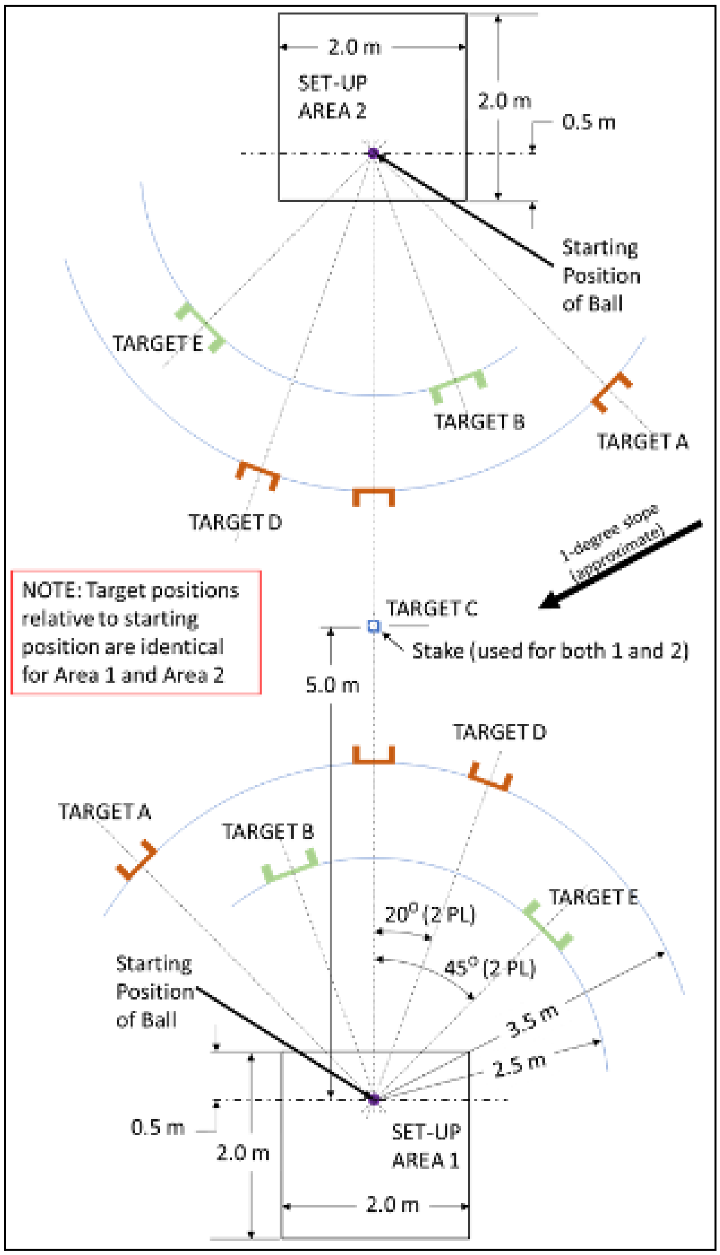
Ocean's 1011/XI/B

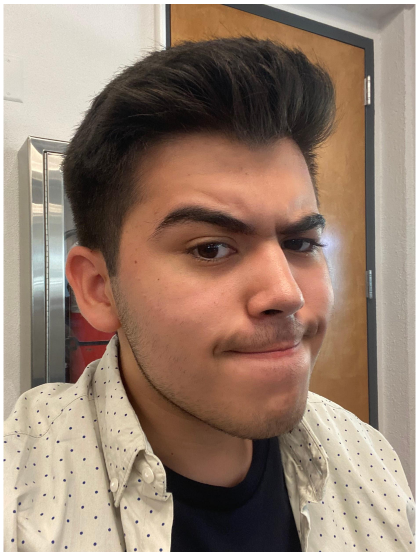
Danny Chmaytelli, Alexa Duffy, Aidan Hernandez, Joshua Kim-Pearson, Aiden Lee, Francisco Martinez Devis, Matthew McAuliffe, Dylan Neumeyer, Anthony Sugars

JPL Invention Challenge
"Sticky Wicket"



Biographies

Name & Picture	Bio
 **Danny Chmaytelli** dsc@smmk12.org www.samohiengineering.com	Danny graduated from Lincoln Middle School in 2019 and is currently a senior at Santa Monica High School. Through various classes and extracurricular activities, Danny has discovered his love for engineering. As Science Bowl team captain, Danny leads a team in extensively studying college-level STEM subjects. Danny has earned second place and third place at the JPL Regional Science Bowl in 2020 and 2021. Using his knowledge of physics and math, Danny has been a research associate at the UCLA Aerospace Engineering Department for the last year. He assists in research on propulsion systems for future hybrid electric aircraft. Based on his leadership and community service, Danny earned the Junior Male Student of the Year award in June 2022. This year, he is a valedictorian candidate and hopes to study Aerospace Engineering at MIT or UC Berkeley. Outside of school, Danny enjoys planespotting, listening to Dua Lipa, reading Tom Clancy novels, and baking cakes!
 **Alexa Duffy** avd@smmk12.org www.samohiengineering.com	Alexa Duffy is currently a senior at Santa Monica High School. She graduated Lincoln Middle School in 2019 and will graduate high school in 2023. Through various school clubs and outside camps, Alexa has found a love for engineering and math-related subjects. During freshman year of highschool, Alexa joined PLTW (Project Lead The Way). Here, she was able to explore general design concepts, electric circuitry, and programming. Outside of engineering, Alexa enjoys doodling, animating, reading dystopian novels, and other various creative outlets.



Aidan Hernandez

aah7@smmk12.org
www.samohiengineering.com

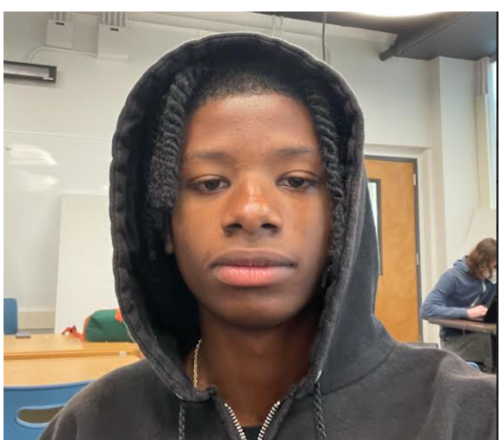
Aidan attended Lincoln Middle School and graduated in 2019. He then went to Santa Monica High School where he is a Senior now. In his youth, Aidan found a growing interest in the technology around him. However, it wouldn't be until his time at SAMOHI that he was truly able to explore and entertain this passion. He was able to go through the engineering program there, named PLTW (Project Lead The Way). Using the skills from this class, at home and on his own, he taught himself how to put together and set up desktop computers. Aside from engineering, some of his hobbies include tinkering with Legos, playing video games, and writing stories/characters.

Joshua Kim-Pearson

jyk@smmk12.org
www.samohiengineering.com

Joshua is a 12th grader in Santa Monica High School and will graduate in 2023. He found his love in engineering from his 8th grade science teacher who encouraged him to apply to PLTW after seeing his creativity. During highschool he went into the computer science class in PLTW. He has always loved problem solving and coming up with new ideas. Joshua loves sharing his ideas with people to see if they can help or give their own input.

 **Aiden Lee** ajl3@smmk12.org www.samohiengineering.com	Aiden went to Lincoln Middle School and discovered his love for engineering through the Botball club, which he attended for three years, and returned to coach during his 11th grade summer. During his time, he received three awards. Aiden loves problem solving, video games, and violin.
 **Francisco Martinez Devis** fm2@smmk12.org www.samohiengineering.com	Francisco Martinez Devis is a visionary, an artist, a genius. As someone who sees the intricacies of engineering, he inspires masterful creations. Some of his creations include a GPS and a barometer during distance learning, and he is currently working on many other engineering projects. A virtuoso of science and math, he prefers to be addressed as your majesty. Not only does he bring hope to the future of engineering, but he brings honor, musicianship and prestige to his school.

