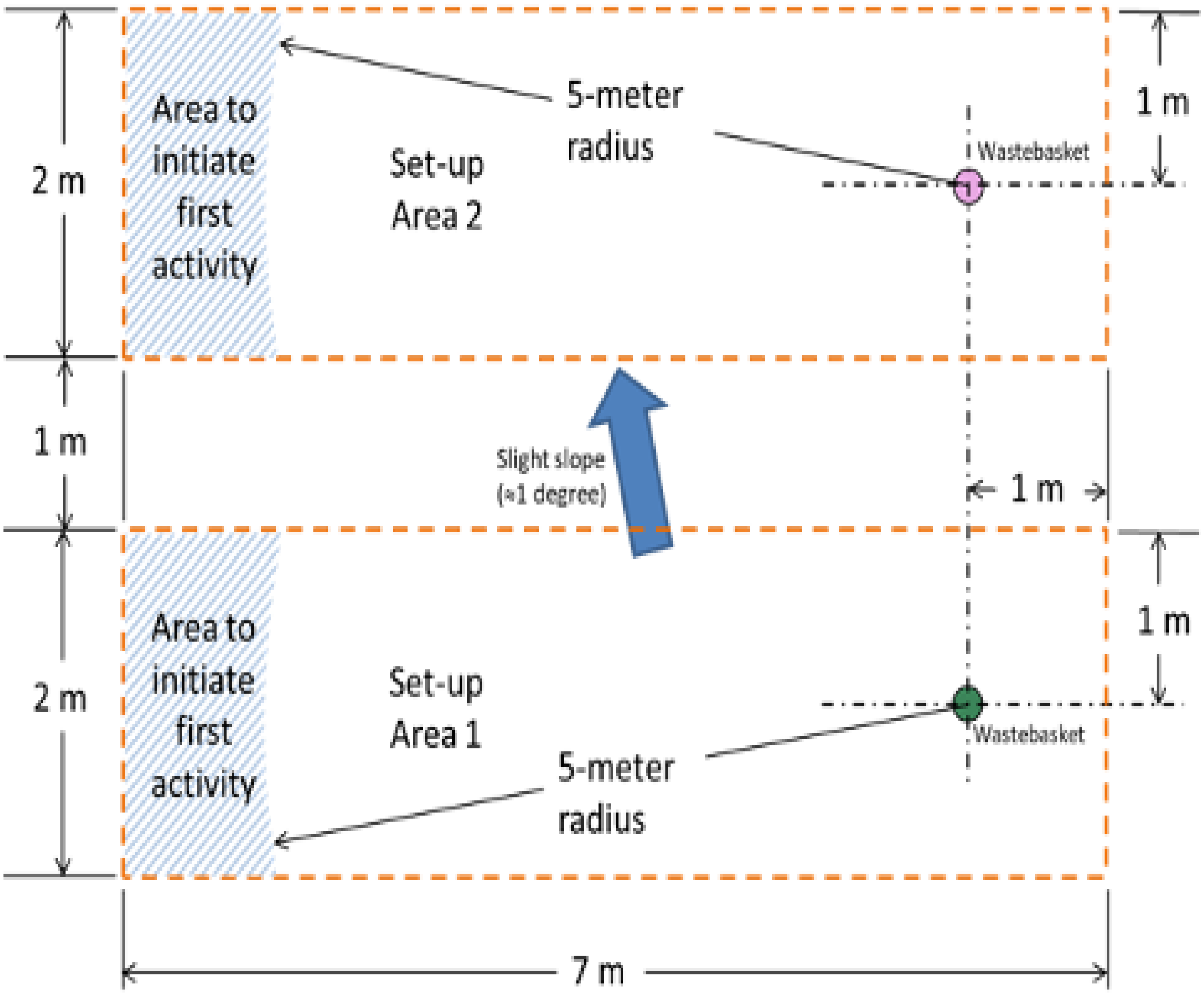
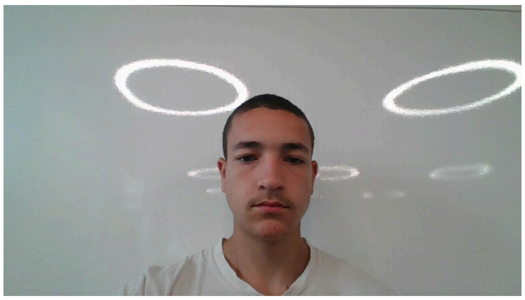
Sugar Gliders

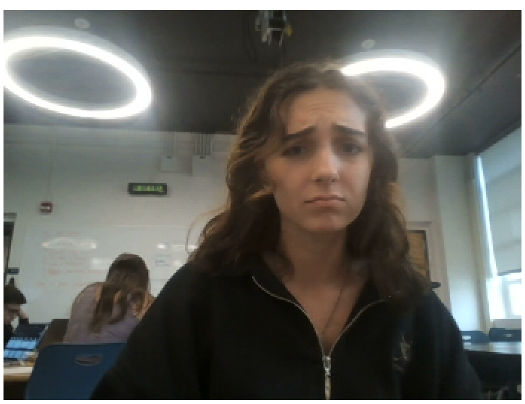
Riley Callahan, Djibril Curley, Nickolas Eggleston, Emma Howard, Jordan Stuart, Benjamin Telanoff

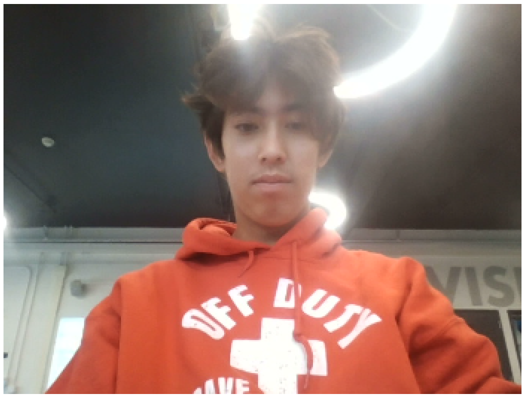


JPL Invention Challenge
"Paper Basket Challenge"

About the Authors

Name & Picture	Bio
 **Djibril** djibrilcurley@gmail.com www.samohiengineering.com	Djibril Curley is a senior at Santa Monica High School. He has participated in the PLTW program since his freshman year in Highschool. In college he hopes to study aerospace engineering. Outside of the classroom, Djibril enjoys playing sports, going to the gym, and spending time with friends.

 **Emma** ekh2@smmk12.org https://ekh216.wixsite.com/my-site-4	Emma Howard is currently a senior at Santa Monica High School. She has been part of the PLTW program for two years, and is planning on majoring in electrical engineering. She has participated in coding programs, rocket design classes, and completed other engineering projects that have combined a variety of engineering processes. Outside of engineering, Emma enjoys reading, watching movies, and cooking.



Ben

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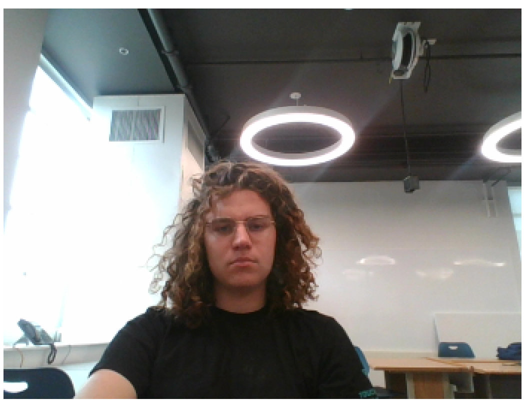
Benjamin Telanoff is currently a senior at Santa Monica High school. He's been a part of the PLTW program since freshman year mainly focusing on computer science. Because of his focus on comp sci he has participated in hackathons, created websites, and coded games outside of school. He hopes to major in computer science at UC Berkeley. Outside of engineering, Benjamin is fluent in Spanish, enjoys writing and reading, and is a swimmer.



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Riley Callahan is a senior in high school at Santa Monica High school and has been part of PLTW for 4 years, on the computer science path. Riley has also been an active part of both Running with Speakers, the schools AV club, and the theater department, mainly focusing on lights in both. Riley has participated in every theater production and public domain since sophomore year. Outside of school Riley enjoys climbing, biking, playing bass, and D&D.

 **Jordan** jcs10@smmk12.org https://jcs107.wixsite.com/Jordan Stuarts Digit	Jordan is currently a senior at SAMOHI. Jordan has been a part of the PLTW program in smmusd since 6th grade. He has participated in coding, electronics, 3D modeling, and aerospace engineering. This wide range of engineering topics has allowed him to participate in modeling camps, complete unique projects and have a wide understanding of the engineering process and how it applies to different fields. Jordan hopes to pursue architecture at Drexel University. Jordan also enjoys rowing, cooking, and watching movies outside of school.

 **Nick** nae3@smmk12.org [https://nae316.wixsite.com/nicholas-egglest on-d](https://nae316.wixsite.com/nicholas-eggleston-d)	Nick is Currently a senior at SAMOHI. Nick has been part of the PLTW program since 10th grade in which he has participated in aerospace engineering and digital electronics. These two classes have allowed him to complete a variety of projects, collaborate with other engineering students, and learn much more about the different engineering fields. Nick is interested in pursuing engineering/architecture into college. Outside of school Nick enjoys hanging out with friends, watching movies, working out, and surfing.

Table of Contents

Component 1 : Rules/Research

Problem Statement

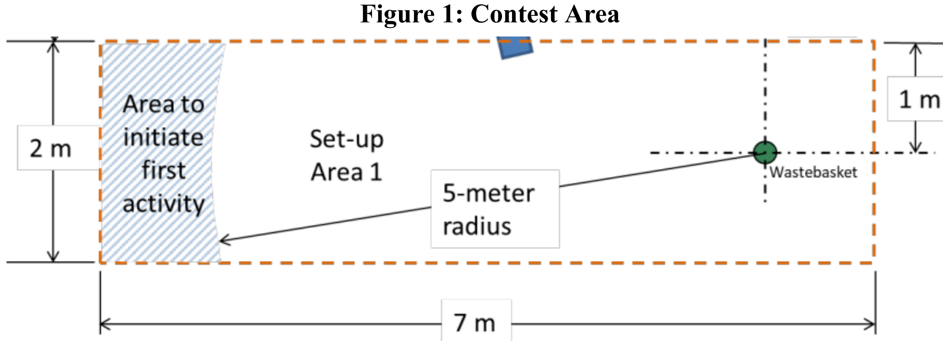
The goal is to use seven subsequent activities, ranging across different power sources, to travel a minimum distance of 5 meters away in order to get a piece of paper into a wastebasket in the fastest time possible.

Rules/Considerations

1)The first activity must be done within the area to initiate the first activity(1mx2m).

2)The area to set-up is 7mx2m.

Figure 1: Contest Area

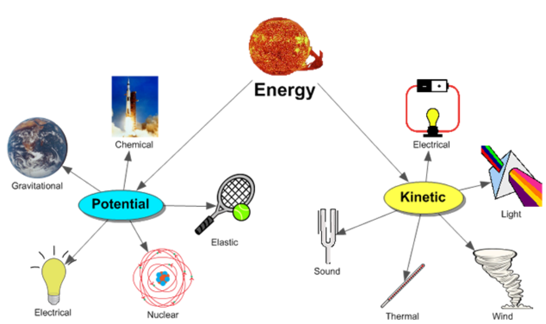


3)The first activity must be initiated by a single action.

4)The end of each activity must initiate the start of the next activity.

5)Must have at least 7 activities, ranging across 3 energy sources including spring and gravitational.

Figure 2. Different Energies



6)No human power is allowed during the event.

7)If the paper comes out of the wastebasket after it has entered, the team is disqualified.

8)No individual activity can cause the paper to travel more than 5 feet in the horizontal direction.

