawings of their completed roller coasters for their portfolios.


0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0


0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0

Marketing: Buyer's Market, Seller's Pitch

Have students make a sales portfolio for their new ride, advertising the name, thrills, and statistics of their roller coaster in order to get riders on board and financial backers to pull out their pocketbooks.

Materials:

- Completed Paper Roller Coaster
- Completed speed calculations (as appropriate for grade level)
- Completed cost of building calculations (as appropriate for grade level)
- Completed scale drawings (as appropriate for grade level)
- Description of building process and engineering decisions
- Paper
- Pencils
- Optional: Poster boards/trifolds for presentation of materials
- Optional: Manila folders for presentation of materials
- Art materials (for optional promotional materials, ex. A themed poster, roller coaster name, etc.)

Students may also prepare a story board that documents their research and the construction of the roller coaster. In their storyboards students may answer questions such as the following:

- Does math apply in the "real world?"
- How did they build their coaster and did it work perfectly the first time?
- What is the name of their roller coaster?
- Do they have any safety features?
- What are its measurements, rate of speed, etc?
- What formulas did they use to arrive at their conclusions?

- How do those formulas work?
- How many loops, turns, and hills did their roller coaster have?
- What did they have to do to make the ball go faster or slower?
- How did they make the ball turn?
- If a life-sized version of your roller coaster was built, would they want to ride it?
- How would you handle any problems that arose?

Have students write a one-page summary of their project, including what they have learned from researching this topic and answering the following question. If a life-sized version of their roller coaster was built, would they want to ride it?

Financial Figures and Rates of Pay:

While students are preparing a portfolio for their roller coaster design the company wants to know the total cost, how much money they will have to pay per months, and how many months it will take them to pay for their new ride. Ex: If you calculate that the cost of your new roller coaster to build was $1,000,000. Assume that an amusement park wants to make a down payment of 10%,that would be $100,000. Then they will finance the remaining $900,000 for 30 years. The current rate of interest offered by the nearest bank is 7.25%. The amusement park wants to know the monthly payment, so use the formula $P = \frac{Cr(1+r)^N}{(1+r)^N - 1}$, where P = monthly payment, C = amount of loan, r = interest rate ÷ 1200, and N = total number of monthly payments.

1. Why do you think that the interest rate, 7.25%, is divided by 1200 in the formula? (The interest rate is divided by 1200 because there are twelve months in a year. You want to reflect the interest rate charged as a decimal, so you can get the true monthly payment because most loans are not calculated with simple interest, but daily compounding interest. In this sample, the 1,200 represents 12 months.)
2. List the values for each variable to use in the expression on the right side of the formula. Be sure you find the total number of monthly payments, not just the number of years of payments.
3. Find the monthly payment for the roller coaster.
4. What if they want to pay over 15 years, 30 years, 60 years? Have students find the different payment rates for at least two options.

Extension Activity: Roller Coaster Review!

It's one wild ride! You can't predict what turns this game will take and the next question just might throw your team for a loop! Roller Coaster Review is a game that works for reviewing any subject.

Materials:

- Review questions related to math facts and calculations *
- Other review questions chosen from lesson materials (ex. science concepts like potential and kinetic energy, what is gravity, history of roller coasters, etc)
- Sets of track piece point cards for each team printed out and points written in.
- Tape or magnets for the board/wall

1. Divide the class in two teams & assign crazy point values to each question. For example, make 2 matching sets of track piece point cards, such as 5 pts, 9 pts, 1000 pts, 2 pts, 500 pts, etc for each team.
2. Then scramble each set of cards before starting the game, team #1's first correct answer might be worth 79 pts, team #2's question might be worth 1000.
3. Discuss with students the game set up and have them follow agreed-upon rules for discussions and carry out assigned team roles. Ask a team a review question if they get it right** they get to pick a track piece and they get however many points the track piece has on it. Have students put the track piece up for every question they got correct.
4. Students have a lot of fun adding up the total points at the end of the game and seeing who has the longest roller coaster. One team might have more points, but another team could have the longest craziest looping ride!

*Math facts can be as simple as addition, subtraction, division or multiplication tables students need further practice with or as complex as speed or velocity formulas.