 **Matthew McAuliffe** mjm2@smmk12.org www.samohiengineering.com	Matthew McAuliffe is a Senior at Santa Monica High School set to graduate in 2023. He found an interest in Engineering early on through his appreciation of cars and buildings as a kid. Through the Engineering program he learned more about the several fields of engineering. Matthew has taken several classes at Santa Monica College throughout High School, focusing on Architecture and Physics, learning how to communicate his ideas effectively into blueprints and plans.
 **Dylan Neumeyer** dkn@smmk12.org www.samohiengineering.com	Dylan Neumeyer is a Senior at Santa Monica High School and will hopefully graduate in July 2023. This is Dylan's fourth year in the PLTW program at SAMOHI, having already taken IED, Aerospace, and Digital Electronics. He was on the botball robotics team at Lincoln Middle School for two years competing in competitions similar to the JPL competition. He is currently on the SAMOHI Theatre council after doing two productions and currently working on a third that will open at the end of October. Dylan will be on the design team for this competition.
 **Anthony Sugars** ads3@smmk12.org www.samohiengineering.com	Anthony is a senior at Santa Monica High School who graduated from John Adams Middle School. He became fascinated with engineering through his love for computers and mechanics. Introduced to engineering in the 7th grade, in coding and 3D modeling Anthony found his true passion. He is currently enrolled in Conceptual Physics 12 at Santa Monica College. He is now competing in his first JPL competition for PLTW, as he's been a part of the PLTW program for all four years of his high school career. He is inspired to go into some type of software engineering because he loves computers and technology.

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Component 1: Rules/Research

Problem Statement

The goal is to design a device that hits five balls into five targets (each target in a different location) in order to get the most points possible.

Rules/Considerations

1) The ball must be hit by a force.

Figure 1: A ball is being hit by a hammer.

2) The targets (wickets) are worth different points based on difficulty. There are five placed at different angles and distances from the machine.
    - Target A has a point value of 20 points.
    - Target B has a point value of 10 points.
    - Target C has a point value of 30 points.
    - Target D has a point value of 20 points.
    - Target E has a point value of 10 points.

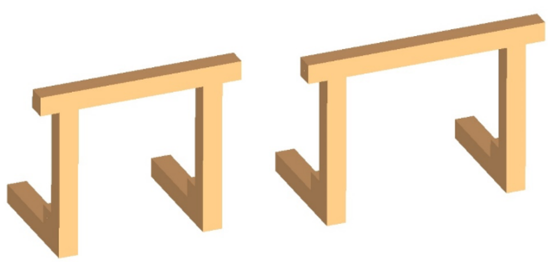


Figure 2: An example of the wickets that will be used.

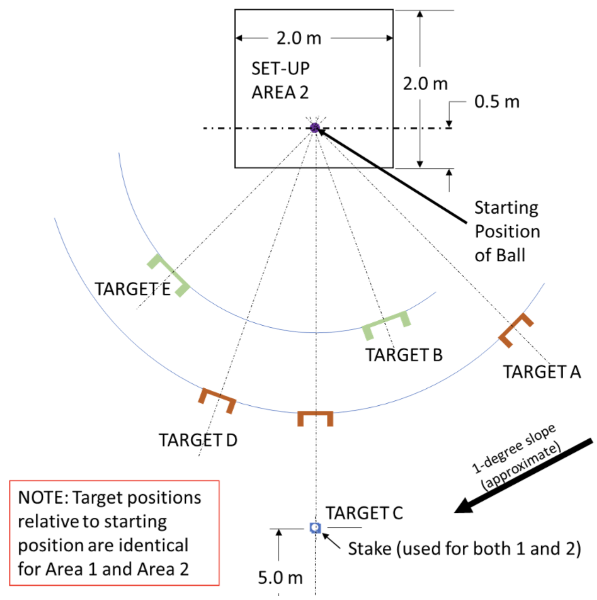


Figure 3: A diagram of the set-up area and targets.

3) The balls have score multiplier values.
   - Blue - multiplier value of 3
   - Red - multiplier value of 2
   - Yellow - multiplier value of 2
   - Green - multiplier value of 1
   - Orange - multiplier value of 1

Figure 4: The five balls that will be used in the competition (purple is not included).

4) The device can be realigned between shooting events.

5) Each event must be initiated by a single action.

6) Everything must be completed in 60 seconds or less.

Figure 5: A 60 second timer.

7) There will be a ninety student team regional elimination round with the top five teams being allowed to compete in the finals. Furthermore, the top ten teams between both regional competitions will also be invited.

8) In case of bad weather the event will be held indoors.

9) Only one ball may be in motion at a time.

10) Only safe energy sources are allowed.

11) Devices may not be significantly changed after the elimination round to prevent plagiarism.

Initial Research

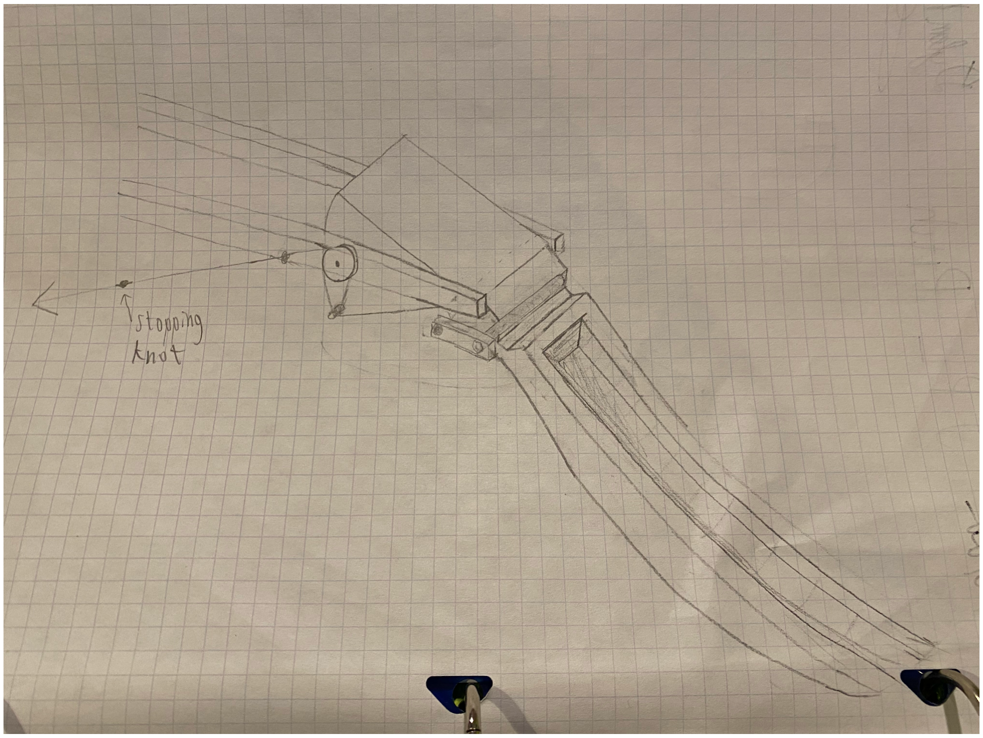


Figure 6: A wedge with a stopper arm to hold the ball that is rotated by a pulley system to launch down the ramp. The ramp and loading ramp on the left both have guide rails on either side instead of being flat to keep the balls straight. The loading ramp is there to allow each ball to be loaded onto the wedge seamlessly.

