Physics lesson Plan – The Human Experience of the Rides using Newton's Laws (9th grade and up)

PA Science Standards addressed: 3.2.8.B.1 ; 3.2.8.B.6; 3.2.10.B.1

At an amusement park, the rides are usually the biggest attraction, enticing people of all ages to come experience the magic. While some people enjoy the more tranquil rides, many of us prefer the thrill rides for maximum excitement. But what makes these rides feel so incredible and why do they affect us so much? The answers are found in physics.

All rides create forces through the use of engines…diesel, electric, steam, hydraulic, etc. They use lots of pulleys, gears, ratchets, levers and other mechanical devices to transfer these forces throughout the ride and eventually to the riders. So why do you feel the forces you experience on the rides?

All can be explained by Newton's Three Laws of motion:

- An object in motion tends to stay in motion and an object at rest tends to stay at rest until acted upon by an unbalanced force. (Inertia)
- F = ma (force is equal to the mass of the object multiplied by its acceleration)
- For every force there is an equal and opposite force

For more specifics, we are going to consider the Phoenix Roller Coaster in the first explanation. Like any coaster, when you start going up the first hill, you feel "heavy". How can that be if you haven't suddenly gained weight as you boarded the ride? By using the energy from the motor and transferring the force through conveyers to the car, the ride is pushing against your back to take you uphill. According to Newton's third law, your body pushes back down in an equal and opposite force. You FEEL your body pushing backwards. This adds to the force of gravity already pulling down on you, so you feel "heavy".

In the opposite way, after cresting the top, you go down the hill and you often feel "weightless". Since you are falling so fast, you're moving as fast as the seat, and no pushing is taking place from the back of your car. With the force of the seat back no longer pushing against you, you simply don't feel it. You only feel the fall. This is called free fall in vertical rides. On coasters, it's similar. You can't feel gravity because there's nothing below you pushing you up, and you can't feel the force from the coaster pulling you down. On the coasters, because it's actually a steep decline and not a perfectly vertical fall, it's not quite freefall, but somewhere between 0G and 1G. Still, you get that weightless feeling and your body seems as though you're both floating and flying as you hurtle toward the earth.

Once you get to the bottom of the first hill, you immediately start to go back up hill again, and there is another factor that kicks in… Inertia, or Newton's first law.   At the bottom of the hill, your body continues to move downward (a body in motion, stays in motion!) but the car starts to move upward. When the upward force of the car pushes on your body, which is still moving downward, the resulting force you feel is very high.   At this point, you experience about 3G of force. Just a note: G forces are actually NOT from gravity! They are measured in amounts of force that are equivalent units to what you feel from gravity, but they are from other causes which accelerate your body and make you feel "heavier" as you're pushed upward. That is the case here. There is tremendous upward force acting on your body and you get a lot of G force as a result.

BIOLOGY NOTE: Increased G forces cause your stomach to squash flat and the fluid in your semicircular canals in your ears to slosh around. This is what leads to dizziness and motion sickness in less fortunate individuals!

After the first big hill, which incidentally provides the energy for the entire ride, there are many smaller hills and turns. On the Phoenix, this is where you will experience the greatest amount of "air time", where you actually leave your seat.   As you go over a series of smaller hills, your body is moving very quickly upward, when the car just as quickly changes its motion and starts to move downward. You continue upward until the force of the lap bar stops you. At this point, you are out of your seat, and this is air time. It's caused by inertia and the fact that your body is trying to stay in the same path of motion, but the coaster rapidly changes the path.   With all the sudden up and down changes, you get LOTS of air time on the Phoenix!

Along with the air time, there are some fabulous turns on the Phoenix. All the forces you feel are caused by acceleration changes (Newton's second law, F = ma).   Since acceleration is a vector quantity, you can change it with either the speed or the direction of travel. The vertical changes have been discussed, but there are also changes in the horizontal motion as well. The turns on the Phoenix cause very sudden changes in direction, which then produce large forces you can feel. These forces are essentially from circular motion, since the turns are curved. In circular motion, the force is tangent to the curve of the motion, and produced from the "inside" of the circle. Your body feels the corresponding opposite force directed "outward".   As a result, you feel flung against the car as you go around the curves.

The centripetal forces (which these circular forces are called) are also felt on other rides if you're not a coaster enthusiast. The Round Up is a ride where you'll see this easily. You are placed against the wall, and as the rides speeds up and spins, you "stick" to the walls. This is from the centripetal force and your bodies equal and opposite force to the ride. The motor in the middle pulls you inward, and you push back outward.   What you feel is the outward push of your body.   The Italian Trapeze works similarly, which is why your swing will be on an angle slanting outward.

Inertia, which was responsible for many effects that are experienced on the Phoenix, has its place in many other rides as well. The Bumper Cars, for instance, are a great place to observe inertia. You get that great "whiplash" feeling from your body continuing in the direction it was going as your car suddenly stops or changes direction as it gets hit by another car. You should also look up before your ride starts or as you're waiting in line, and notice that the cars run on an overhead electric grid. They have no brakes. Once the ride's power is cut, you need to sit in your car and wait for it to decelerate from frictional forces, because they are the only forces acting on the car to bring it to a halt (unless of course you hit someone or the walls as you drift!). The Bumper Cars were designed to be free-mowing vehicles to take advantage of inertia and its principles.

Another ride you need to be cautious about getting out of too early is the Bumper Boats. They work on the same principles as the Bumper Cars, and they too have no break. They are a bit freer moving since they ride on water, but the ideas are all the same. However, when the ride is over, you need to be "docked" by the attendant before disembarking. This isn't true for the bumper cars. The cars sit on a platform, and have enough friction with the floor that they are not easily moved. However, the boats have little friction with the water. If you are not tethered or held to the dock, your attempt to get out of the boat will lead to a watery first step. As you push against the boat to go forward, the boat will go backward (those equal and opposite forces again!) If it's not tethered, it can't push against you with an equal and opposite force, and you will land in the water.

Of course there are a lot of other rides and there is a lot of physics involved in your experience of the rides like kinetic and potential energy, momentum and impulse, friction, normal forces, etc, but Newton does a pretty good job of explaining the basics. Enjoy the rides!

EXTENSION QUESTIONS FOR BEFORE OR AFTER VISITING THE PARK:

Which point on the Paratrooper ride will you experience true 0G on every revolution?

Think about the Galleon. As you are whooshed back and forth, you experience a lot of stomach flattening and internal sensations. These are from G force fluctuations. What do you think causes the Rapid changes in G forces in the Galleon?

At the Merry Mixer and The Whipper, the ride operators often advise the bigger people to sit on the "outside" of the car. Using the idea of centripetal force, explain why this is a good idea.