9)The time will end once the entirety of the paper enters the waste basket.

Figure 3. Paper falling into wastebasket

10)The velocity cannot exceed 25 ft/second or 6lb feet/second.

11)The paper can start anywhere within the contest area outlined in Fig.1.

12)You can have multiple of the same activity.

13)You must fill out a table of activities that includes details about each activity.

14) Each activity must traverse a distance greater than 15 inches in combined horizontal and vertical motion.

Initial Research

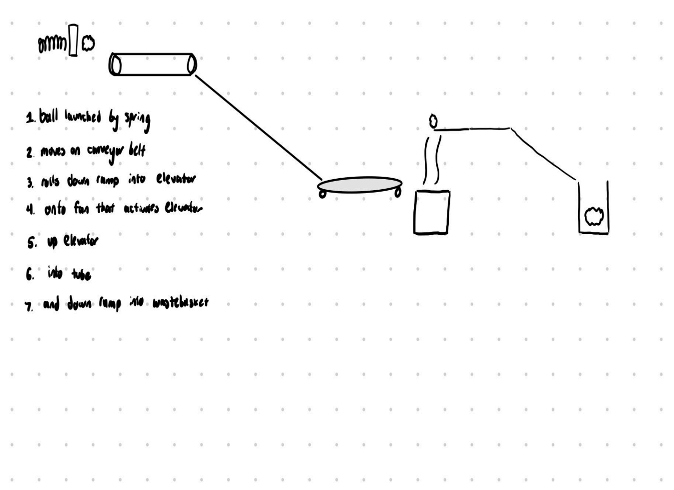
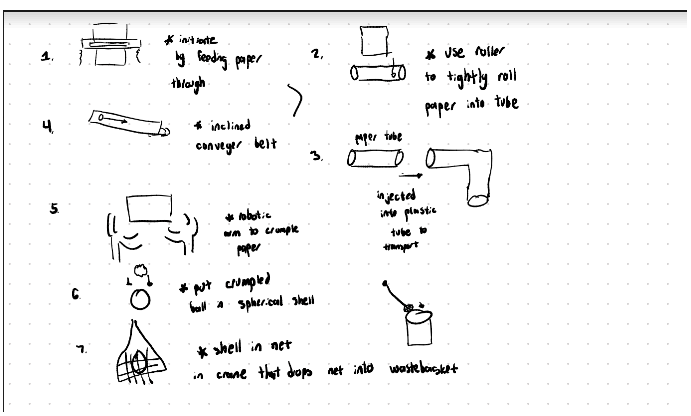
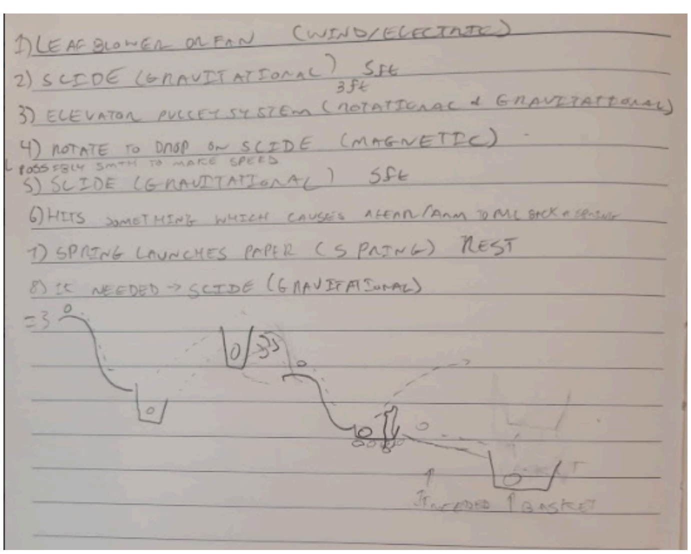
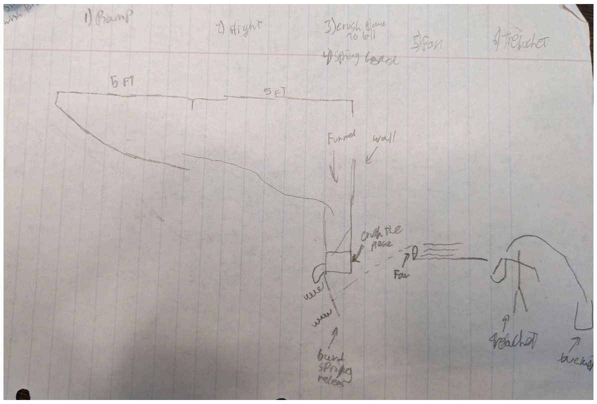
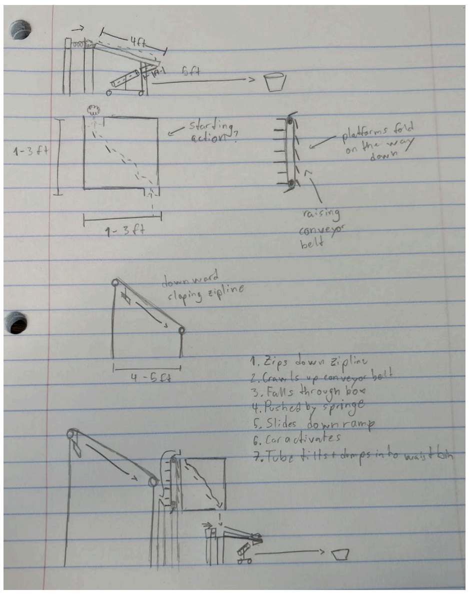
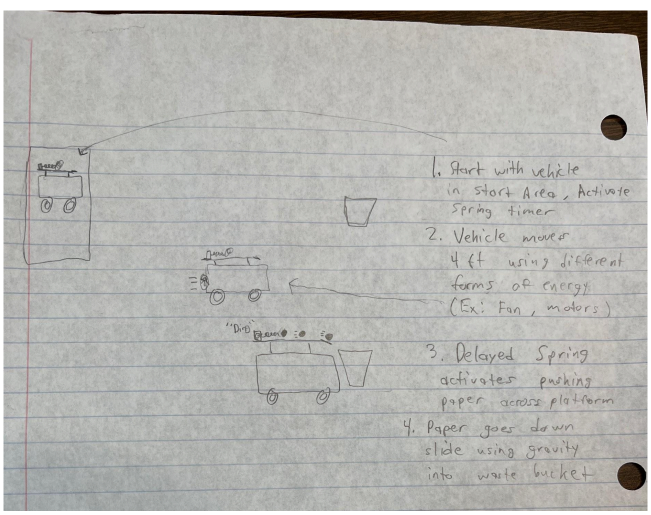
Author	Initial Sketch	Description
Figure 4: Djibril Curley's Design		This initial design was created under the assumption the paper would have to start in the initial area. We later came to realize this was not true. In this design the paper ball is pushed by a spring into a conveyer belt. This leads into a slide that deposits the paper into a train on a track. The train carries the ball into a counterweight elevator that raises the ball into a wind tunnel. The wind tunnel pushes the ball into the basket.
Figure 5: Emma Howard's Design		In this initial design, the idea was to use the most reliable sources of energy possible. Utilizing gravity, springs, and rotational energy as opposed to electricity, the purpose of this design was to create seven different activities that would transport the paper quickly.
Figure 6: Benjamin Telanoff's Design		In this initial design, the idea was to get the paper into the wastebasket as fast as possible. Because of this 3 approximately 5ft slides would exist on top of a 2ft diagonal pulley system. The 3 energy sources used would be wind, spring, and gravitational energy.

Figure 7: Riley Callahan's design		In my initial design, I mainly relied on gravity because it is the most reliable form of energy. The idea was to try to get the paper in the basket reliably without sacrificing too much time. The first action was a slide then a flight landing in a chute then a spring into a fan chute into a trebuchet then finally in the basket
Figure 8: Jordan Stuart's Design		A majority of this initial design relied on gravity because gravity is one of the most reliable ways to get the ball from point A to point B. The first action would be a zipline that then enters a vertical conveyor belt. Most of the actions after that would be centered around gravity due to its reliability. This design didn't really work out because it involved a lot of complex parts and the group later found out that the paper ball does not have to be a part of every activity in the design.
Figure 9: Nickolas Eggleston's Design		This initial design relied on the misconception that the entire project design had to be confined to the starting area. With this in mind, my design was a small vehicle with a platform on top that had a delayed spring with the paper ball. The idea was the vehicle would move towards the waste bucket using different energy such as a fan or an electric motor. Once close enough the delayed spring would activate pushing the paper ball across the platform then use gravity to roll down a small slide into the waste bucket.

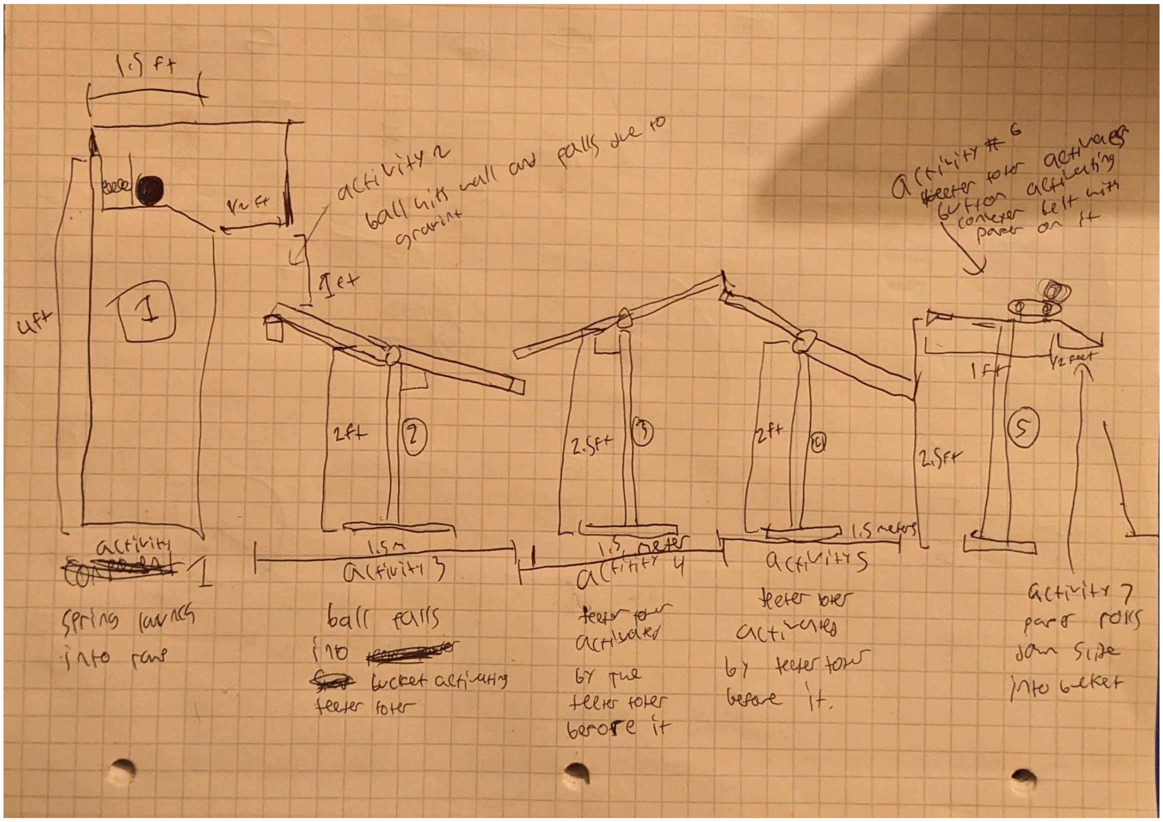
Conclusion

After our initial consideration of the rules we decided that to have the fastest time possible, we would put the paper ball by the basket. Our focus is on having six different, simple, activities that could be done in rapid succession whilst covering a large distance. This way we travel the furthest in the shortest amount of time. To do this we are considering certain components such as a spring launch mechanism, teeter totters, conveyor belts, and/or slides.