- Dylan Neumeyer

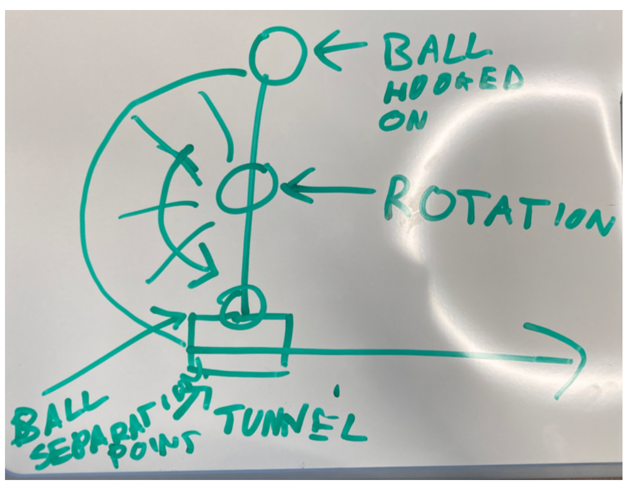


Figure 7: A ball is hooked onto a rotating arm. The ball disconnects from the rod and is shot out of the tunnel.

- Matthew McAuliffe

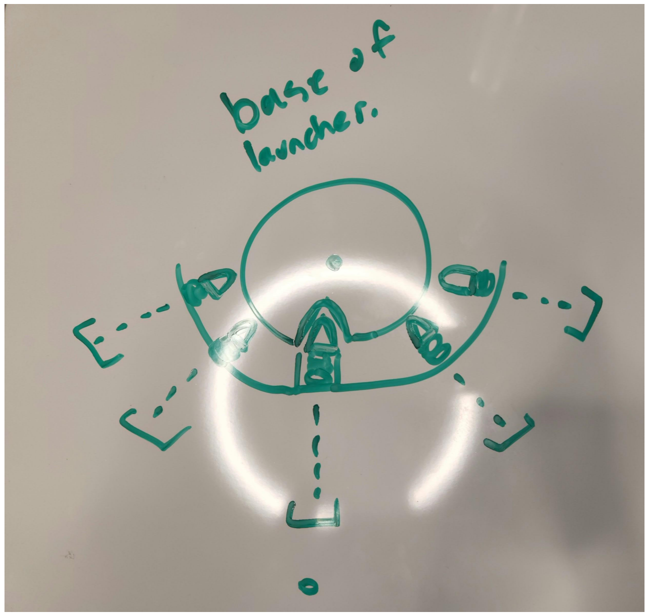


Figure 8: A design for a swivel system at the bottom of the device that could lock in pegs at the right spots for aiming the balls.

- Joshua Kim-Pearson

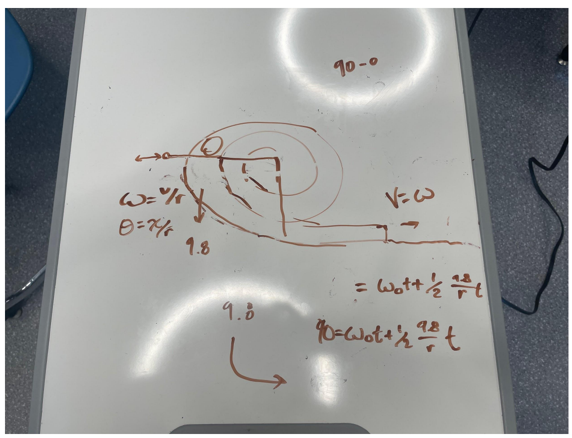


Figure 9: Instead of a rotation trebuchet style launcher, this design uses a set of rotating bands that create friction against the balls in the x direction.

- Francisco Martinez

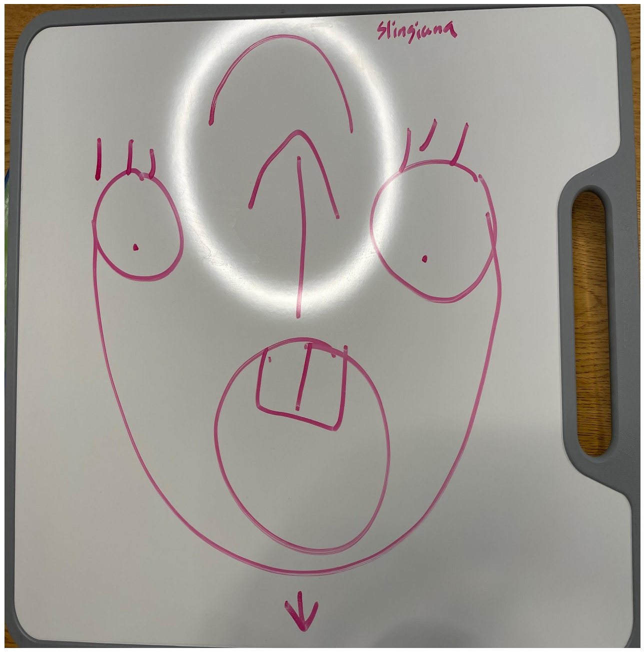


Figure 10: This is a super slingshot that uses the user's pulling force to create an accelerating action sending the ball in a straight line for a specific amount of time. The slingshot can also be angled in a way that can easily be aimed in a specific direction.

- Anthony Sugars

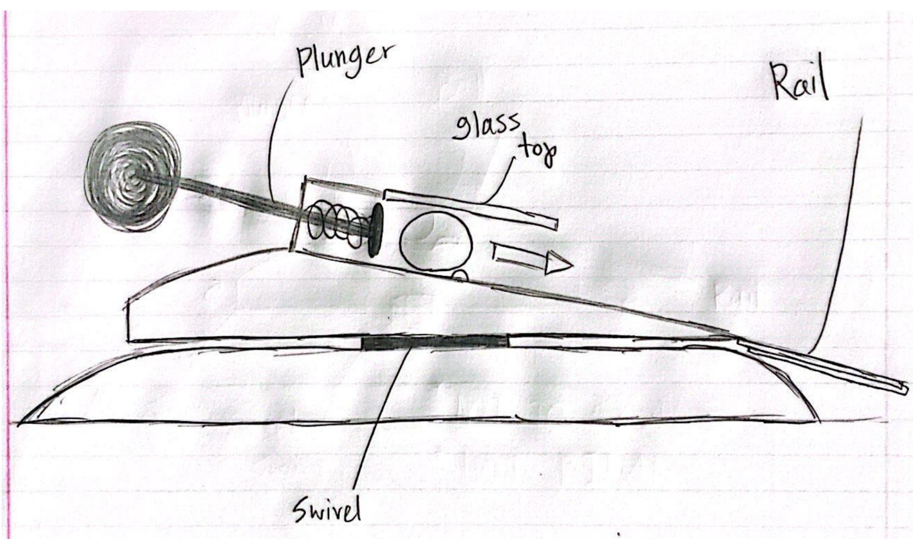


Figure 11: A pinball based design with a swivel base and rail system meant to launch the ball in any given direction with maximum speed, and maximum accuracy. The swivel base allows for the machine to be easily directed towards the goal, and locked in place.

