International Journal of New Developments in Engineering and Society
ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

The Rube-A-Thon Project

Ziqian Shao

Bancroft school, 110 Shore Dr, Worcester, MA 01605

ABSTRACT. *This Rube Goldberg machine executes seven specific; each last longer that 2 seconds and represents an important topic in physics: elastic collision, inelastic collision, rotational motion, torque, conservation of energy, conservation of momentum, and projectile motion. The biggest constrain was that this entire project has to be built in blender, which means the Rube Goldberg machine must be designed to adapt the physics simulation incorporated in Blender.*

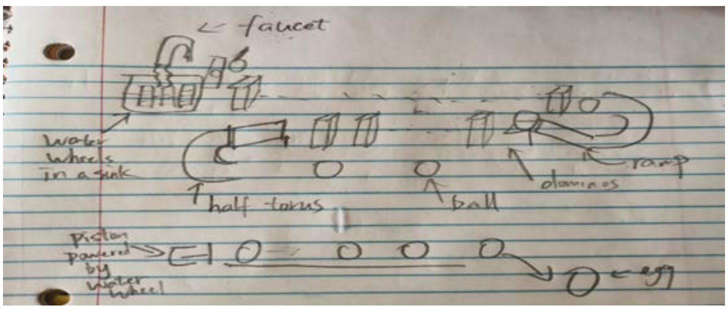
KEYWORDS: *Physics simulation, Mechanical Analysis, Blender, Rube Goldberg Machine*

Design Process

The task was to build a Rube Goldberg machine in Blender that demonstrates what we have learned in class and crack an egg in the end. Then using render feature to make a video of how the machine works.

I combined different ideas like domino, water wheel, lever, and collision of balls together and came up with my initial design. The setting is in a kitchen so the sink is accessible.

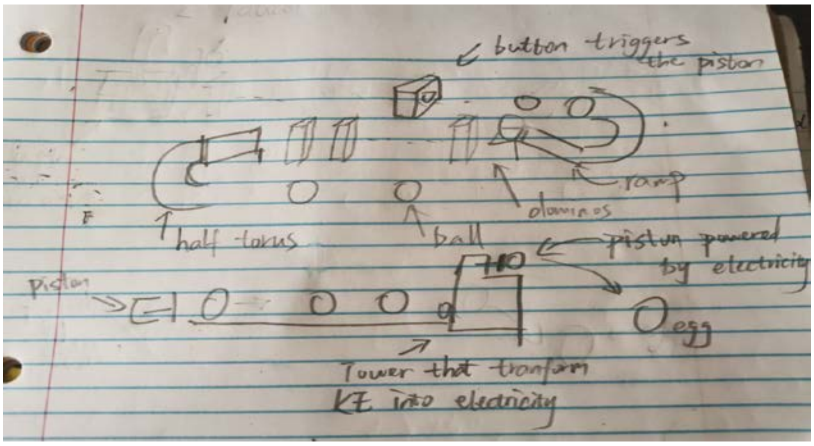
Fig. 1: Initial Design



ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

However, as I started getting into building the machine. I realized that some of my idea can not materialize in Blender world, such as the water wheel; additionally, the lever does not act like it in the real word. So I discarded some of my ideas and came up with a new sketch.

Fig. 2: Revised Design



The revised design had taken out the faucet and water wheel and added in the tower that can transform energy since initially, the conservation of energy was demonstrated by water wheel.

Results

Physical Concept	Description
Elastic Collision	Collision between the purple ball 1 and the purple ball 2: initially, purple ball 1 is pushed by the hand and starts moving, and purple ball 2 is at rest; after the collision, purple ball 1 is at rest and rolls down the ramp, and purple ball 2 is moving. Because both purple balls have 100% bounciness, all KE is transfer from ball 1 to ball 2 and momentum is conserved.