Component 2: Design

Initial Design Concept

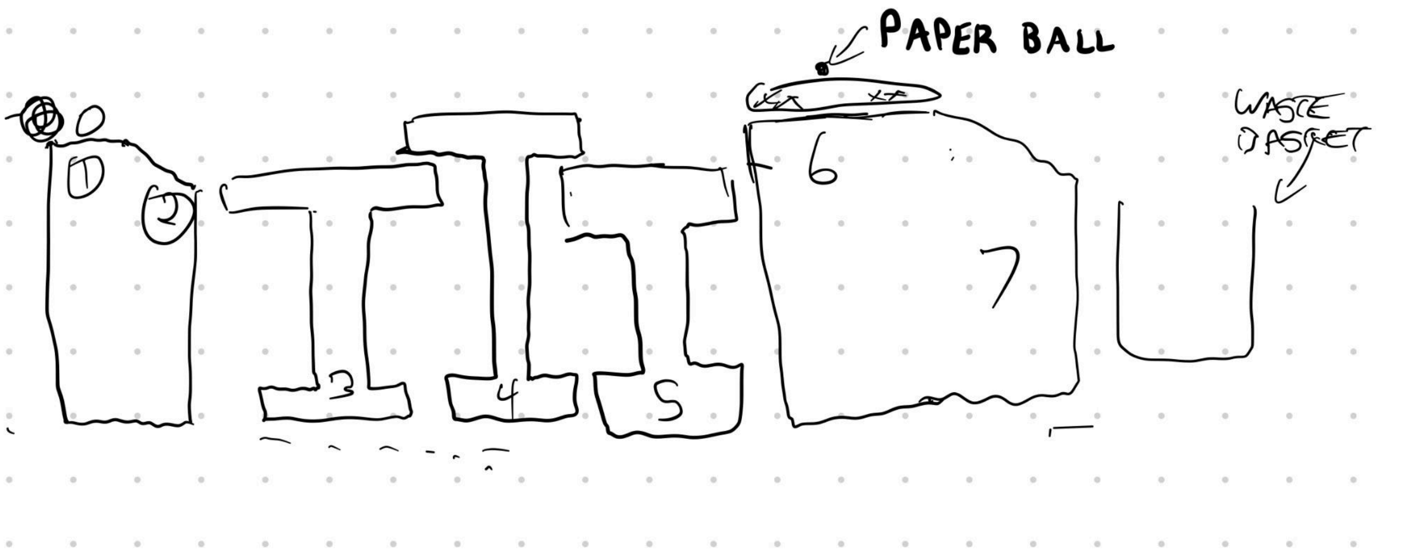
Figure 10: Sketch of Our Initial Design Concept with basic dimensions and descriptions



Activity 1: A spring launches a ball onto a ramp that falls onto Activity 2.
Activity 2-5: Teeter-totters. Activity 2 starts with a ball falling into a bucket which activates the other side to go up, hitting the next one, which hits the next one… Eventually hitting a button that launches Activity 6.
Activity 6: A button activates a conveyor belt with the crumpled up paper on it, which rolls the paper onto a ramp, initiating Activity 7.
Activity 7: The paper rolls down the ramp into the wastebasket, marking the end of the process.

Revised Design Concept

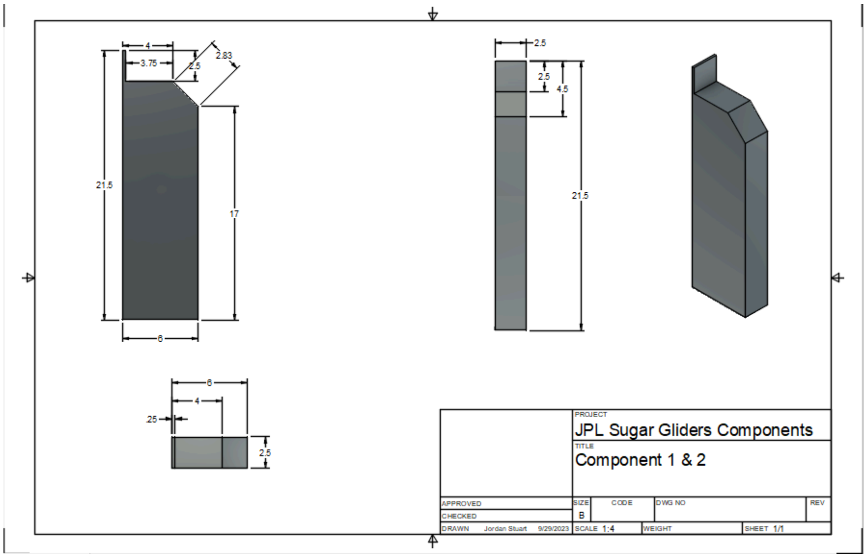
Figure 11: Sketch of our revised design concept



For the revised design model, we switched the 2nd activity (represented in the top right image) from a ball hitting a backboard and falling to a ball rolling down a slide after our peers shared how they found that activity unreliable. Every other activity was kept the same. Our revisions mainly focused on altering the dimensions of the components and assembling the system as a whole.

* In the actual build, the transition from Activity 1 to Activity 2 was switched back to the original idea of it hitting the backboards. Activities 2-7 were changed, and we added another activity, Activity 8. For Activity 2, we had a drop down 15in after the spring launcher. For Activities 3-6, we used four teeter-totters instead of three. At the end of the last teeter totter, instead of hitting a button, it hits a paper ball resting on top of a leaf blower which initiates Activity 7. With the paper ball now in the leaf blower, it gets blown to Activity 8 where it wraps around a ramp and eventually falls into the basket.*

Prototype Design Model



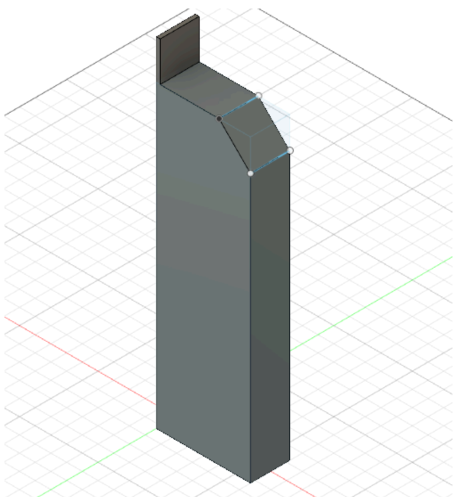


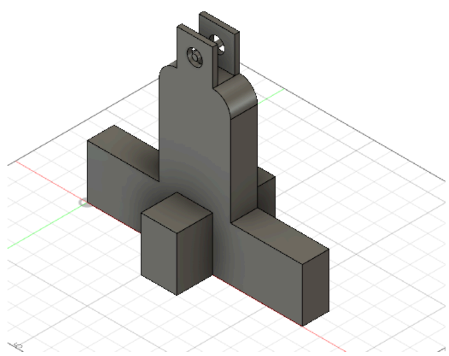
Figure 12: 3D model of Activity 1 and 2

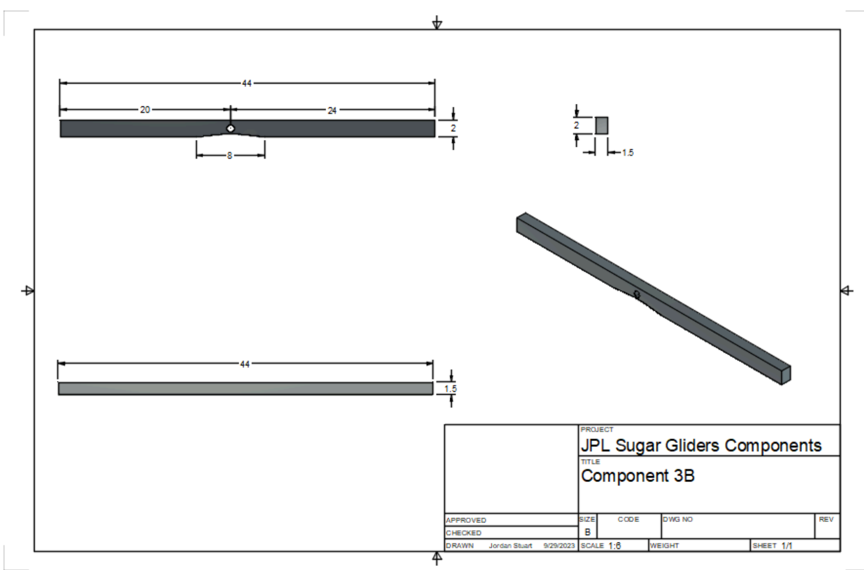
Parts List

Material	QTY	Price
Wood, plywood	2	In Shop
Wood, 2 by 4	4	In Shop
Screws	16	In Shop
Spring	1	$2.99

We increased the height of the activity and used a table instead of a solid block

Figure 13: 3D model of Activity 3, 4, and 5

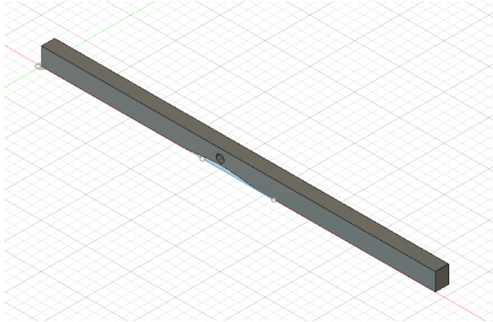


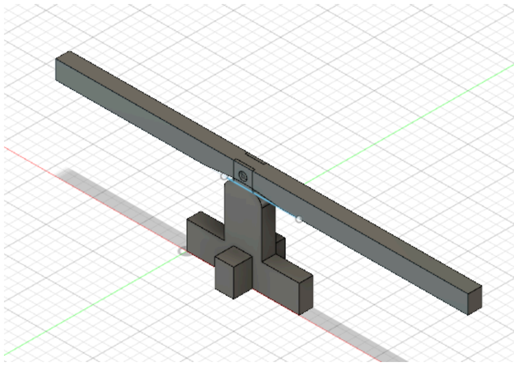


Parts List

Material	QTY	Price
Wood Base Plate	3	$27.33
Wood support Pillar	3	$21.96
Foam	3	$41.97
Rods	3	$5.47
Screws	72	In Shop

The actual base for the teeter totters included a box at the bottom with two vertical planks that the rod goes through.