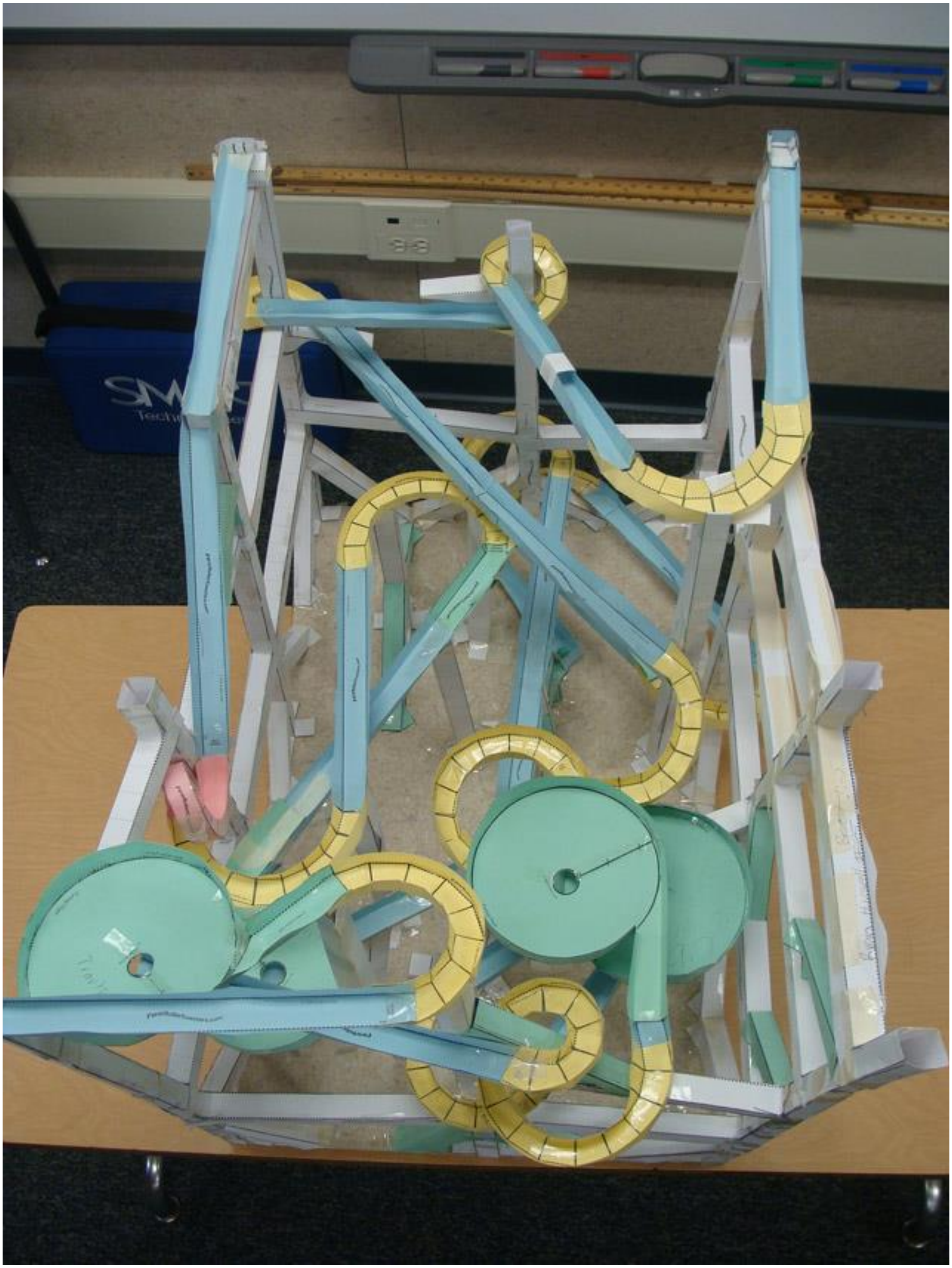
** If needed: If teams or students are confused during the game, or have forgotten a concept, quickly review the key ideas expressed from the project and have students explain their own ideas and understanding in light of the discussion. Allow students to pose and respond to specific questions by making comments that contribute to the discussion and elaborate on the remarks of others, explicitly drawn on their experiences during the project and other information known about the topic to explore ideas under discussion.