- Aidan Hernandez

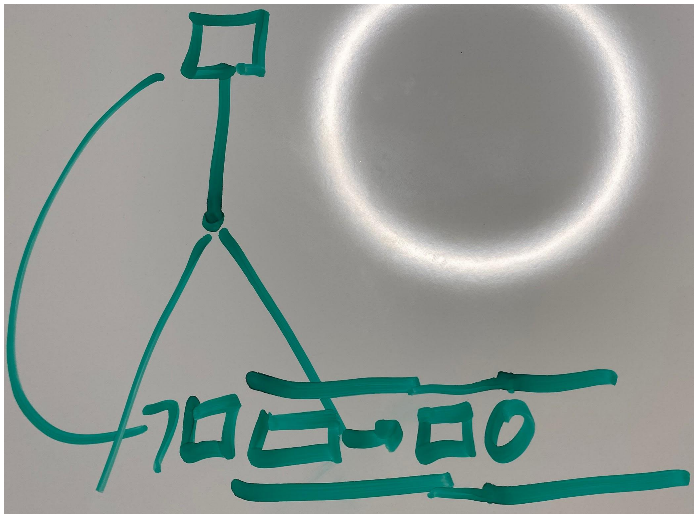


Figure 12: A hammer swings on an axle hitting a block horizontally through a rail, hitting another ball and transferring only its forward momentum.

- Aiden Lee

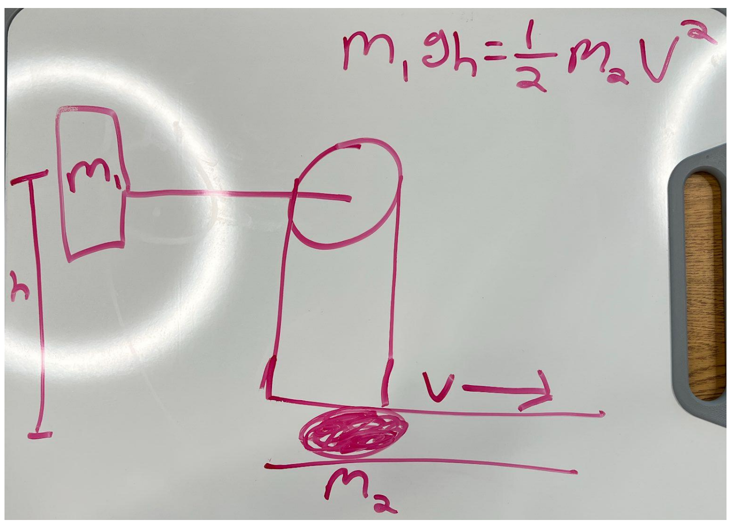


Figure 13: A hammer is held at a certain height h by an axle. When triggered, the mechanism releases the hammer with the mass m1, swings down and strikes the ball. The gravitational potential energy of the hammer is transferred to the kinetic energy of the ball, causing the ball of mass m2 to travel with a velocity v. The appropriate energy conservation equation is shown in the top left corner of the figure.

- Danny Chmaytelli

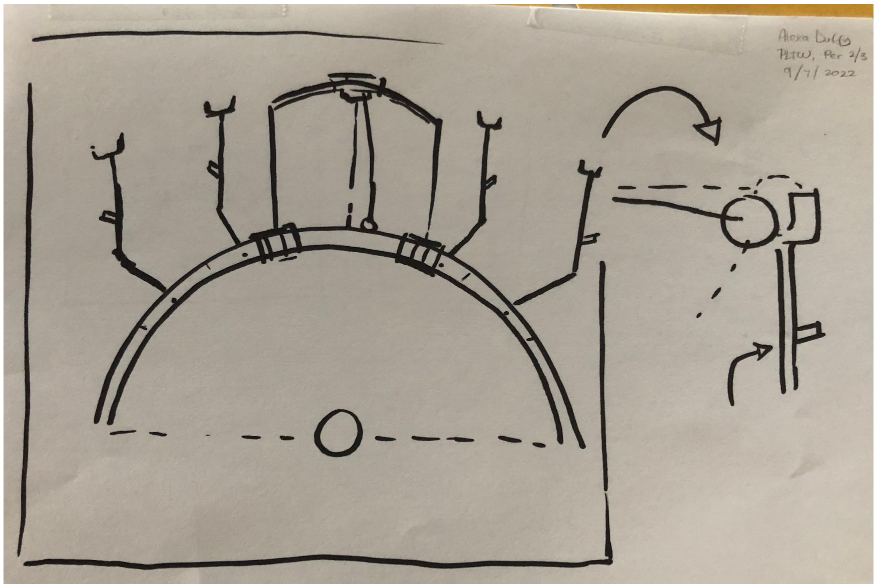


Figure 14: A stand holds up a hammer which turns on a swivel device. The hammer has five resting spots attached underneath the swivel, which, if pulled, releases the hammer and allows it to hit the ball.

- Alexa Duffy

Conclusion

The device is in between two wooden boards. A hammer is attached inside, which swings down and strikes the ball. The ball goes through metal rails (rods) which are curved inwards, but with space at the top so that the hammer can swing through. The device is set up on top of a lazy susan, which locks in place through a peg and hole mechanism. Going forward, the plan is to gather the materials and build the device. In addition, a second hammer and gear system may be included to increase the velocity of the ball upon launch. The rail system will likely require refinement as well, including an adjustment of the angle and an addition of a laser pointer to improve accuracy.

Component 2: Design

Initial Design Concept

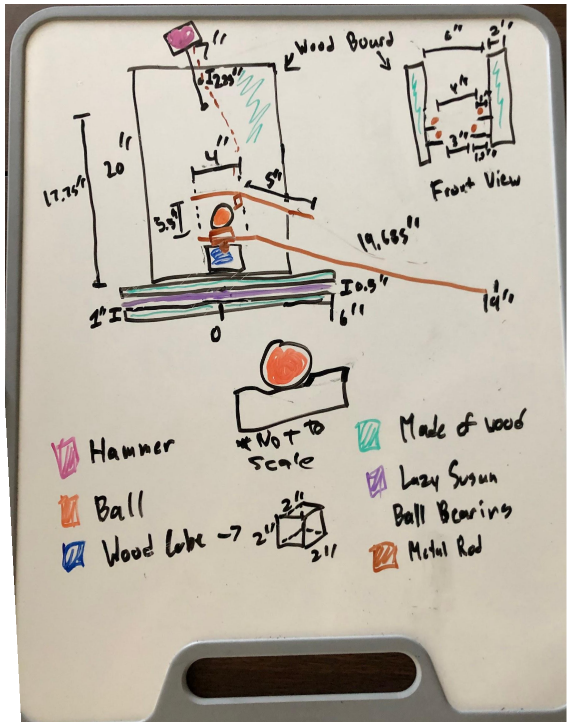


Figure 15: The initial design with measurements and color coded component materials. There is a large cross-section looking through the right support plank and into the central mechanism. On the top right, there is a view of the front without the hammer to show the measurements of the rails that will guide the ball. Also shown is the basic design developed to hold the ball in place before it is struck by the hammer.