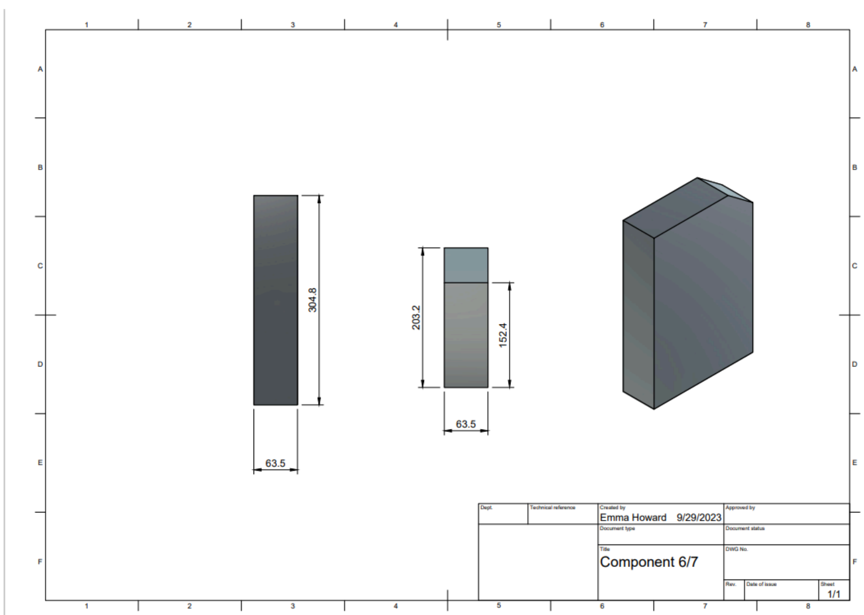
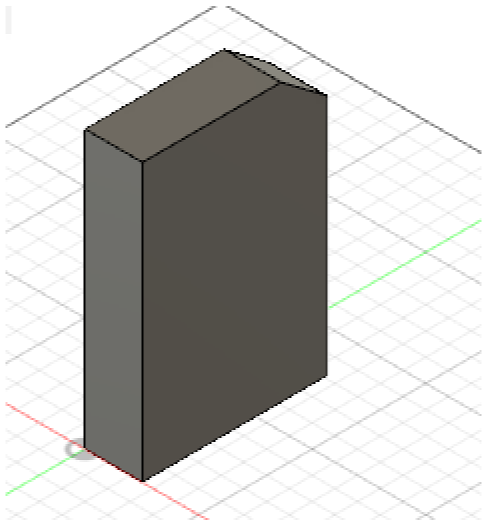


Figure 14: 3D model of Activity 6 and 7

Material	QTY	Price
Wood, plywood	1	In Shop
Screws	8	In Shop
Leaf blower	1	$109.99

Since we did not use these activities, we never actually built them.

We did not end up using this design as we were aiming at maximizing the velocity while minimizing time. Therefore, we did not end up constructing a full assembly of this CAD model.

Cost Analysis

Part	Cost per part	Quantity Per Prototype	Total cost of part	Example Link
Wood slide Planks	$8.96	~1	$8.96	1 in x 4 in x 12 ft wood
Wood Support Pillars	$21.96	~1	$21.96	4 in x 4 in x 20 ft wood
Spring	$2.99	1/6	$0.50	Spring
Wood Base Plate	$9.11	3	$27.33	2 ft x 2 ft x ¼ in wood
Leaf Blower	$109.99	1	$109.99	Leaf Blower
Foam	$41.97	1	$41.97	NGX 4x8 foam
Rods	$5.47	1	$5.47	¼ inch rod
Wood, plywood	$0	7	$0	Wood in Shop
Wood, 2 by 4	$0	10	$0	Wood in Shop
Screws	$0	40	$0	Screws in Shop
Nails	$0	20	$0	Nails in Shop
Total of parts			**$174.21**	
Cost of Labour			$1,512.45	
Total Cost			**$1686.66**	

Cost of Labour

The average wage for a general contractor in California is 28.02 - 39.20 $/hour, so we'll say $33.61, the average of those two. A model would be expected to take around 9 hours to assemble with 5 workers at a time 9 hours * $33.61/hour * 5 people = $1,512.45 in labor costs

This cost analysis is inaccurate as we changed our device after this point and utilized different material. Furthermore, we did not purchase rods, any wood, or the leaf blower. All of those materials were found in the shop.

Equipment and Technology

Overview

- Marker
- Saw
- Tape Measurer
- Drill Press
- Screwdriver
- Protractor

Activity 1 and 2: We utilized the marker (for marking points) and tape measurer (for dimensions) to outline the base piece of wood and the cuts needed to form the wooden block. A saw is then used to actually cut the piece about the lines.

Activity 3-5: First, we use the marker and tape measurer on 3 blocks of wood to outline the cuts needed. A saw is utilized to actually cut the piece about the marked lines. Afterwards, on the base - using a marker and tape measurer - we will mark where the plank has to be drilled. A screwdriver is then used to secure the first block to the middle block. Next, the tape measurer and marker are used to mark the hole needed at the top of the second block where the ball bearing goes, using a drill press to make the hole itself. Then, we will drill a similar hole with the same dimensions in the plank that's getting tilted. Putting it in place, we lastly place the ball bearing where it goes and use a protractor to place it at its desired angle.

Activity 6 and 7: A marker and tape measure are used to mark the intended cutting and drilling spots on a block of wood. We utilized a saw to cut the wood into the intended shape. A conveyor belt is then suspended over the block using four wooden legs (like a table).The legs will be built by marking and cutting wood. A drill press will be used to create four holes for screws (marked by tape measurer and marker) that are drilled to connect the legs to the block. A button/switch will be connected to the rearward side of the block facing upward. It's going to be connected by screws or glue.

* We did not use Activities 1,2,6, and 7 listed above, modified Activities 3-5, and added an eighth activity. For Activities 1 and 2, instead of using the block, we changed it to a table with a larger height so that the ball dropping on the teeter totter would have the optimized force to cause the chain reaction. For Activities 6 and 7, we changed them entirely, adding in a fourth teeter totter which knocked the paper ball into a leaf blower. This leads to the 8th activity in which, connected to the leaf blower, the ball goes at a downward angle to fall into the wastebasket in order to not get blown out (a backboard didn't work). For Activities 3-5, in order for structural stability, we changed it to have a square base with two vertical wooden planks on opposite sides. *

Component 3: Physics Analysis

Table of Activities

In Activity 1, a spring is initiated by the pull of a pin, and forces a ball forward a horizontal distance. The ball hits a vertical plank and momentarily stops moving before dropping a vertical distance in Activity 2. In Activity 3, the descending ball hits the first teeter-totter, starting its motion. One side of the teeter-totter moves upward to hit another teeter-totter, and the process repeats in Activities 4 through 6. In Activity 7, the fourth teeter-totter knocks a paper ball through the tube of a leaf blower. In the final activity, Activity 8, the paper moves down an inclined tube and is propelled into the wastebasket by the wind force and assistance from gravity.

Activity Number	**Description of Activity**	**Energy Source**	**Energy Category (Gravity, Springs, Other)**	**Total Distance Traveled (feet)**	**Estimated Maximum Velocity of Object (ft/sec)**	**Product of Weight and Maximum Velocity (lb-ft/sec)**
1	Initiated by the pull of a pin, a spring forces a ball forward a horizontal distance.	Spring	Springs	X = 1.25 feet	21.185 ft/sec	5.351 lb-ft/sec
2	The ball hits a vertical plank which stops its movement momentarily, before the ball falls a vertical distance.	Gravity	Gravity	Y = 6.833 ft	20.963 ft/sec	5.547 lb-ft/sec
3	The ball hits a foam teeter-totter on one side, which moves the other side upward.	Teeter-totter	Other: Rotational	X = 0.167 feet Y = 1.208 feet Total = 1.375 feet[1]	11.3778 ft/sec	2.8422 lb-ft/sec
4	The first teeter-totter hits the second teeter-totter upward on one side, moving the other side downward.	Teeter-totter	Other: Rotational	X = 0.167 feet Y = 1.15 feet Total = 1.317 feet	11.564 ft/sec	2.8424 lb-ft/sec
5	The second teeter-totter hits the third teeter-totter	Teeter-totter	Other: Rotational	X = 0.167 feet Y = 1.25 feet Total = 1.417 feet	11.6578 ft/sec	2.8422 lb-ft/sec

[1] The space each teeter totter occupies is 4 feet, however the horizontal and vertical distance each travels are around 0.167 feet and 1.208 feet respectively.

	downward on one side, moving the other side upward.					
6	The third teeter-totter hits the fourth teeter-totter upward on one side, moving the other side down to hit the paper ball down.	Teeter-totter	Other: Rotational	X = 0.217 feet Y = 1.58 feet Total = 1.797 feet	9.3864 ft/sec	2.8422 lb-ft/sec
7	The fourth teeter-totter hits the paper ball into the leaf-blower tube, propelled forward by wind.	Leaf Blower	Other: Wind	X = 1.312 feet	6.56 ft/s	0.066 -ft/sec
8	The paper ball moves through an inclined tube and out into the wastebasket with both wind force and assistance from gravity.	Gravity and Leaf Blower	Gravity and Other: Wind	X = 1.167 feet Y = 0.729 feet Total = 1.896	10.567 feet/sec	0.107 lb-ft/sec

Equations

In Activity 1, a ball of mass m_b, is at rest. Initiated by the pull of a pin, a spring of spring constant k, activates the spring stretched a distance Δx, moving the ball forward at a velocity v_1.

$$E_{in} = E_f \tag{1}$$

Energy in the system is approximately conserved. Therefore, the initial energy is equal to the final energy.

$$U_S = \frac{1}{2}k(\Delta x)^2 \tag{2}$$

The potential energy of a spring U_s is defined as the equation above, and is utilized as our device has a spring with constant k, pulled back a distance Δx, and contributing energy to the system.

$$K = \frac{1}{2}(m_b)(v_1)^2 \tag{3}$$

The linear kinetic energy K, is defined as the equation above, and is used as the ball with mass m_b, moves with a velocity v_1.

$U_{\text{in}} = K_f$

$\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}(m_b)(v_1)^2$

Since energy in the system is conserved, we can say the initial energy is equal to the final energy. The system originally has no kinetic energy as the ball is at rest, so the initial energy only comes from the potential energy of the spring. Because all of that potential energy has been used once the spring has been activated, the final energy is only the linear kinetic energy of the ball. Under the assumption that the surface the ball travels on is frictionless, the ball rolls without slipping, so no rotational kinetic energy contributes to this part of the design. Combining these, the initial potential energy of the spring is equal to the final linear kinetic energy.

$\frac{k(\Delta x)^2}{m_b} = (v_1)^2$

$$v_1 = \sqrt{\frac{k(\Delta x)^2}{m_b}} \qquad (4)$$

Solving for v_1 , the equation for the velocity of the ball after the spring propels its motion is defined above.

$$U_g = (m_b)g(\Delta h) \qquad (5)$$

The gravitational potential energy (U_g) is defined as the equation above and is utilized as the ball of mass m_b is being affected by the gravitational acceleration (g) through a change in height (Δh).

$U_g = K_f$

$(m_b)g(\Delta h) = \frac{1}{2}(m_b)(v_1)^2$

After the ball moves a horizontal distance Δx_2, it hits a vertical wooden plank and falls to hit the teeter-totter in Activity 2. Assuming the ball stops moving after it hits the plank, there is only gravitational potential energy originally in the system. After the ball falls a vertical distance Δh, there is only linear kinetic energy in the system right before the ball hits the teeter-totter. Substituting the gravitational potential energy for U_i and linear kinetic energy for K_f, we can set the gravitational potential energy equal to the final linear kinetic energy.