Scream Machines Activities Supply List

Introduction, p. 1

- Access to first person point of view (POV) roller coaster riding videos as part of introduction
- Images of roller coasters

Activity: Rushing Ice Riders, p. 4

Materials:

- Ice Cubes (1-2 per student)
- Paper plates (1 per student)
- Salt (1 canister)
- Other available construction materials (ex. craft foam, cloth, etc)
- Cardboard (1 large box should give enough) covered in wax paper (1 roll), outside slide, or other ramp materials to form a ramp.
- Stopwatch
- Small plastic figurines, ex. the size that would be on cupcakes
- Optional: Sand for the end of the ramp

Activity: Can you give me a lift? p. 13

Materials:

- Water
- Aquarium Tubing
- 2.5 cm3 syringes (one per group)
- 10 cm3 syringes (one per group)
- Books, bricks, or other heavy objects
- Option: sealant or waterproof tape for security (one roll)

Activity/Demonstration: The Stop: Magnetic Braking Systems, p. 15

Materials:

*Note: If doing it as a demo, only one of each of the following is needed. Otherwise, one is needed per group of students.

- A copper or aluminum pipe
- A fairly powerful neodymium magnet (or several small ones stacked together) that are small enough to fit inside the pipe.
- Option: PVC pipe to match the size of your copper pipe, for comparison
- Option: Non-magnetic pizza cutter

- Option: Powerful horseshoe magnet

Coaster Challenge! P. 26

Materials:

- Cardstock, white and colored (six different colors)
- Marbles (for riders)
- Ball point pens, for scoring templates
- Pencils (for drawings, notes, and keeping track of costs, measurements, etc.)
- Notebook paper (for notes, keeping track of costs, measurements, putting together the portfolio, calculating speed, etc.)
- 12" rulers (1-2 per group)
- Magazine or catalog - used as a cushion, it helps to score the templates when tracing.
- Rolls of transparent tape (1-2 per group) Ex. One class may need six rolls of 3/4" x 600" transparent tape.
- Roller Coaster Element Standard & Advanced Templates from paperrollercoasters.com (an average class will need six times as many pre-printed sheets of card stock and marbles as found in an Individual Set):
    - Copy the structural pieces (i.e. columns, beams, diagonal supports, and shelves) on white paper. Then **copy each of the other pieces on different colored paper**. That makes it much easier for the students to find the desired piece and copy the template and use it to inspire a redesign or adjustment. It also helps you to see which pieces are getting low.
    - Cut the sheets into strips using a paper cutter or scissors. Tips: *Cut along every thin gray line. **Practice making each piece so you'll be able to explain it to your students**.*
    - *Create a sample reference board with each stage of each piece (including a finalized one) for students to go to when confused. This saves the teacher being asked many many times "How does this one go?" You'll want to decide on a price for each piece to help students calculate how much their roller coasters would cost to 'build' for their portfolios.*
- The Booklet Step by Step Instructions for Building Incredible Roller Coasters by Andrew Gait, www.paperrollercoasters.com
- A Master Template reference board with each template at each stage from initial cuts to final construction as well as a price for that piece
- Scissors (1 per student)
- Graph paper (for scale drawings, multi-view drawings of each group's unique track element template, etc.)
- Stop watches (1-2 total that students can borrow)
- Optional: Foam board or cardboard for bases
- Optional: cup and/or other materials to add in

- Optional: mailing labels to identify areas and shifts of potential and kinetic energy on the roller coasters

A Need for Speed!, p. 38

Per group:

- completed Paper Roller Coaster
- yard stick
- pencil
- calculator
- string
- Optional: Mailing labels for identifying marks
- Printed test trials sheets and instructions

Imagineers: Design in Mind?, p. 41

Per group:

- completed Paper Roller Coaster
- 2 sheets of graph paper per student
- yard stick
- 12-inch rulers with centimeters (one per student)
- Protractors (one per student)
- Pencils (one per student)
- White board or large sheet of paper
- White board markers or regular markers

Marketing: Buyer's Market. Seller's Pitch!, p. 45

- Completed Paper Roller Coaster
- Completed speed calculations (as appropriate for grade level)
- Completed cost of building calculations (as appropriate for grade level)
- Completed scale drawings (as appropriate for grade level)
- Description of building process and engineering decisions
- Paper
- Pencils
- Optional: Poster boards/trifolds for presentation of materials
- Optional: Manila folders for presentation of materials
- Art materials (for optional promotional materials, ex. A themed poster, roller coaster name, etc.)