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

Inelastic Collision	Collision between the purple ball 3 and the blue ball 1: initially blue ball 1 is at rest and purple ball 3 is moving; after the collision, the blue ball 1 and the purple ball 3 is moving together at same speed, KE is partially dissipate.
Rotational Motion	Purple ball 3 goes through a u-shape tunnel: Purple ball 3 rolls down the ramp and enters a u-shape tunnel which is made from torus. Because the table has no friction, the purple ball 3 has an constant angular velocity.
Conservation of Energy	Purple ball 2 climbs up the ramp: Purple ball 2 rolls up the ramp; during that process, it slow down and its KE is partially converted into gravitational potential energy.
Conservation of Momentum	Collision between light the blue ball and the blue ball 2 and between the blue ball 2 and the purple ball 4: Because all three balls have the same mass and bounciness of 1, the KE is totally transfer from light blue ball to blue ball 2 and from blue ball 2 to purple ball 4. The center of mass is moving at a constant speed. Momentum is conserved.
Torque	The purple ball 2 hitting the domino: the purple ball 2 collides with the domino, creating a torque on it, causing the domino to fall down in the direction of the torque force, and resulting in a domino effect.
Projectiles in 2-Dimension	The blue ball 3 being pushed off the tower: the blue ball 3 is pushed off the edge of the tower with an initial velocity. It goes into a free fall.

Table 1: Description of Physical Steps

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

Elastic Collision, the purple ball 1 hitting the purple ball 2:

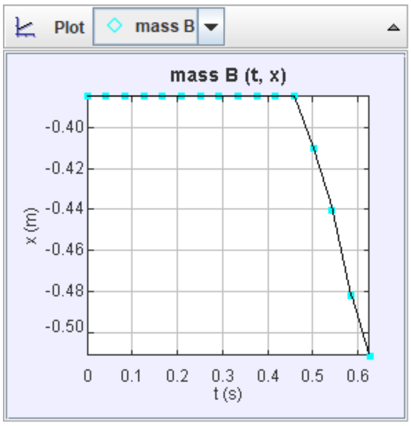


Figure i.1, position vs. time for purple ball 2

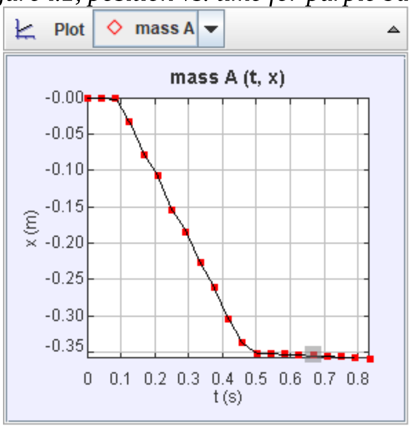


Figure i.2, position vs. time for purple ball 1

Key: 1= purple ball 1, 2= purple ball 2

In an elastic collision, the energy and the momentum is conserved so $\frac{1}{2}mv^2{}_{initial} = \frac{1}{2}mv^2{}_{final}$, $mv_{initial} = mv_{final}$

$m_1 = 5kg$ $m_2 = 5kg$ $v_{1,initial} = -0.9m/s$ $v_{2,initial} = 0$ $v_{1,final} = 0$ $v_{2,final} = -0.86m/s$

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

To calculate the conservation of momentum:

$$p_{initial} = -0.9m/s \times 5kg = -4.5Ns$$

$$p_{final} = -0.86m/s \times 5kg = -4.3Ns$$

To calculate the energy to put the machine in motion

$$\frac{1}{2} \times 5kg \times (-0.9m/s)^2 = 2.025J$$

To calculate the conservation of energy:

$$\frac{1}{2} \times 5kg \times (-0.86m/s)^2 = 1.849J$$

To calculate the coefficient of restitution

$$e = -\frac{-0.9m/s - 0}{0 - (-0.86m/s)} = 1.0465$$

Inelastic Collision, the purple ball 3 hitting blue ball 1:

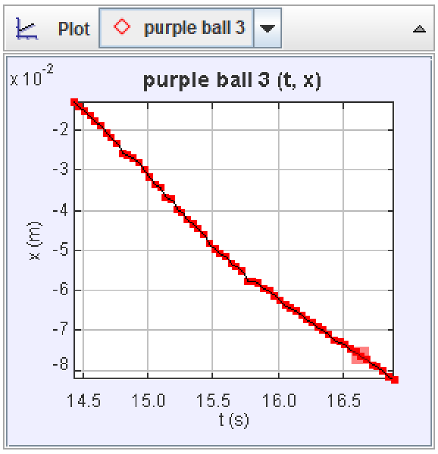


Figure ii.1, position vs. time for purple ball 3

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

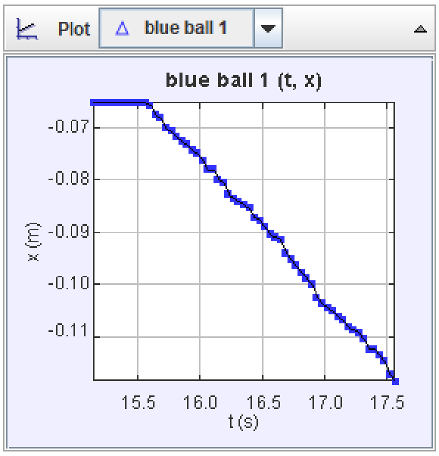


Figure ii.2, position vs. Time for blue ball 1

Key: p=purple ball 3 , b=blue ball 1

$m_p = 20kg$ $\quad m_b = 10kg$ $\quad v_{p,initial} = 0.0295m/s$ $\quad v_{b,initial} = 0$

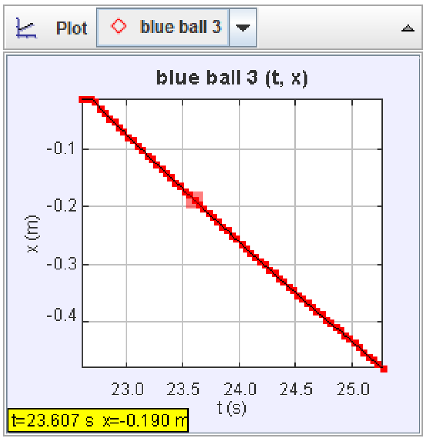
$v_{b,final} = v_{p,final} = 0.02m/s$

To calculate the conservation of momentum:

$$p_{initial} = 20kg \times 0.0295m/s = 0.59Ns$$

$$p_{final} = (20kg + 10kg) \times 0.02m/s = 0.6Ns$$

Projectile motion, blue ball 3 being pushed off the tower and goes into a free fall



ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

Figure iii.1, position in x vs. Time

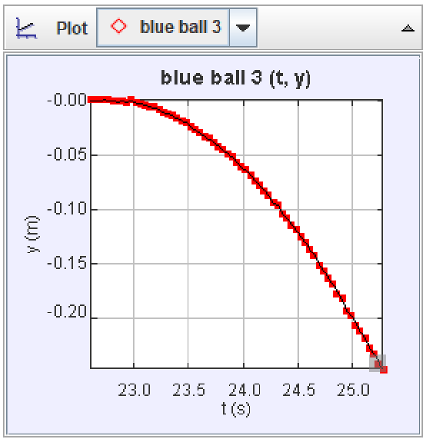


Figure iii.2, position in y vs. time

Key: b=blue ball 3, x for x direction, y for y direction

Initial Position:(-0.0192, 0.001056), Final Position:(-0.481, -0.247)