$\cancel{(m_b)}g(\Delta h) = \frac{1}{2}\cancel{(m_b)}(v_2)^2$

$$g(\Delta h) = \frac{1}{2}(v_2)^2$$

$$(v_2)^2 = 2(g)(\Delta h)$$

$$v_2 = \sqrt{2(g)(\Delta h)} \qquad (6)$$

From Equation 5, we can solve to find the final linear velocity v_2, of the ball before it hits the teeter-totter. The mass of the ball cancels on each side of the equations, and by multiplying by two and taking the square root, we can derive the equation for v_2.

$$\omega = \frac{v}{r} \qquad (7)$$

The angular velocity is defined as the linear velocity divided by the distance from the pivot point r, in our case, half of the length of the teeter-totter.

$$p = (m)(v) \qquad (8)$$

Linear momentum is defined as the mass of the object m, multiplied by its linear velocity v.

$$L = (I)(\omega) \qquad (9)$$

Angular momentum is defined as the product of the moment of inertia and the angular velocity, ω.

$$L_i = L_f \qquad (10)$$

In Activity 3, the ball hits the first teeter-totter, initiating its rotational motion around the pivot point at its center. As there is no external torque, or rotational force, in the system as the ball hits the teeter-totter, we can utilize conservation of angular momentum to find the final linear velocity of the teeter-totter.

$$I_b = m_b(r_b)^2 \qquad (11)$$

Because we can treat the ball as a point mass, the moment of inertia of the ball is defined as the product of its mass m_b, and its radius r_b, squared.

$$I_{TT} = \frac{1}{12} m_{TT} (L_{TT})^2 \quad (12)$$

As we are applying the conservation of angular momentum, we will need to find the moment of inertia of the teeter-totter I_{TT}. While the teeter-totter boards do have cutouts for weight reduction, we can use a beam approximation to calculate the moment of inertia. The moment of inertia of a beam is defined by Equation 12.

$$L_i = L_f$$

$$m_b (r_b)^2 (\omega) = I_{TT}(\omega_1)$$

$$m_b (r_b)^2 (v_2/r_b) = I_{TT}(\omega_1)$$

$$(m_b)(r_b)(v_2) = I_{TT}(\omega_1)$$

$$\omega_1 = (m_b)(r_b)(v_2)/ I_{TT} \quad (13)$$

From Equation 10, we can substitute the initial angular momentum using the moment of inertia I_{ball}, and replacing ω with (v_2/r_b), from Equation 7. Finally, in Equation 13, we can solve for the final angular velocity of the teeter-totter, after the collision with the ball.

$$L_i = L_f$$

$$\cancel{I_{TT}}(\omega_1) = \cancel{I_{TT}}(\omega_2)$$

$$\omega_1 = \omega_2 \quad (14)$$

In Activity 4, the first teeter-totter moving with angular velocity ω_1, hits the second teeter-totter of angular velocity ω_2. Because no external torque is acting on the system, we can still use conservation of angular momentum to solve for the velocity of the second teeter-totter, after the first moves with angular velocity ω_1 and hits the second teeter-totter, initiating its movement. Since the teeter-totters are identical, the moment of inertia of the first teeter-totter is equal to the moment of inertia of the second. Therefore, they cancel and we can conclude that the initial angular velocity of the first teeter-totter as it hits the second, is equal to the angular velocity of the second teeter-totter after the collision.

As our design involves four teeter-totters which hit the next in Activities 4 through 6, we can use Equation 14 to determine the angular velocity of all of the teeter-totters, repeating the same process.

$$v = \sqrt{2(g)(\Delta h)}$$

$$v_{pb1} = \sqrt{2(g)(\Delta h_2)}$$

After the fourth teeter-totter moves downward in Activity 6, it hits the paper ball, which is positioned inside a tube connected to the leaf blower, down a vertical distance (Δh_2). Acting under the assumption that the paper ball is initially at rest, we can set the gravitational potential energy equal to the final kinetic energy, utilizing Equation 6 to calculate the velocity of the paper ball as it enters the leaf blower.

$$F_w = (m_{pb})(a_{pb}) \qquad (15)$$

A manipulation of Newton's Second Law of Motion, the force of the wind in the leaf blower system is equal to the mass of the paper ball m_{pb}, multiplied by the acceleration of the ball due to the wind, a_{pb}.

$$v_x^2 = v_{x0}^2 + 2a_x(\Delta x_3) \qquad (16)$$

$$v_f^2 = 2a_{pb}(\Delta x_3)$$

$$a_{pb} = \frac{v_f^2}{2(\Delta x_3)} \qquad (17)$$

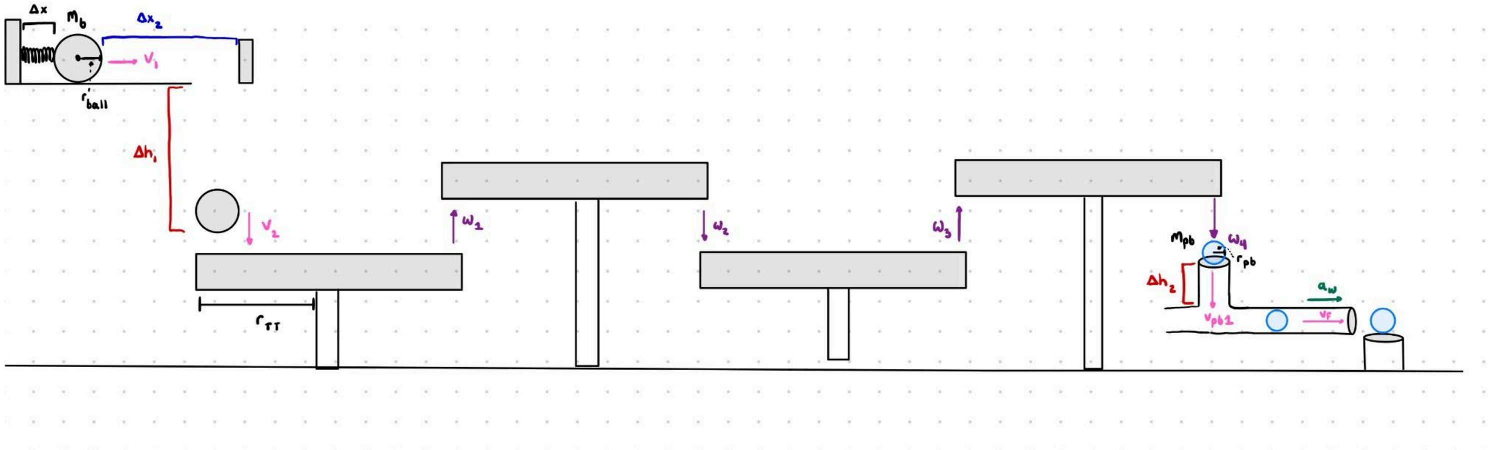
In Activity 7, the paper ball moves a horizontal distance, Δx_3, through the leaf blower and out into the wastebasket. Utilizing the known kinematics equation, Equation 16, we can eliminate the initial velocity in the x direction as the paper ball is not moving horizontally. We can substitute the horizontal acceleration, with the acceleration due to wind force, as that is the cause of the acceleration. Using a motion sensor to find the final velocity of the paper ball after it moves through the leaf blower and into the wastebasket, we can substitute v_f , and derive Equation 17.

Theoretical Device Performance

Table of Variables and Values:

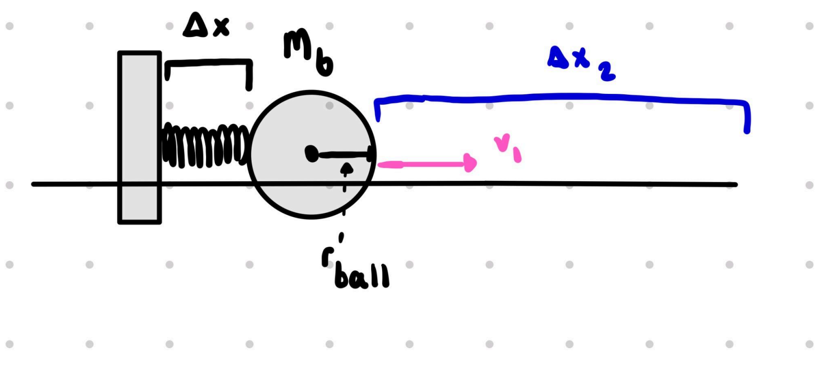
Variable	Value
k (spring constant)	3900 N/m
Δx (distance spring is stretched)	0.035 m
m_b (mass of the ball)	0.2646 lbs
v_1	21.185 ft/s
Δx_2 (horizontal distance first ball travels after spring hits it)	0.74 feet
r_b (radius of the ball)	4.1 in 0.10414 m
Δh_1 (vertical distance ball travels to hit teeter-totter)	15 in or 0.381 m
v_2 (velocity as it hits the teeter-totter)	8.957 ft/s
ω_1 or v_3	4.491 rad/sec or 7.481 ft/s
r_{TT} (distance from pivot to end of teeter-totter)	20 in or 0.508 m
m_{TT} (mass of teeter-totter)	0.328 lb or 0.1488 kg
Δh_2 (vertical distance paper ball falls into leaf blower)	0.17 m or 6.69 in
m_{pb} (mass of paper ball)	0.0101 lb or 0.00458 kg
L_{TT} (length of teeter-totter)	40 in or 1.016 m
Δx_3 (horizontal distance paper travels in leaf blower)	0.75 m or 29.528 in
a_w (acceleration due to wind)	266.667 $\frac{m}{s^2}$
v_f (final velocity of paper ball)	20 m/s
v_{pb1}	5.989 ft/s

Figure 15: A diagram of our entire device with vectors corresponding with the variables listed in Table of Variables and Values



In Activity 1, initiated by the pull of a pin, a spring with spring constant k, stretched a distance Δx, propels a ball of mass m_b and radius r_b to move forward horizontal with a velocity v_1.

Figure 16: A diagram of Activity 1, the spring forcing the ball forward a horizontal distance.



k = 3900 N/m

Δx = 0.035 m

m_b = 0.11458 kg

$$v_1 = \sqrt{\frac{k(\Delta x)^2}{m_b}}$$

Using Equation 4 with the values listen above we get the equation for the velocity of the ball after the spring forces it forward:

$$v_1 = \sqrt{\frac{3900(0.035)^2}{(0.11458)}}$$

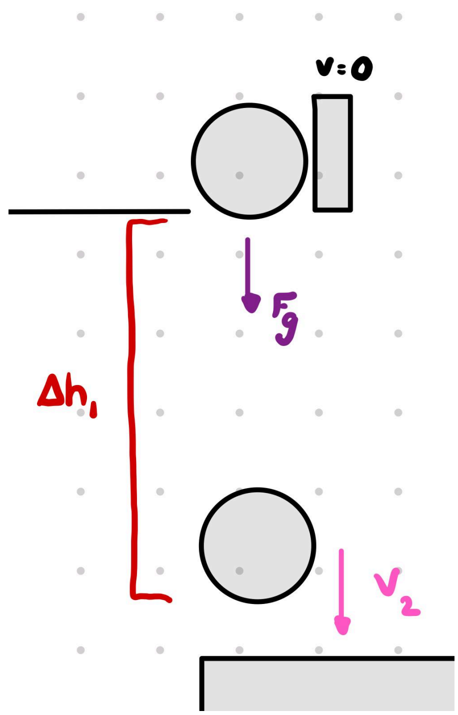
$v_1 = 6.457$ m/s

$v_1 = (6.457$ m/s$)(3.281$ ft/m$)$

$v_1 = 21.185$ ft/s

Through testing[2], we found the spring constant to equal 3900 Newtons per meter, and the spring displacement to be 0.035 meters. Substituting in the values for k, Δx, and m_b into Equation 4, we found that the velocity of the ball after it is propelled forward by the spring is 21.185 feet per second.

Figure 17: A diagram of Activity 3, the movement of the teeter-totter after the collision with the ball.



After moving a horizontal distance Δx_2, the ball hits a vertical plank, and drops a vertical distance Δh in Activity 2. We determined Δh to be 1.25 feet, or the 15 inch minimum requirement under JPL guidelines. However, this is subject to change as we may ultimately decide to increase the height to increase the velocity. The ball has a velocity v_2 just before it hits the teeter-totter.