Extension Activity: Roller Coaster Review! p. 47

- Review questions related to math facts and calculations Math facts can be as simple as addition, subtraction, division or multiplication tables students need further practice with or as complex as speed or velocity formulas.

- Other review questions chosen from lesson materials (ex. science concepts like potential and kinetic energy, what is gravity, history of roller coasters, etc)
- Sets of track piece point cards for each team printed out and points written in.
- Tape or magnets for the board/wall

Sample Academic Standards to Reinforce through Discussion & Activities

Kindergarten:

- K.G.1.a. Describe objects in the environment using names of shapes.
- K.G.1. b. Describe the relative positions of these objects using terms such as above, below, beside, in front of, behind, and next to.
- K.G.2. Correctly name shapes regardless of their orientations or overall size.
- K.G.3. Identify shapes as two-dimensional (lying in a plane, "flat") or three-dimensional ("solid").
- K.G.5. Model shapes in the world by building shapes from components and drawing shapes.
- 7.11.1 Use a variety of objects to demonstrate different types of movement. (e.g., straight line/zigzag, backwards/forward, side to side, in circles, fast/slow).
- K.MD.2. Directly compare two objects with a measurable attribute in common, to see which object has "more of"/"less of" the attribute, and describe the difference. For example, directly compare the lengths of two pieces and describe one piece as longer/shorter.

1st Grade:

- SL.1.5. Add drawings or other visual displays to descriptions when appropriate to clarify ideas, thoughts, and feelings.
- 1.MD.1. Order three objects by length; compare the lengths of two objects indirectly by using a third object.
- 1.MD.2. a) Express the length of an object as a whole number of length units, by laying multiple copies of a shorter object (the length unit) end to end.
- 1.MD.2. b) Understand that the length measurement of an object is the number of same-size length units that span it with no gaps or overlaps.
- 7.11.2 Investigate and explain how different surfaces affect the movement of an object.
- 1.G.2. Compose two-dimensional shapes and/or three-dimensional shapes to create a composite shape.
- 1.MD.4. Organize, represent, and interpret data with up to three categories.

2nd Grade:

- W.2.7. Participate in shared research and writing projects.
- 2.MD.1. Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.

- 2.MD.3. Estimate lengths using units of inches, feet, centimeters, and meters.
- 7.12.2 Describe what happens when an object is dropped and record the observations
- 2.MD.9. a. Generate measurement data by measuring lengths of several objects to the nearest whole unit.
- 2.MD.9. b. Generate measurement data by making repeated measurements of the same object.
- 2.MD.10. a) Draw a picture graph and a bar graph (with single-unit scale) to represent a data set with up to four categories.
- 2.G.1. Recognize and draw shapes having specified attributes, ex. such as a given number of angles.

3rd Grade:

- W.3.2. Write informative/explanatory texts to examine a topic and convey ideas and information clearly. Introduce a topic and group related information together; include illustrations when useful to aiding comprehension.
- 3.MD.1. Tell and write time to the nearest minute and measure time intervals in minutes.
- 3.MD.1.b. Solve problems involving addition and subtraction of time intervals in minutes,
- 7.11.1 Identify how the direction of a moving object is changed by an applied force.
- 3.MD.4. a) Generate measurement data by measuring lengths using rulers marked with halves and fourths of an inch.
- 3.MD.3. a) Draw a scaled picture graph and a scaled bar graph to represent a data set with several categories.
- 3.MD.3b) Solve one- and two-step “how many more” and “how many less” problems using information presented in scaled bar graphs.
- 3.MD.8. Solve real world and mathematical problems involving perimeters of polygons

4th Grade:

- SL.4.4. Report on a topic or text, tell a story, or recount an experience in an organized manner, using appropriate facts and relevant, descriptive details to support main ideas or themes.
- 4.MD.1. Know relative sizes of measurement units within one system of units including km, m, cm; kg, g; lb, oz.; l, ml; hr, min, sec. Within a single system of measurement, express measurements in a larger unit in terms of a smaller unit.
- 4.MD.2. Use the four operations to solve word problems involving:
    - a) distances,
    - b) intervals of time,
    - e) money,

