

FABRIC OF SPACETIME TEACHER'S GUIDE

The stretched-out fabric around the ring can be used as a model of how gravity works in 2-dimensions when a weight is put in the middle of the ring.

1. Play around with the marbles on the table and record your observations for the following experiments.
 - a. Release a marble from rest near the top.
 - b. Roll a marble on the table tangent to the table so that it stays on the table.
 - c. Roll a marble on the table tangent to the table so that it flies off of the table.
 - d. Roll two marbles next to each other tangent to the table so that they stay on the table.
 - e. Take a random uneven number of marbles in each hand and roll them in opposite directions around the table.

2. Break into groups and explain how the fabric imitates the effect of gravity that led to the results in the experiments above. Start with Newton's 1st Law to explain the effects.

Placing the large mass in the middle depresses the fabric.

- a. *When the marble is released, it is at rest, but it cannot stay at rest because of an unbalanced force acting on it. The unbalanced force is from the dip in the fabric turning the fabric into an incline plane. So, it accelerates towards the center of the table because of the dip in the fabric. The acceleration increases as the marble approaches the center because the angle of the dip increases.*
- b. *The marble is given a tangential velocity and an object in motion wants to stay in motion in a straight line, but the dip in the fabric gives the marble a centripetal force caused by part of the normal force from the surface of the fabric pushing the marble towards the center. The marble is put into orbit around the table, but it is a decaying orbit because friction takes energy away from the system, which continually decreases the radius of the orbit. As the radius decreases the angle of the bent fabric increases, which increases the centripetal acceleration. The circumference of the orbit becomes smaller, which both decreases the period of the orbit and increases the angular speed of the marble as it goes towards the center, like water turning around an open drain.*
- c. *The marble is given a tangential velocity, and an object in motion wants to stay in motion in a straight line, but the dip in the fabric gives the marble a centripetal force caused by part of the normal force from the surface of the fabric pushing the marble towards the center. However, the marble is not put into orbit around the table because it*

has enough velocity to escape. The path is still curved by the centripetal force, but not sharp enough to make it orbit.

- d. *After multiple tries you can get the two marbles to orbit each other while they orbit the central mass. Both objects want to stay in motion in a straight line, but the bent fabric from the central weight and the smaller depressions in the fabric from each of the marbles alters the path of the marbles. Each marble creates its own smaller depression in the fabric, and so the two marbles are pushed towards each other as well.*
- e. *The marbles all start with chaotic motion crashing off each other sending marbles in every direction. Marbles with too much velocity fly off the table. Many marbles head right into the center, and other marbles quickly head to the center after colliding with other marbles and losing most of their velocity. However, even though one hand threw marbles clockwise and the other hand threw marbles counterclockwise the marbles usually all end up spinning the same way before everything ends up in the middle. This is because angular momentum is conserved in the system, if you ignore the torque caused by friction that is slowly decreasing the angular momentum of the system to go to zero. The centripetal force caused by the inward component of the normal force from the fabric changes the direction but not the speed of the marbles. There probably was a net angular momentum in the beginning from one hand having more marbles or initially having more velocity. Most of the marbles traveling opposite directions crash into each other and cancel their angular momentum and so whichever direction had more angular momentum in the beginning ends up with a few remaining marbles rolling in that direction in the end until the torque from friction reduces the angular of the system to zero and all of the remaining marbles that did not fly off head into the center.*