$\Delta h_1 = 1.25$ ft or 0.381 m

[2] Link to testing data and graph: https://docs.google.com/spreadsheets/d/1fyt5UmIr3KNn-Y8DIm80h2IDq5O0LgrNFZYivZ9fRQA/edit?usp=sharing

g = 9.8 $\frac{m}{s^2}$

$$v_2 = \sqrt{2(g)(\Delta h_1)}$$

Utilizing Equation 6 with the values listed above, we found the equation for the velocity of the ball just before it hits the teeter-totter:

$$v_2 = \sqrt{2(9.8)(0.381)}$$

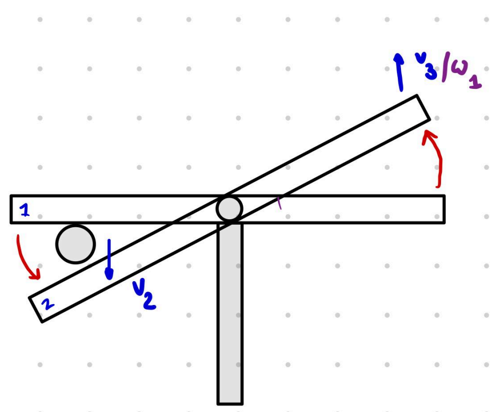
v_2 = 2.73 m/s

v_2 = (2.73 m/s)(3.281 ft/m)

v_2 = 8.957 ft/s

Substituting the value for the change in height Δh, and the gravitational constant g, in Equation 6, the velocity of the ball just before it hits the teeter-totter is 8.957 feet per second.

Figure 18: A diagram of Activity 3, the movement of the teeter-totter after the collision with the ball.



In Activity 3, after the ball hits the teeter-totter downward, the other side rotates upward, hitting the second teeter-totter.

m_{ball} = 0.11458 kg

r_b = 0.10414 m

v_2 = 8.957 ft/s

$\omega_1 = (m_{ball})(r_b)(v_2)/ I_{TT}$

From Equation 13, we can conclude that the angular velocity of the teeter-totter after the collision with the ball is:

ω_1 = (0.11458)(0.10414)(8.957)/ I_{TT}

In order to calculate the moment of inertia of the teeter-totter, I_{TT}, we used a beam-approximation.

m_{TT} = 0.1488 kg

L_{TT} = 40 inches = 1.016 m

Substituting in the values for the mass of the teeter-totter m_{TT}, and the length of the teeter-totter L_{TT} into Equation 12:

$$I_{TT} = \frac{1}{12} m_{TT} (L_{TT})^2$$

$$I_{TT} = \frac{1}{12} (0.1488)(1.016)^2$$

$$I_{TT} = 0.0238\ kgm^2$$

Substituting this value into Equation 13, we can find ω_1:

ω_1 = (0.11458)(0.10414)(8.957)/ (0.0238)

ω_1= 4.491 rad/sec

To find the linear velocity of the teeter-totter, we can use Equation 7:

r_{TT}= 20 inches or 0.508 m

$$\omega_1 = \frac{v_3}{r_{TT}}$$

$v_3 = (\omega_1)(r_{TT})$

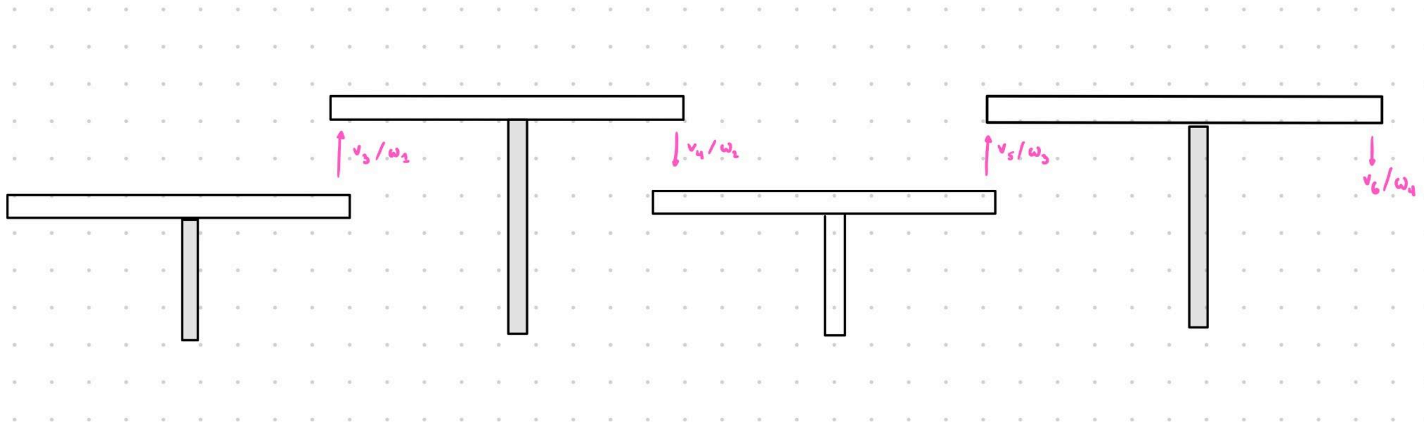
$v_3 =$ (4.491)(0.508)

v_3 = 2.28 m/s

v_3 = (2.28 m/s)(3.281 ft/m)

v_3 = 7.481 ft/s

Figure 19: A diagram of Activities 3, 4, 5, and 6, each teeter-totter hitting the next.



As proven in Equation 14, the angular velocity of the first teeter-totter as it hits the second, is equal to the angular velocity of the second teeter-totter as it hits the third, and so on. Therefore, we can conclude:

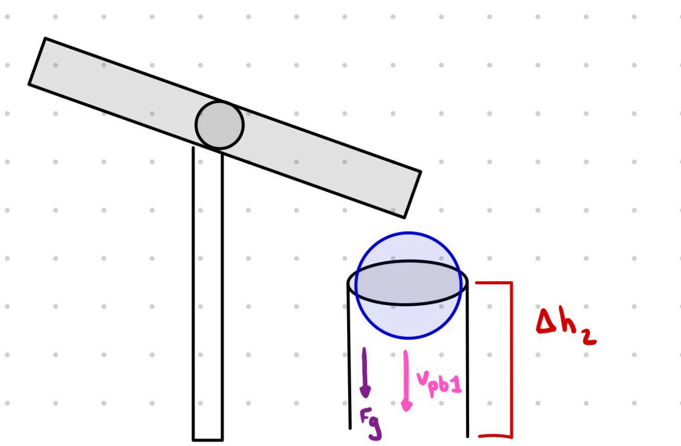
v_3 = 7.481 ft/s

v_4 = 7.481 ft/s

v_5 = 7.481 ft/s

v_6 = 7.481 ft/s

Figure 20: A diagram of Activity 7 the fourth teeter-totter hitting the paper ball downward a vertical distance.



In Activity 7, as the fourth and final teeter-totter moves downward with a velocity v_6, it hits a paper mall of mass m_{pb}, and radius r_{pb}. The paper ball, positioned atop a tube leading straight down into the leaf blower, moves downward with a velocity, v_{pb1}. Using Equation 6, substituting the vertical distance the paper traveled, Δh_2, as well as the gravitational constant, g, we can find v_{pb1}:

Δh_2 = 15 in or 0.381 m

$v_{pb1} = \sqrt{2(g)(\Delta h_2)}$

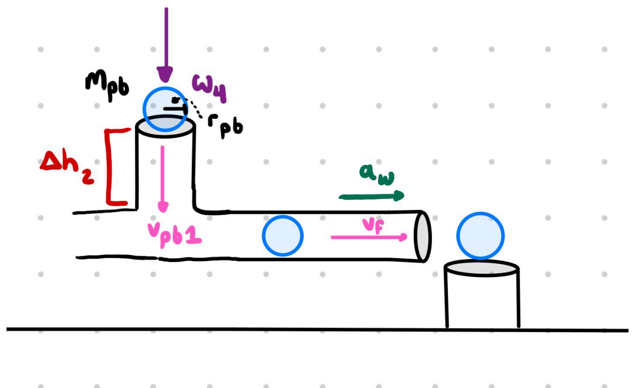
$v_{pb1} = \sqrt{2(9.8)(0.381)}$

$v_{pb1} = 2.73$ m/s

$v_{pb1} = (2.73$ m/s$)(3.281$ ft/m$)$

$v_{pb1} = 8.957$ ft/s

Figure 21: A diagram of Activity 8, the paper ball moving through the leaf blower and out into the wastebasket.



In Activity 8, the paper ball move through the leaf blower a horizontal distance Δx_3, it leaves the wind system and enters the paper basket at a velocity v_{pb2}. While in the leaf blower, the paper is accelerated due to the force of wind. From testing a paper ball of a radius r_{pb} , and mass m_{pb} with a motion detector, we calculated the approximate velocity of the paper as it leaves the leaf blower to be approximately 20 meters per second or 65.281 feet per second. Substituting the velocity of the paper ball,v_{pb2}, into Equation 17, we can find the acceleration due to the wind, a_w:

$v_{pb2} = 20$ m/s

$\Delta x_3 = 0.75$ m

$$a_w = \frac{v_f^2}{2(\Delta x)}$$

$$a_w = \frac{(20)^2}{2(0.75)}$$

$$a_w = 266.667 \frac{m}{s^2}$$

Device Limitations

In Activity 1, the maximum energy able to be stored by our device occurs when the initial spring with spring constant k, was stretched a particular distance Δx. With these values, we generate a potential energy U_s, specifically calculated to move the ball at a velocity close to 25 feet per second, the maximum under JPL guidelines. The calculation is shown below:

$m_b =$ 0.115kg

v_1 = 24.5 ft/s* = 7.4676 m/s

k = 3900 N/m

$\frac{1}{2}k(\Delta x)^2 = \frac{1}{2}(m_b)(v_1)^2$

$\frac{1}{2}(3900)(\Delta x)^2 = \frac{1}{2}(0.115)(7.4676)^2$

$(\Delta x)^2 = 3.2065/(3900/2)$

$\Delta x = 0.041$ m

* We chose to use 24.5 instead of 25 or a number closer to the maximum in order to account for unknown factors in the competition, such as wind or rain, and in our own design, such as the precise weight of the ball, calculation of the spring constant, etc.

This equation can be used to calculate a particular distance Δx to stretch said spring that would generate the maximum velocity of the ball. However, as our spring is extremely powerful, stretching it further than the 3.5 cm we are currently estimating may cause the ball to move at a speed over the JPL requirements. We will continue to test various stretch distances and their effect on the velocity of the ball as well as time. Furthermore, this velocity is assuming that there is no friction between the ball and the surface. While we can choose materials to minimize friction, it is unlikely that there will be no friction. In addition, if the competition is held outside, factors such as wind may also affect the velocity.

Similarly, in Activity 2, the maximum energy possible who involve generating the maximum gravitational potential energy of the ball as it falls a vertical distance h to collide with the teeter-totter.

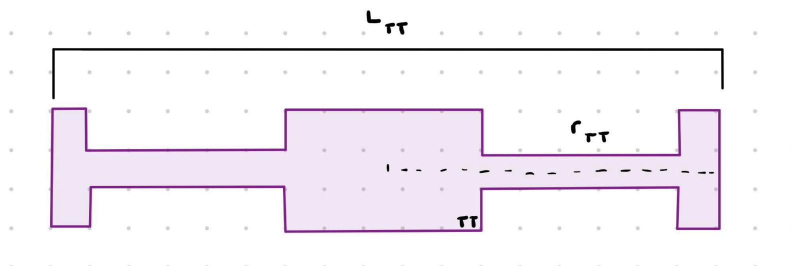
v_2 = 24.5 ft/s or 7.4676 m/s

$g(h) = \frac{1}{2}(v_2)^2$

$h = \frac{\frac{1}{2}(7.4676)^2}{9.8}$ = 2.84 m = 9.31 ft

The concern with this displacement is the time it would take the ball to fall a distance of about nine feet. As we are only graded on the time it takes us to get the paper into the wastebasket, the optimized height for maximum velocity is not the optimized height for minimal time. In Theoretical Device Performance, we used 15 inches as the height in Activity 2, to minimize the overall time. However, this height is subject to change, and we will continue to experiment with various vertical distances during testing. Furthermore, this velocity and corresponding height are assuming no air resistance, which is unlikely, and will therefore affect the true velocity of the ball as it hits the teeter-totter. The equation is also being applied under the condition that the ball is initially at rest. This is assuming that after the ball hits the vertical plank at the start of Activity 2, its velocity will be zero. However, it is not certain that this will be the case. As the initial velocity will be close enough to zero to not affect the result dramatically, we can set the gravitational potential energy equal to the final kinetic energy to calculate the velocity of the ball as it hits the first teeter-totter.
Through time trials and further calculations, we determined the optimal height for the initial ball to fall was 6.833 ft.