Revised Design Concept

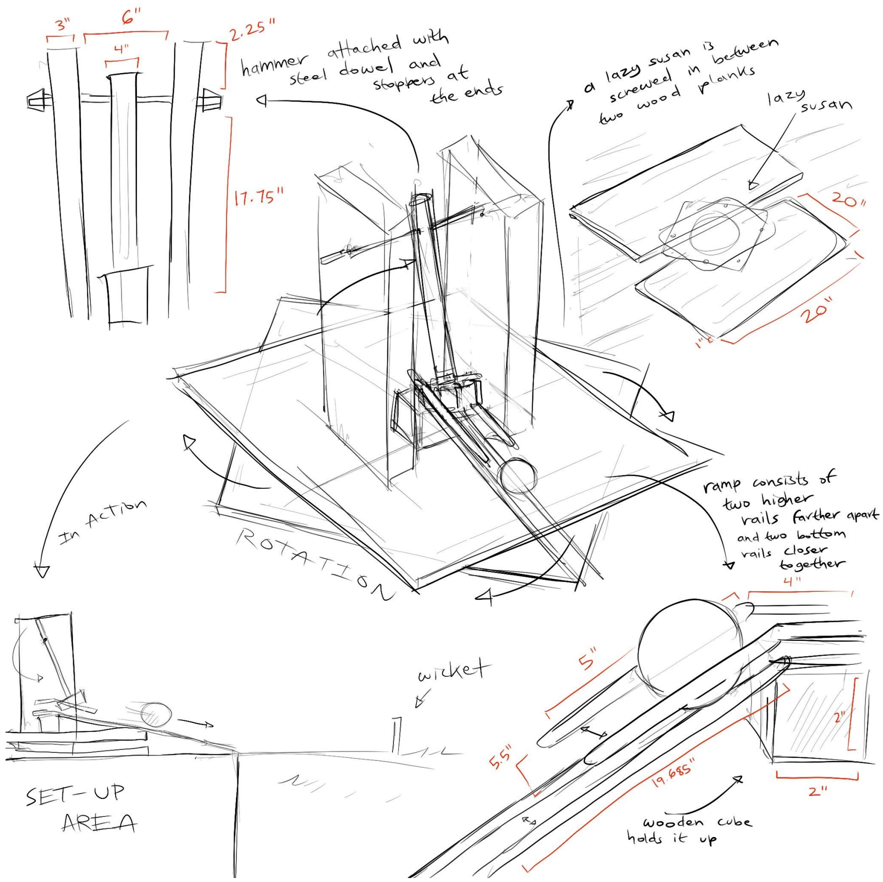


Figure 16: More detailed revision with a multitude of viewpoints and measurements. In the center is a complete view of the device. In the bottom right, there is a detailed close up on the ball with its guide rails and the starting point block. In the bottom left there is a general cross section to reveal the mechanics hidden behind the wood planks. The top left has a front view of just the hammer with its respective measurements. In the top right there is an exploded-view drawing of the lazy susan swivel within the base.

*In the actual build, the hammer swivel was moved further back, and a second set of vertical wood boards was added to the device. A metal dowel was placed through the second set of vertical wood boards in order to keep the hammer in a locked position. The cube, which served as the ball's resting spot, was replaced with a 3D printed cylinder. In addition, horizontal wood planks were added to the base in order to keep the guiding rails strictly horizontal, instead of at an incline as seen in the above figure.

Prototype Design Model

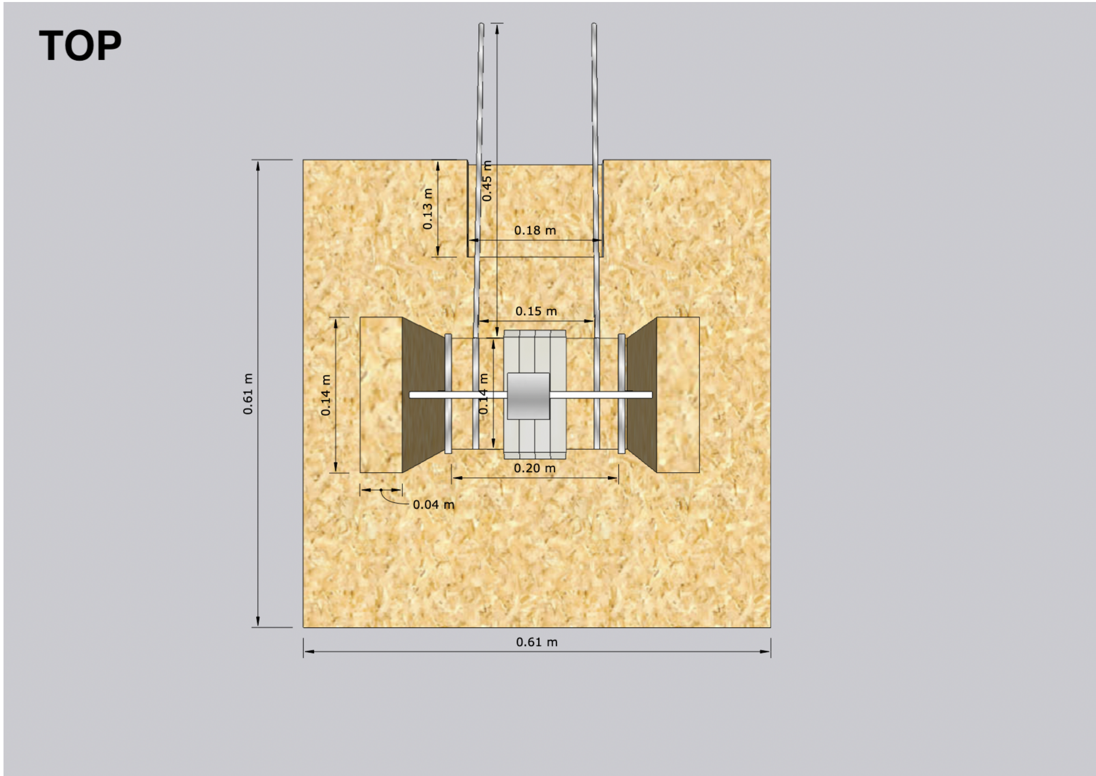


Figure 17: A top view of the 3D model in CAD (with dimensions labeled).

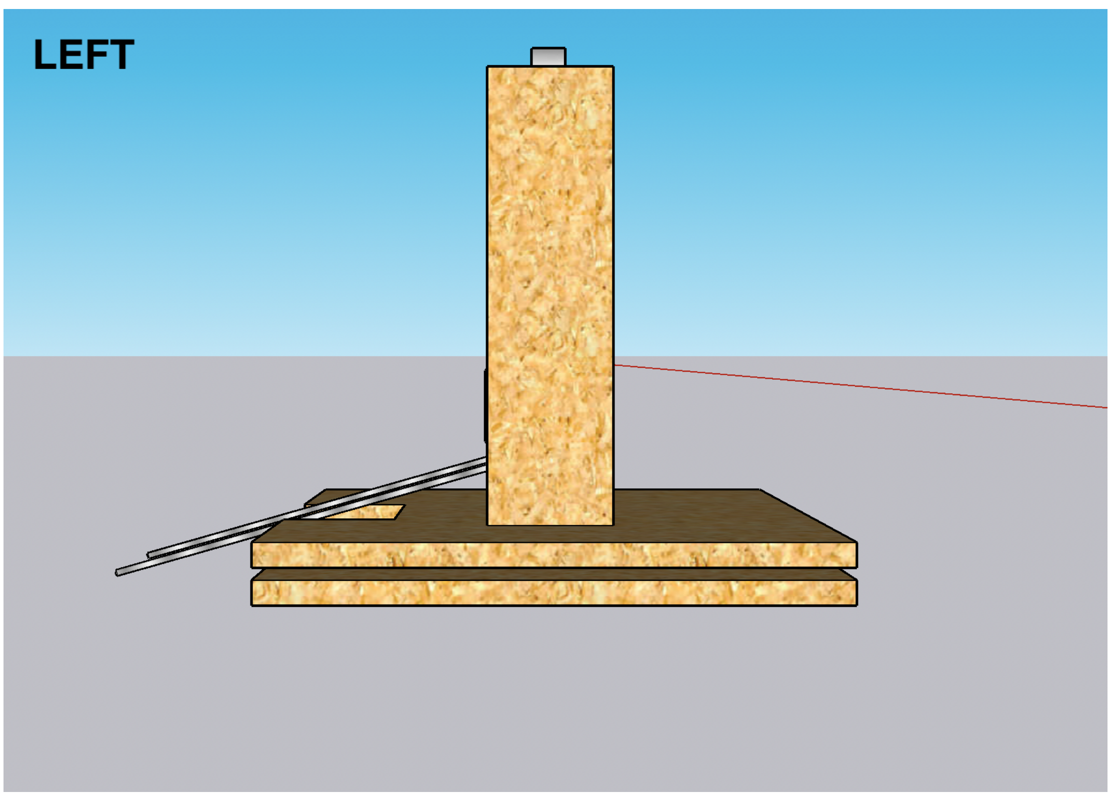


Figure 18: A left view of the 3D model in CAD.