- f) simple fractions
    - g) decimals,
    - h) problems that require expressing measurements given in a larger unit in terms of a smaller unit.
- 4.MD.6. Measure angles in whole-number degrees using a protractor. Sketch angles of specified measure.
- 4.MD.5. a) Recognize angles as geometric shapes that are formed wherever two rays share a common endpoint.
- 4.MD.5. b) understand concepts of angle measurement:
- 4.MD.6. a) Measure angles in whole-number degrees using a protractor.
- 4.MD.6 b) Sketch angles of specified measure.
- 7.11.3 Determine the relationship between speed and distance traveled over time.
- 7.11.2 Identify factors that influence the motion of an object.
- 7.11.4 Plan and execute an investigation that demonstrates how friction affects the movement of an object.

5th Grade:

- 5.MD.1.a. Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m),
- 5.MD.1.b. Use these conversions in solving multi-step, real world problems.
- 7.12.2 Identify the force that causes objects to fall to the earth.
- 7.10.1 Differentiate between potential and kinetic energy.
- 7.10.1 Design and conduct an investigation to demonstrate the difference between potential and kinetic energy.
- 5.NF.5. Interpret multiplication as scaling (resizing), by comparing the size of a product to the size of one factor on the basis of the size of the other factor, without performing the indicated multiplication.
- Introduce a topic clearly, provide a general observation and focus, and group related information logically; include formatting (e.g., headings), illustrations, and multimedia when useful to aiding comprehension. Develop the topic with facts, definitions, concrete details, quotations, or other information and examples related to the topic.
-

6th Grade:

- SL.6.4. Present claims and findings, sequencing ideas logically and using pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation.
- 6.SP.5. Summarize numerical data sets in relation to their context, such as by:
    - a) Reporting the number of observations.
    - b) Describing the nature of the attribute under investigation, including how it was measured and its units of measurement.
- 6.RP.1. Understand the concept of a ratio and scale and use ratio language to describe a ratio relationship between two quantities.
- SPI 7.10.2 Interpret the relationship between potential and kinetic energy.
- SPI 7.10.3 Recognize that energy can be transformed from one type to another.
- 7.10.1 Compare potential and kinetic energy.
- 6.NS.3. Fluently add, subtract, multiply, and divide using the standard algorithm for each operation.

7th Grade:

- SL.7.4. Present claims and findings, emphasizing salient points in a focused, coherent manner with pertinent descriptions, facts, details, and examples; use appropriate eye contact, adequate volume, and clear pronunciation.
- 7.NS.3. Solve real-world and mathematical problems involving the four operations with rational numbers.
- 7.G.2. a) Draw (freehand, with ruler and protractor, and with technology) geometric shapes with given conditions.
- 7.11.3.a. Summarize the difference between the speed and velocity based on the distance and amount of time traveled.
- 7.11.3.b. Apply proper equations to solve basic problems pertaining to distance, time, speed, and velocity.
- 7.RP.3. Use proportional relationships to solve multistep ratio and percent problems. Examples: simple interest, tax, markups and markdowns, gratuities and commissions, fees, percent increase and decrease, percent error.
- 7.11.4 Identify and explain how Newton's laws of motion relate to the movement of objects.

8th Grade:

- SL.8.4. Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.

- 8.G.7. Apply the Pythagorean Theorem to determine unknown side lengths in right triangles in real-world and mathematical problems in two and three dimensions.
- 7.T/E.2 Apply the engineering design process to construct a prototype that meets certain specifications.
- G-MG.1. Use geometric shapes, their measures, and their properties to describe objects.
- G-MG.3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost.
- 7.T/E.5 Develop an adaptive design and test its effectiveness.
- N-VM.3. (+) Solve problems involving velocity and other quantities that can be represented by vectors.
- N-Q.1. Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.
- 1.1.1 Explore displacement, velocity, and acceleration
- N-VM.3. (+) Solve problems involving velocity and other quantities that can be represented by vectors.
- 1.T/E.7 Design a series of multi-view drawings that can be used by others to construct an adaptive design and test its effectiveness.
- 1.1.5 Evaluate and describe the phenomena related to Pascal’s Principle.

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