Figure 22: A diagram of the shape of our teeter-totter boards for Activities 3 through 6



To calculate the angular velocity of the first teeter-totter, and therefore all four of the teeter-totters, we needed the moment of inertia of the teeter-totter. However, as we cut parts of the board out for weight reduction(figure 22) to calculate the moment of inertia we used a beam approximation. While this is not the exact moment of inertia of the teeter-totter, it is a close enough approximation to be utilized in this situation.

In Activity 8, the maximum energy in the system would involve maximizing the force due to wind, as well as the cross-sectional area of the paper ball that is hit by the air flow. However, as we are restricted to the 25 feet per second maximum velocity as per JPL guidelines, maximizing the acceleration would result in a velocity far above this maximum. Currently, the final velocity of the paper ball as calculated by a motion sensor was found to be 20 meters per second or 65.281 feet per second. As this is far over the JPL guidelines, during building and testing we must find a way to lower this velocity, which involves lowering the force due to wind. Furthermore, our calculation for the acceleration due to wind is assuming constant acceleration, which is unlikely in the system.

Through time trials and measuring the distance the paper ball traveled through the tube, we determined the final velocity of the paper ball as it moves through the tube to be less than the 25 feet per second maximum. We estimated the final velocity to be approximately 10.567 feet per second.

Component 4: Build/Test

Build Progression

Phase 1: Scaled down Model

Figure 23: Djibril connecting styrofoam pieces for scaled-down model

Firstly, we constructed a scaled-down version of our most used activity: the teeter-totters. For our bases, we used wickets from the previous year's JPL challenge. Since the height of the wickets was significantly shorter than the height we were planning (11.8 inches compared to 36 inches), we scaled everything down by a value of one-third. Our group gathered the rest of the materials needed including a pencil, styrofoam, rods, wood, a tape measure, and a ruler. With the 16in long teeter-totters made of styrofoam, the 2in tall blocks to place every other teeter-totter on, and the makeshift stand to secure the styrofoam, we connected two pieces of styrofoam by sticking a pencil through both sides and secured the styrofoam on the stand. Upon running the test five times, we concluded that the mechanism would work and began designing the final contraption.

Phase 2: Building

Figure 24: Nick testing the spring mechanism

Activity 1: To build the first activity, we started by drilling a 0.25in hole through a 12in x 2in x 3in piece of wood screwed down to a 23.5in x 12in wooden base. To initiate the spring mechanism, we put a 0.1in rod through our spring which in turn went through the piece of wood connected to the base. After we drilled the hole, we placed the rod and the spring through the hole and hot glued the back of the spring to the wood. On the side of the rod touching the ball, we attached three washers as well as a 1.5in diameter circular piece that we 3D-printed. On the other side of the rod, we hot glued two washers and a 3in x 1.75in rectangular metal piece. Then, we drilled a 3.5in x 1.75in x 2in block of wood next to the back of the rod. The rectangular metal piece was pulled back and rotated to rest on the block, and with a wrench, we moved the metal piece off the block to initiate the spring and propel the ball forward. We used metal hinges to secure two 25in x 2in x 1in pieces of wood to the base. These pieces of wood forced the ball to move in a straight path.

Figure 25: Jordan, Nick, and Riley constructing the table for Activity 2

Activity 2: For our next activity, we started by creating a backboard for the ball to hit after moving a horizontal distance. We drilled in two screws to connect four 8in x 1in x 1in pieces of wood to both the base of Activity 1 and the backboard. Next, we hot glued a 21.5in long 6 in diameter tube to the backboard for the ball to fall down after hitting the board. We secured the tube with a 1.5in x 1in x 21.5in piece of wood and 3 nails. After testing, we added a 6 in x 1in x 1in piece of foam on the backboard, so that when the ball hit the board and the foam, both the rotation of the ball and the time were minimized. Lastly, we built the table for the mechanism to rest on. Using four 82in long 2.5in diameter PVC pipes, we connected each pipe to the base of our table with hot glue, metal hinges, and 8 screws. We used a level at the top to ensure that the table would be level. At the top, we attached two 18in x 3.5in x 1in wooden boards with hot glue, screwed in four metal hinges, and drilled in two screws.

Figure 26: Djibril and Riley drilling holes into the stand for a teeter-totter

Activity 3 and 5: We started by creating the base that we would use for all the teeter-totters. Using a tape measure and sharpie, we marked four sets of 14in long blocks onto 2in thick wood. We then utilized a circular saw to cut the pieces out and a drill to screw in 1.75in screws to make the long blocks into the box. Then, we found the center of the box on opposite sides, marking them with a sharpie to tell us where to attach our vertical boards. For these teeter-totters, the boards were 3.5in x 0.75in x 36in, which we drilled into the base using 2 of the 1.75in screws each. Next, 0.5in from the top of the board, we drilled holes for our rod to go inside of. The rods we used are 0.25in in diameter. The next part we executed was creating the styrofoam that would be rotating, using a sharpie and straightedge metal to measure out 4in x 48in x 2in blocks. We then used an X-acto knife to separate the block from the rest of the styrofoam. After utilizing a tape measurer and sharpie to find the middle of each teeter-totter, we then drilled to get the rod into each one. We put the rod through one of the vertical wooden boards, then through the styrofoam, and finally through the board on the other side. To finish it off, we used an angle finder to determine the exact angle we wanted for each teeter-totter, and then we used a drill to screw two nails through a 2.5in x 8in wooden board into the stand for each teeter-totter. This horizontal piece of wood ensured that the boards remained at the correct angle.

Activity 4: We used the same process that we did for Activity 3 and 5 except that we used 3.5in x 0.75in x 44in vertical planks.

Activity 6: We used the same process that we did for Activity 4, however, we cut into one side of the foam with an X-acto knife to add a 2in x 13in rectangular piece of foam that would hit the paper ball into the leaf blower.

Figure 27: Emma testing rubber bands for Activity 7

Activity 7: For the last activity, we created an attachment to add to the leaf blower to increase the distance the paper ball would travel through the wind system. To do this, we attached a 22in pipe (4in in diameter). One inch from the start and 2in from the end, we outlined a 4in diameter circle that we cut out with a steel saw on the top. In order to keep the paper ball from entering the leaf blower without an external force, we placed four rubber bands (two on each side of the space for the paper ball) 0.75in away from the outer circle and secured them using duct tape. With wood found in the shop and a partially built table from a previous project, we constructed a 20in x 9in x 5in table for the leaf blower to rest on. We used a tape measure to record the horizontal and vertical distance from the wastebasket and drilled eight screws into the four wooden blocks at the base.

<u>Phase 3: Assembly</u>

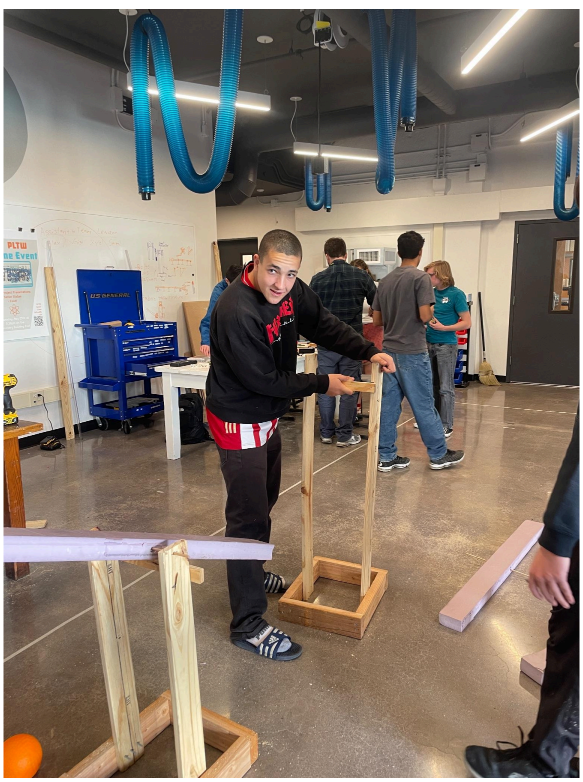


Figure 28: Djibril arranging teeter-totters

After we constructed the individual activities, we began to assemble our final device. We placed our spring mechanism along with the attached backboard and tube on top of the table, however, we did not screw in the base to the top until we arrived at the competition to make our device easier to transport. We put the first activity in the set-up area and began to place the teeter-totters in order accordingly. Through testing, we found 17in to be the appropriate distance between the base of our table and the base of our first teeter-totter so that the ball would move down the tube and hit the teeter-totter in the correct place. Next, we found 26in, 28in, and 27in to be the appropriate distance between the bases of the first and second teeter-totter, the second and first teeter-totter, and the third and fourth teeter-totter, respectively. To ensure the paper went into the basket each time, we positioned the tube at the end to be 2.5in left of the vertical projection of the wastebasket.

Phase 4: Refinement

Figure 29: Ben cutting circular path for ball in Activity 1

Firstly, we encountered an issue with the transition from Activity 1 to Activity 2. The foam that was meant to stop the rotation of the ball wasn't working well enough, with the ball frequently spinning around the rim before dropping down Activity 2 and costing us upwards of 0.3 seconds. Instead of trying to stop the rotation, we attempted to utilize it by directing the ball down the path instead. We used a circular saw to cut out a 9.5in diameter circle from a 9.5in x 8in rectangle, using the saw once again to cut the remaining rectangle into the appropriate shape to fit the needed design. After finding the optimal placement, we secured both directors to the backboard using a glue gun.

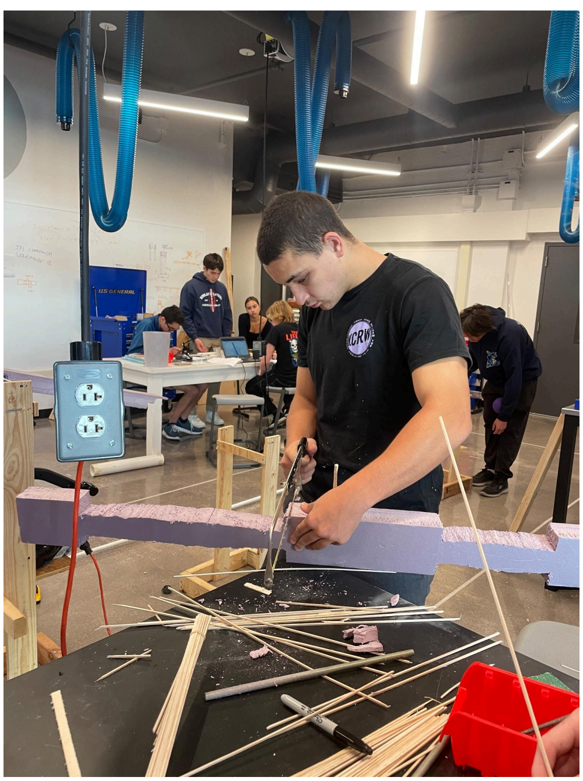


Figure 30: Djibril cutting a teeter-totter into an I-beam

A further issue we encountered surrounded the styrofoam teeter-totters. The design we originally had was going against two of the rules: the 6ft/lbs speed limit, and the minimum 15in that each activity must traverse. Because of this, we modified the teeter-totters in two ways. Firstly, we converted each teeter-totter into an I-beam, of sorts, so it would maintain most of its structural integrity whilst reducing the weight so that it fulfilled the speed requirement. Using an X-acto knife, we cut an average of 7in from the edges and 1in towards the center (*each teeter totter isn't exactly those dimensions, but very close to it*). The second was utilizing the X-acto knife once again to cut the styrofoam at the end the previous teeter-totter would hit. Cutting distance at the bottom would allow each teeter-totter to move an average of 2in further.