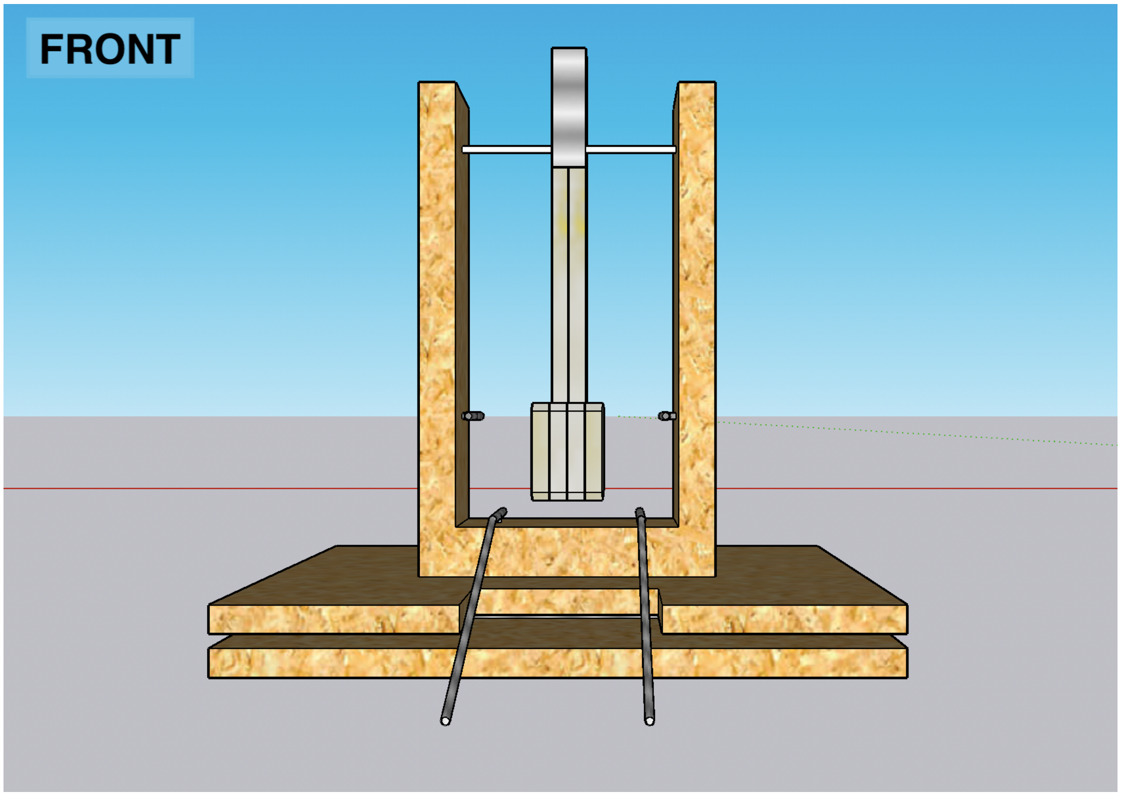


Figure 19: A front view of the 3D model in CAD (with dimensions labeled).

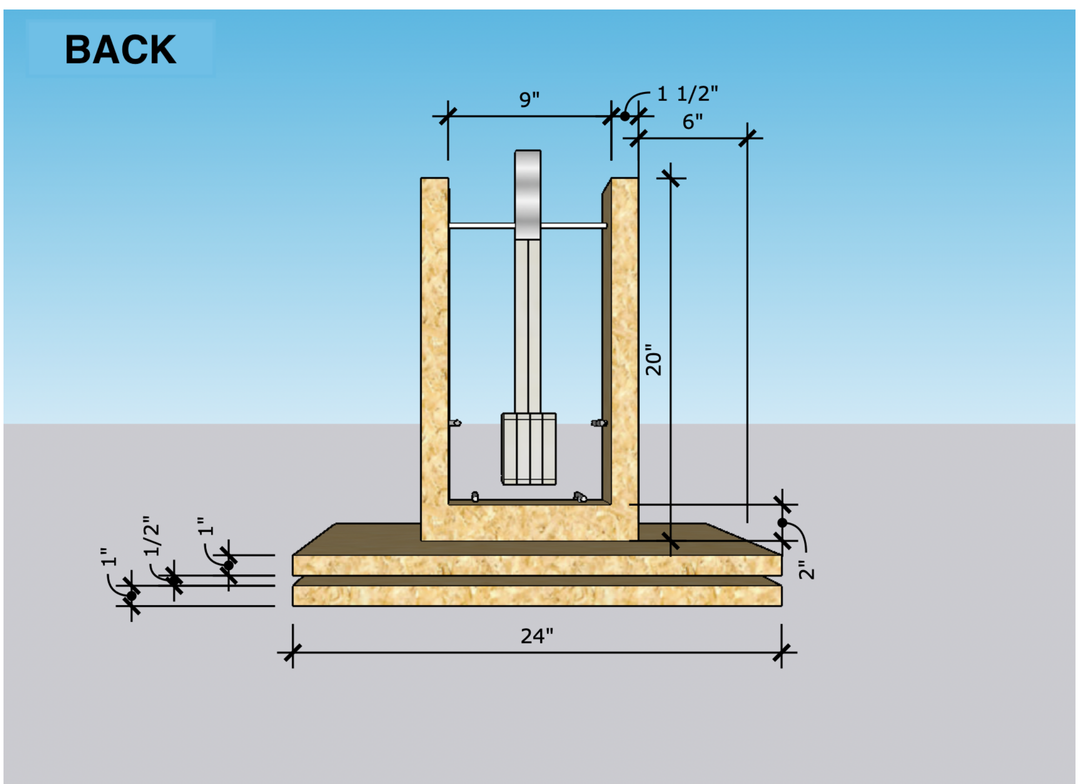


Figure 20: A back view of the 3D model in CAD.