Displacement in x: -0.4691m Displacement in y: -0.245944m

To calculate the speed and acceleration in x direction:

$$v_x = 0.1814m/s$$

$$a = \frac{-0.1814m/s}{(22.814-22.689)s} = 1.4512m/s^2$$

To calculate the energy required to break the egg:

$$m = 10kg$$

$$KE = \frac{1}{2}\times 10kg \times (-0.1814m/s)^2 = 0.1645J$$

$$PE = mgh = 10kg \times 9.8m/s^2 \times 0.24806m = 24.31J$$

$$E = PE + KE = 24.475\,J$$

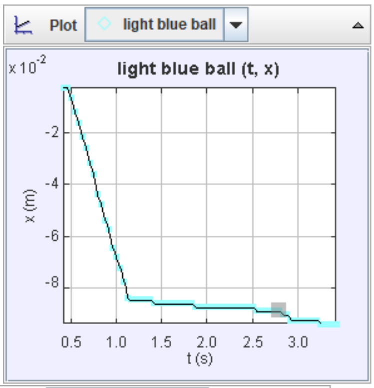
To calculate the impulse to set the ball in motion:

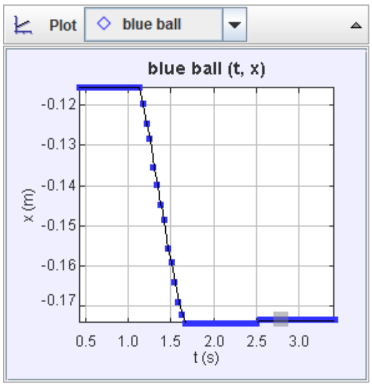
$$F = ma = 10kg \times 1.4512m/s^2 = 14.512N$$

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

$$\Delta p = F \times \Delta t = 14.512N \times 0.125s = 1.814Ns$$

Conservation of Momentum, Collision between light the blue ball and the blue ball 2 and between the blue ball 2 and the purple ball 4:





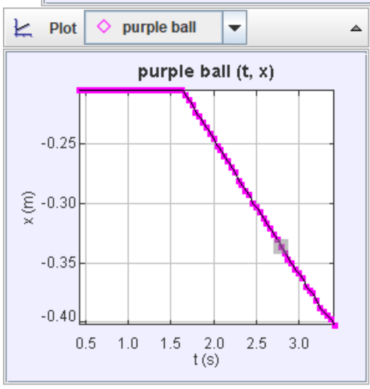


Figure iv.1, position vs. time *Figure iv.2, Position vs. time* *Figure iv.3, Position vs. time*

for light blue ball *for blue ball 2* *for purple ball 4*

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

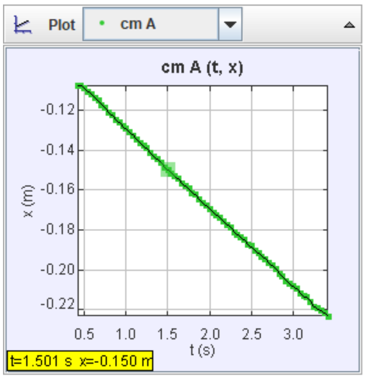


Figure iv.4, Position vs. time for center of mass

Key: l=light blue ball, b=blue ball 2, p= purple ball 4

Because the center of mass is moving at a constant, the momentum of this isolated system is conserved.

To Calculate the momentum of the center of mass:

$$M = m_l + m_b + m_p = 30kg$$

$$p_{CM} = M \times v_{CM} = 30kg \times (-0.03884m/s) = -1.1652Ns$$

Discussion

Conservation of momentum in elastic collision:

The purple ball 1 with a mass of 5kg collides at the velocity of -0.9m/s with the purple ball 2 with a mass of 5kg initially at rest. After the collision, the purple ball 1 stays at rest and purple ball 2 moves at a velocity of -0.86m/s. The initial momentum of the system which is -4.5Ns does not equal to the final momentum of the system which is -4.3 Ns. Ideally, purple ball 2's final velocity should be equal to the initial velocity of purple ball 1. However, because of insufficient data and systemic discrepancy, those two numbers do not match.

Energy required to set the machine in motion:

The energy required to set the machine in motion equals to the KE of the purple ball 1 which has a mass of 5kg and a velocity of -0.9m/s before collision, which is 2.025J

Conservation of energy:

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

The initial energy of the system is 2.025J. The final energy of the system is1.849J.