Figure 31: Ben and Djibril testing Activity 7 and 8

A major concern we encountered was that the leaf blower was often blowing the paper ball out of the basket, even with a backboard, which would lead to disqualification. Because of this, we decided to add another activity at the end. Our 8th activity is attached at the end of Activity 7 and consists of a pipe and a pipe elbow. The pipe elbow is directly connected to Activity 7, with a 4.1in diameter so it fits the leaf blower properly. On the other end of the elbow, we attached an 11in long pipe at an angle of 40 degrees below the horizontal, so that it would push the paper ball into the basket without blowing it out.

Test Criteria

Criteria/Benchmark	Description of data needed	Quantitative or qualitative
Time to complete seven activities after a single activation	Time trials performed testing the entire device	Quantitative
The time to set up the device is under 3 minutes	Duration of device set-up, ensure that time is under 3 minutes (Pass or Fail)	Qualitative
The device fits within a 2x1 meter starting area	Approximate dimensions of the final device, ensure that the data meets the benchmark (Pass or Fail)	Qualitative
No part of the device moves out of the setup area	Dimensions of final device in action, ensure that the data meets benchmark (Pass or Fail)	Qualitative
The device uses three different energy sources	Energy sources utilized in the final device, ensure that the design meets the benchmark (Pass or Fail)	Qualitative
Each activity after the initial action activates the subsequent activity	Ensure the energy of each activity is generated from the previous one (Pass or Fail)	Qualitative
The device has the official entry number on at least two sides of the device with 3in high numbers or larger	The device has entry numbers on two sides with 3in high numbers (Pass or Fail)	Qualitative
The estimated maximum velocity for each activity is below 25 feet per second	Maximum velocity for each activity	Quantitative
Product of Weight and Maximum Velocity for each activity is below 6 pound-feet per second	Product of Weight and Maximum Velocity for each activity	Quantitative
Each activity travels at least 15 inches	Distance each activity travels horizontally, vertically, or both.	Quantitative
The Table of Activities is completed before check-in	Table of Activities is completed and ready for check-in (Pass or Fail)	Qualitative
The device is initiated only by a single action provided by the contestant	How much human energy is exerted after initial action, ensure than none is used (Pass or Fail)	Qualitative

Test Procedure

Set-Up Procedure:

Assuming that the setup area is marked, and the wastebasket is in its required spot.

1. Start a 3-minute timer.
2. The designated speaker hands over the sheet of paper that will be used.
3. Set up the activities in the set-up area during this time, while one person (the designated speaker) is off to the side explaining what the contraption is in three minutes.
4. Timers start a stopwatch when the initiation of the first activity occurs.
5. Timers then stop the stopwatch after the paper ball completely has fallen below the rim of the waste basket.
6. Record the average final time across all the timers.
7. Repeat the process.

Velocity Calculation Procedure:

Most activities in our device had velocities easy to calculate with physics, however, the wind force of the leaf blower was complicated. To find the maximum velocity of the paper ball as it moved through the leaf blower, we used the following procedure.

Assuming distance traveled has already been calculated, and the device is already set up.

1. Timers start the clock as the paper ball enters the leaf blower.
2. Timers stop the clock after the paper ball completely has fallen below the rim of the waste basket.
3. Record the final timers and average various results.
4. Divide the distance traveled (given in feet) by the time traveled in seconds to calculate the ft-sec velocity.
5. Measure the mass of the paper ball used in pounds.
6. Multiply the mass of the paper ball by the ft-sec velocity.
7. Record the maximum ft-sec velocity and the product of weight and maximum velocity in lb-feet/sec.
8. Repeat the process ten times.
9. State the average of these velocities in the Table of Activities.

Measurement Procedure:

To ensure that each activity in our device followed the 15in minimum, we measured the distance traveled (horizontally, vertically, or both depending on the activity).

1. With a tape measure, place the metal end directly in front of the ball in Activity 1. Measure the horizontal distance from that position to the backboard.
2. Record the distance in feet in the Table of Activities under “Total Distance Traveled” for Activity 1.

3. With a tape measure, place the metal end at the start of the tube the ball drops down in Activity 2. Measure the vertical distance from that position to the first teeter-totter.
4. Record the distance in feet in the Table of Activities under "Total Distance Traveled" for Activity 2.
5. With a tape measure, place the metal at the end of the first teeter-totter closest to the next one. Measure the vertical distance from that position to the lowest end of the next teeter-totter.
6. Place the metal end horizontally at the end of the first teeter-totter. Measure the horizontal distance from the end of the first teeter-totter to the start of the next teeter-totter.
7. Add the horizontal and vertical distances and record that value under "Total Distance Traveled" for the activity.
8. Repeat Steps 5-7 for Activities 4 and 5.
9. Place the metal part of the tape measure at the end of the foam piece sticking out of the final teeter-totter. Measure the vertical distance from that position to the leaf blower where the paper ball is resting.
10. With a tape measure, measure the horizontal distance from the same foam piece to the leaf blower where the paper ball is resting.
11. Add the horizontal and vertical distances and record that value under "Total Distance Traveled" for Activity 6.
12. With a tape measure, place the metal end directly in front of the paper ball. Measure the horizontal distance along the leaf blower before it moves through the pipe elbow.
13. Record the distance in feet in the Table of Activities under "Total Distance Traveled" for Activity 7.
14. Detach Activity 8 from the leaf blower and set it on a table.
15. Place the metal part of a tape measure at one end of the pipe elbow. Measure the distance in the x-direction from that position to the other end where the paper will fall out (the distance to the left that the paper will travel).
16. Place the metal part of a tape measure at one end of the pipe elbow and measure the distance in the y-direction to the other end (the distance forward that the paper will travel).
17. Add the horizontal and vertical distances and record that value under "Total Distance Traveled" for Activity 8.

Component 5: Results/Conclusion

Testing Results:

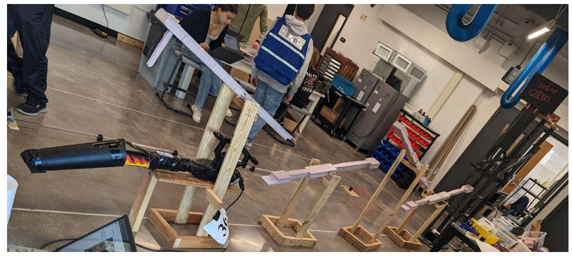


Figure 31(left): The design setup before test

Figure 32(middle): The design after successful run

Figure 33(right): The final design before JPL competition

Criteria/Benchmark	Description of data needed	Quantitative or qualitative	Pass or Fail?
Time to complete seven activities after single activation	Time trials performed testing the entire device	Quantitative	Yes
Time to set up device in under 3 minutes	Duration of device set-up, ensure that time is under 3 minutes (Yes or No)	Qualitative	Yes
Device fits within 2x1 meter starting area	Approximate dimensions of final device, ensure that the data meets benchmark (Yes or No)	Qualitative	Yes
No part of device moves out of set up area	Dimensions of final device in action, ensure that the data meets benchmark (Yes or No)	Qualitative	Yes
Device uses three different energy sources	Energy sources utilized in final device, ensure that design meets benchmark (Yes or No)	Qualitative	Yes
Each activity after the initial action activates the subsequent activity	Ensure energy of each activity is generated from the previous one (Yes or No)	Qualitative	Yes
Device has the official entry number on at least two sides of the device with 3 inch high numbers or larger	Device has entry number in on two sides with 3 inch high numbers (Yes or No)	Qualitative	Yes
Estimated maximum velocity for each activity is below 25 feet per second	Maximum velocity for each activity	Quantitative	Yes

activity is below 6 pound-feet per second	Product of Weight and Maximum Velocity for each activity	Quantitative	Yes
Each activity travels at least 15 inches	Distance each activity travels horizontally, vertically, or both.	Quantitative	Yes
Table of Activities is completed before check-in	Table of Activities is completed and ready for check-in (Yes or No)	Qualitative	Yes
Device is initiated only by single action provided by contestant	How much human energy is exerted after initial action, ensure than none is used (Yes or No)	Qualitative	Yes

Set Up:

Criteria/Benchmark	Successful	Time (Minutes)
Trial 1	**Yes**	**2:43**
Trial 2	**Yes**	**2:41**
Trial 3	**Yes**	**2:29**

Device Test:

Criteria/Benchmark	Successful	Time (Seconds)
Trial 1	**Yes**	**1.93**
Trial 2	**Yes**	**2.20**
Trial 3	**Yes**	**2.13**
Trial 4	**Yes**	**2.34**

Measurement Procedure:

Criteria/Benchmark	Length longer than 15in
Activity 1	**pass**
Activity 2	**pass**
Activity 3	**pass**
Activity 4	**pass**

Activity 5	pass
Activity 6	pass
Activity 7	pass
Activity 8	pass

Leaf Blower Velocity Calculations Procedure:

Criteria/Benchmark	Successful (Less than 25 m/s)	Velocity (ft/s)
Trial 1	Yes	10.43
Trial 2	Yes	11.04
Trial 3	Yes	10.23

Test Reflection: The device was successful for all of our test runs. One problem we noticed was the varying ranges of time. The time variation was caused by inconsistencies in the way the ball was striking the first teeter totter and in the way the teeter totters were striking each other. We were able to set the device up in the given time. All of our activities were greater than fifteen inches, and we did not go over 6 pound feet per second.

Prototype Evaluation:

1. Was the design a success?

   Based on feedback from teachers and peers, our design was successful. All parts of our design functioned properly after several tweaks. At first we were having many issues, especially with the connection point between activities 6 and 7 not functioning properly(figure 27). We also had issues with the efficiency of the teeter totters(figure 28), which was fixed using ball bearings for stabilization and speed. In testing, the design has worked consistently well. The device test table shows that our design worked with times between 1.9 to 2.4 seconds. The testing section also shows how our device followed all the criteria in the rule book. We were also able to consistently set the device up in the three minutes. The success of our device was highlighted by the fact we finished in the top ten teams of the competition.

   The most obvious fault in our device was the build quality. The teeter totter bases in figure 26 were not built very well, leading to them being unstable. The table used for the ball drop shown in figure 25 was also built poorly. The table would shake if handled improperly. This could result in the ball missing the first teeter totter. The poor build quality meant it was important to set up and activate the device properly.

2. Do the results reflect a problem with the materials used for the prototype?

The results do reflect a problem with the materials used. Our design needs to be lined up perfectly for it to work at maximum efficiency. The large table with the spring has poor build quality which causes it to shake when not handled correctly. The shaking can cause the falling ball to miss the teeter totter.

3. Do the results reflect a problem with the quality of the building process of the prototype?

The results reflect a lack of quality in the building process. Our building quality suffered because we were running out of time to finish the build. The large table holding activity one and two is the most obvious example of poor build quality. We had an issue with the spring not connecting fully with the ball, and we had an issue with the table wobbling. To solve the first issue we have to make sure the ball is in the correct position before activating the design. To solve the table from shaking we weighed the table down so it would be more stable. Another example of poor build quality is the bases of our teeter totters. The bases are not level at the bottom, and they are crooked. This issue is solved by making sure the teeter totters are lined up and not the bases.

4. Do the results reflect a problem with the design of the prototype?

Although there were issues that required solutions none of them were inherent to the design. The design we chose certainly restricted the speed of the device, but every design has a ceiling. Our results reflected our design choices, but these results were not negative.