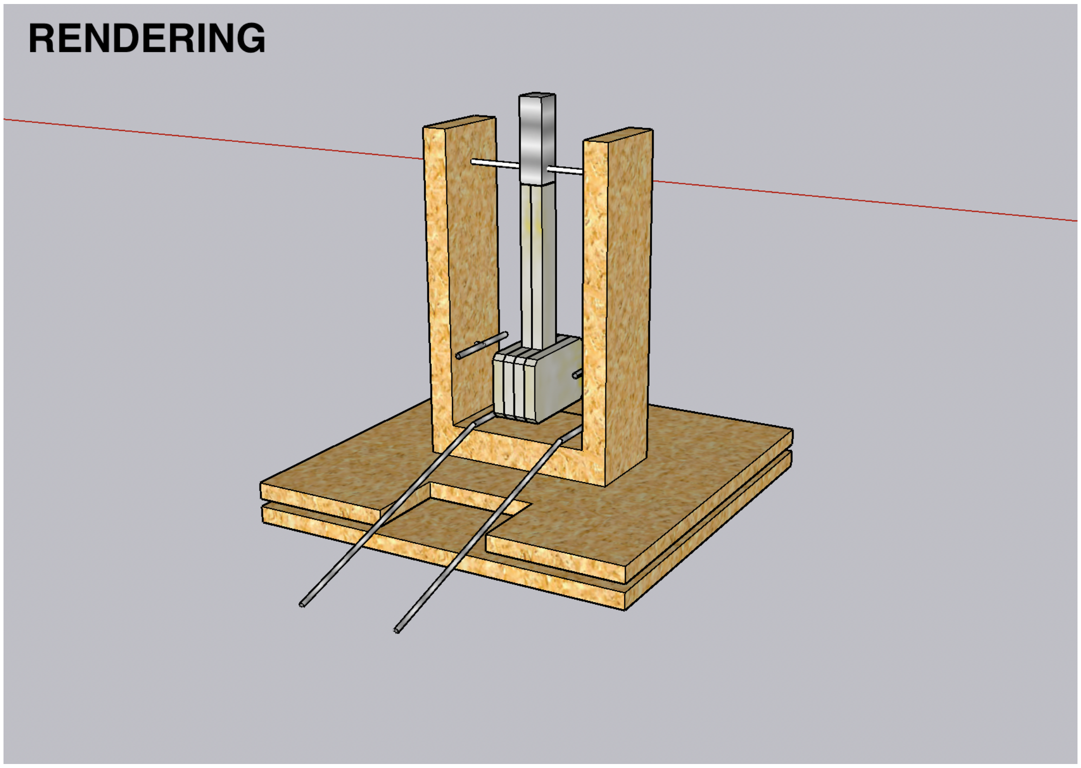
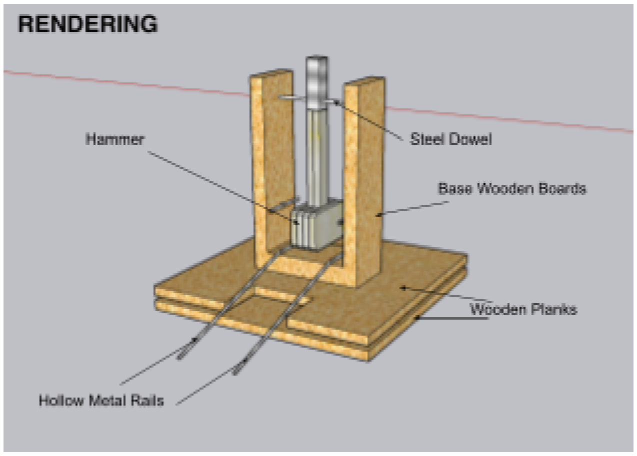


Figure 21: The 3D model in rendering.

*In the actual build, the hammer swivel was moved further back, and a second set of vertical wood boards was added to the device. A metal dowel was placed through the second set of vertical wood boards in order to keep the hammer in a locked position. The cube, which served as the ball's resting spot, was replaced with a 3D printed cylinder. In addition, horizontal wood planks were added to the base in order to keep the guiding rails strictly horizontal, instead of at an incline as seen in the above figure.



Part	Number Ordered	Cost per Part	Total Cost
6" wide 4 ft tall Wooden Plank	1	$9.92	$9.92
Hammer	1	$24.77	$24.77
Hollow Metal Rails	3	$7	$21
L Braces	1 (40 per pack)	$7	$7
Bearing	1	$6.99	$6.99
Base Wood Boards	1	$17.28	$17.28
Steel Dowel	1	$3.93	$3.93
Laser Pointer	1	$17.59	$17.59
			$108.48

Figure 22: The 3D model with parts labeled, alongside a column for cost.

Cost Analysis

Item	Link to Item	Number Ordered	Cost Per Item	Total Cost
6" wide 4 ft tall Wooden Plank	Plank	1	9.92	9.92
Hammer	Hammer	1	24.77	24.77
Hollow Metal Rails	Rails	3	7	21
L Braces	L Braces	1 (40 per pack)	7	7
Bearing	Bearing	1	6.99	6.99
Base wood boards	Plywood	1	17.28	17.28
Steel dowel	Dowel	1	3.93	3.93
Laser pointer	Laser Pointer	1	17.59	17.59
				108.48

Average general contractor makes 25.6 dollars per hour according to Indeed.com. There are around 4 people working on the device at a time. The device takes around 12 hours to build. Thus, labor cost = 25.6 x 4 x 12 = $1,228.80.

Labor Cost: $1,228.80
Material Cost: $108.48
Total Cost: $1,337.28

Equipment and Technology

Overview:

- Marker
- Saw
- Sander
- Drill press
- Screwdriver
- Level
- Protractor
- Tape Measure

<u>Base:</u>

The marker (for marking points) and tape measure (for dimensions) are used on the large base wooden piece to divide it into two equal parts, so that the piece ends up as two flat planks. A saw is then used to actually cut the piece. Afterwards, the tape measure and marker are used to mark where the two base planks should be drilled. A drill is then used to actually drill the holes. Finally, a screwdriver is used to secure the lazy susan in between the two wood planks, and a level is used to make sure the base is level.

<u>Hammer/Securing board:</u>

First, the marker and tape measure are used to draw out where the vertical wood boards should lie on the base piece. L braces are then used on either side of the vertical boards to attach the boards to the piece. The braces are placed at the bottom of the boards, and attached using a screwdriver. Then, a protractor and level are used to make sure that the vertical boards are perfectly upright and pointing in the same direction. The marker and tape measure are then used again to mark where on the vertical boards to drill a hole so that a dowel can be placed. Similarly, the marker and tape measure are used to mark where to drill on the hammer. The drill is then used to drill through the marked holes on the vertical boards and the hammer, and a wooden dowel is placed through each of the holes. After that, a second dowel is cut, measured, and placed above the hammer in order to secure it in place. Finally, everything is checked with a level and protractor so that the device is straight and orderly.

<u>Rails:</u>

There are three long rails being used. Two of the rails are used in their original form. The third is cut in half, so that it becomes two smaller rails. The longer rails are lined up so that they form the lower track that the ball goes across on. The shorter rails are lined up so that the distance between the two shorter rails is longer than the distance between the two longer rails. This is so that the shorter rails form the upper guiding rails of the ball, located around the ball instead of under them. All of the rails start out flat, but the longer rails are eventually bent so that they can slope downwards. The rails are sloped in a way that causes the least resulting bounce in the ball once it leaves the result.