Because purple ball 2's final velocity does not equal to the initial velocity of purple ball 1, the final energy does not equal to the initial energy. Ideally, they should equal.

Conservation of momentum in totally inelastic collision:

The purple ball 3 with a mass of 20kg collides at the velocity of 0.0295m/s with the blue ball 1 which has a mass of 10kg and is at rest initially. After the collision, two balls move together at 0.02m/s. The initial momentum of the system is 0.59Ns. The final momentum of the system of the system is 0.6Ns. The discrepancy can be explained by the same reason in "Conservation of momentum in elastic collision."

Projectile motion:

The blue ball 3 is initially at rest. A force is exerted on it for 0.125s, causing the ball to move at a velocity of 0.1814m/s off the tower and go into a free fall. the acceleration thus can be calculated, which is 1.4512m/s^2.

Energy required to crack the egg:

The energy required to crack the egg equal the sum of KE and PE relative to the egg of the blue ball 3 before it perform projectile motion. The KE is 0.1645J. The PE is relative to the height above the egg, which is 0.24806m. By calculation, PE=24.31J. So the sum is 24.475J.

The impulse to set blue ball 3 in motion:

The force put on blue ball 3 can be calculated using its mass and velocity in x direction, which is 14.512N. The impulse equals the force multiplied by time which is 1.814N.

Mass center:

The mass center of light blue ball, blue ball 2, and purple ball 4 is moving at a constant velocity of -0.03884. The total mass of the system equals the sum of mass of all three balls equals 30kg. The total linear momentum of the systems equals the total mass multiplied by the velocity of the center of mass, so we get 1.1652Ns for the total momentum.

Conclusion

Speaking of an egg, people usually think of kitchens or cooking breakfast. So I chose kitchen for the setting. In order to came up a design that both meet all the constrains and criteria and can work in Blender reliably, I discarded multiple ideas, revised my design, experiment the design in Blender, and repeated the process until it worked. Initially, I planed to demonstrate the conservation of energy using water wheel. However, the fluid function in Blender couldn't act the way I want and I

ISSN 2522-3488 Vol. 4, Issue 4: 45-55, DOI: 10.25236/IJNDES.040404

would be difficult to calculate the initial energy and the converted energy, so that idea was discarded. The entire machine was in one piece on the kitchen table, but the kitchen table was not big enough. In the end, the machine was break into two parts: one on the kitchen table: the other one on a part leading to the stove. After another several adjustments, my machine was able to meet the time constrains. Then I had my Rube Goldberg machine.

Admittedly, there are some improvements that can be made. If I were to do this project all over again, I would make my machine easier to analyse. Because the camera is change the position, analyzing the video is difficult. To fix that, I made another two videos that each captures a part of the machine. It would be beneficial to know which part will be analyzed and adjust the camera before making the actually render animation.

My biggest takeaway from this project is that discrepancy is unavoidable. Even though my machine is built in Blender, a ideal world with no air resistance, adjustable mass and friction, and adjustable coefficient of restitution; there was still discrepancy generated during data collection and calculation. Measurement can not be perfect.

References

[1] Nitro. (2015, June 19). Pointer Hand 1 Free 3D print model. Retrieved July 18, 2020, from https://www.cgtrader.com/free-3d-print-models/hobby-diy/other/pointer-hand-1

[2] Youngsoft. (2017, August 14). Button Free low-poly 3D model [Computer software]. Retrieved July 18, 2020, from https://www.cgtrader.com/free-3d-models/electronics/computer/button-fd084274-9386-45b2-b915-f75d362db613

[3] Redbeared-ssa. (2019, November/December). D Arredamenti Legno Vivo Free 3D model (Version 2014). Retrieved July 18, 2020, from https://www.cgtrader.com/free-3d-models/interior/kitchen/gd-arredamenti-legno-vivo-07295245-db13-4352-8a86-3a141555d767