Component 3: Physics Analysis

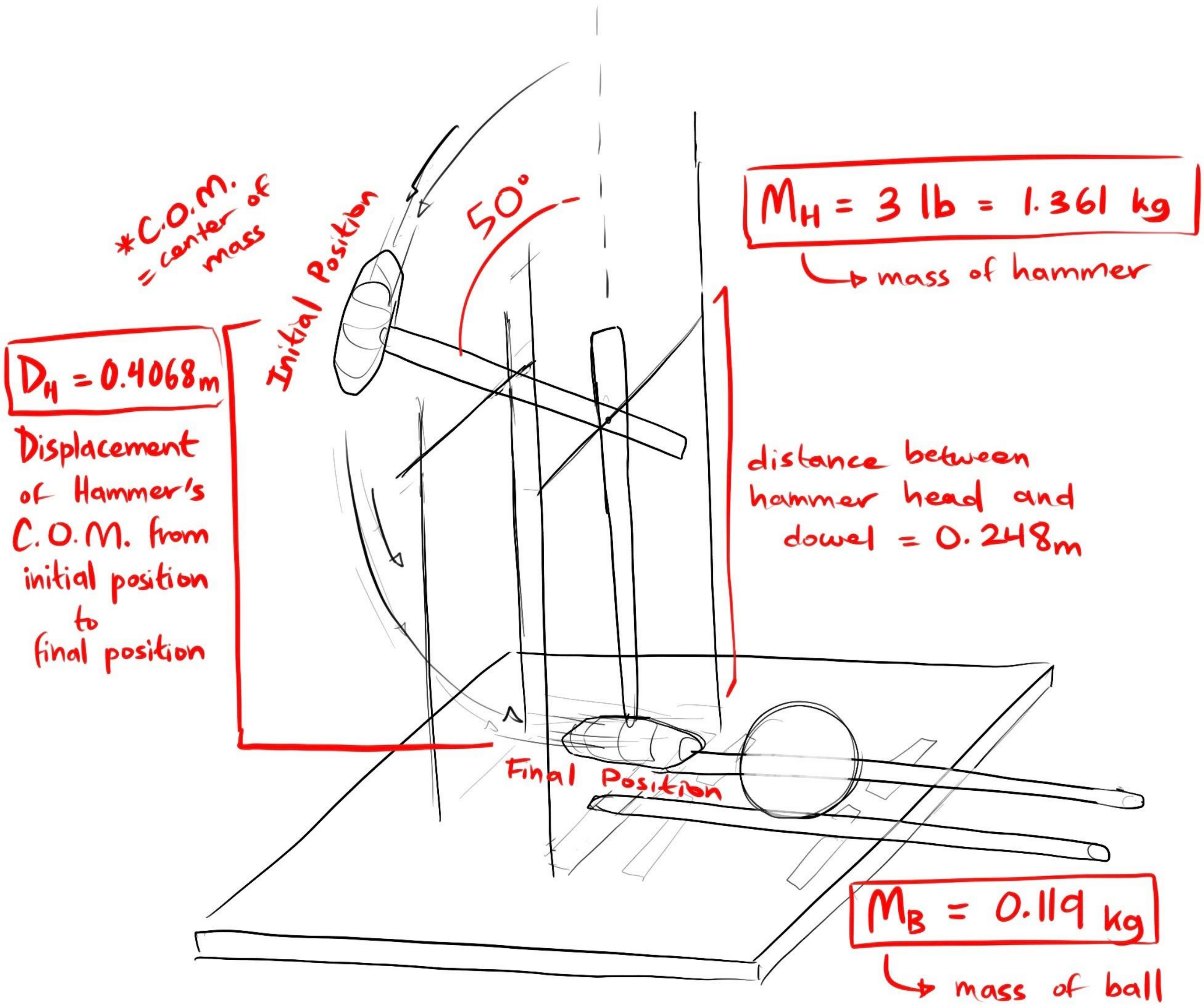


Figure 23: A technical diagram of the device, showing the geometry of the hammer as it swings from its initial position to its final position.

Equations

The hammer, of mass M_H, is initially at rest above the system. As shown in Figure 23, the angle between the hammer and the vertical is 50°, and the vertical displacement between the initial position of the hammer's center of mass and the position of the center of mass during the hammer's collision with the ball is D_H. Once the hammer swings through its initial position and collides with the ball at the bottom of the system, its velocity immediately before the collision is given by V_H. According to the Law of Conservation of Energy:

$$(M_H)(g)(D_H) = (\frac{1}{2})(M_H)(V_H^2) \tag{1}$$

After the hammer swings through, it collides inelastically with the ball, of mass M_B. In order to calculate the velocity of the ball immediately after the collision, V_B, the coefficient of restitution, COR, must be calculated for the collision between the hammer and the ball. When the ball is dropped from a height of 36 inches, H_i, the ball inelastically collides with the ground and rebounds to a height of 27.5 inches, H_f. This information, combined with the Law of Conservation of Energy, can be used to calculate the ratio between the velocity of the ball immediately after its collision with the ground, V_2, to the velocity of the ball immediately before its collision with the ground, V_1, which is equal to the COR:

$$(M_B)(g)(H_i) = (\frac{1}{2})(M_B)(V_1^2) \tag{2}$$

$$(M_B)(g)(H_f) = (\frac{1}{2})(M_B)(V_2^2) \tag{3}$$

Combining Equations 2 and 3 gets Equation 4:

$$\frac{(M_B)(g)(H_f)}{(M_B)(g)(H_i)} = \frac{(\frac{1}{2})(M_B)(V_2^2)}{(\frac{1}{2})(M_B)(V_1^2)} \tag{4}$$

$$COR = \frac{V_2}{V_1} = \sqrt{\frac{H_f}{H_i}} \tag{5}$$

The velocity at which the hammer and the ball travel away from each other is the velocity of recession, V_R, which can be found using the COR and the velocity of approach, V_H, which is the velocity of the hammer immediately before the collision.

$$V_R = (V_H)(COR) \tag{6}$$

The velocity of the ball after the collision, V_B, and the velocity of the hammer after the collision, V_{H2}, can be related using the velocity of recession, V_R.

$$V_{H2} = V_B - V_R \tag{7}$$

The Law of Conservation of Momentum can be used to solve for V_B.

$$(M_H)(V_H) = (M_H)(V_{H2}) + (M_B)(V_B) \tag{8}$$

Taking Equation 7 and putting it into Equation 8 yields:

$$(M_H)(V_H) = (M_H)(V_B - V_R) + (M_B)(V_B) \tag{9}$$

Equation 9 can be algebraically rewritten to solve for V_B.

$$V_B = \frac{(M_H)(V_H+V_R)}{(M_H+M_B)} \tag{10}$$

Theoretical Device Performance

$M_H = 1.361\ kg$

$M_B = 0.119\ kg$

In its initial position above the system, the hammer is 50° away from the vertical. The radius, or distance the hammer is away from the dowel (its axis of rotation) is 9.75 inches.

$D_H = (9.75\ +\ 9.75cos(50°))\ in\ =\ 16.017\ in$

$D_H = 0.4068\ m$

Plugging in the above values into Equation 1:

$V_H = \sqrt{(2)(g)(D_H)}$

$V_H = \sqrt{(2)(9.8\ m/s^2)(0.4068\ m)}$

$V_H = 2.824\ m/s$

Plugging in the initial and final bounce heights of the ball provided by JPL into Equation 5:

$COR = \frac{V_2}{V_1} = \sqrt{\frac{27.5}{36}} = 0.874$

Plugging in the COR into Equation 6:

$V_R = (2.824\ m/s)(0.874)$

$V_R = 2.468\ m/s$

Plugging in V_R into Equation 10 yields the value for V_B:

$V_B = \frac{(1.361\ kg)(2.824\ m/s+2.468\ m/s)}{(1.361\ kg+0.119\ kg)}\ =\ 4.866\ m/s$

Device Limitations

The maximum energy able to be stored by the device is the gravitational potential energy of the hammer if it was perfectly vertical. In reality, the hammer makes a 50° angle with the vertical. To calculate the change in gravitational potential energy of the hammer, the position of the hammer's center of mass relative to the axle was estimated. The calculations also do not account for the small height between the ball's initial position and the floor of the device because the height is so small which makes it negligible. To reduce the initial rotation of the ball, the hammer's center of mass is horizontally aligned with the ball's center of mass. This minimizes the rotation of the ball and thus the ball will have insignificant rotational kinetic energy, so the calculations assume that the kinetic energy of the ball is only translational for the brief moment after being struck. The calculations do not account for the high amount of friction between the hammer and the axle, which will reduce the amount of kinetic energy that the hammer is transferring to the ball. After the collision with the hammer, the ball will encounter significant friction as it moves along the metal bars and across the ground, which will cause the ball to begin to roll. This will ultimately reduce the ball's translational velocity, and it will be lower than 4.866 m/s. However, this will not significantly affect the objective of getting the ball through the wickets. Also, the device's vertical wooden boards are quite thick in order to reduce the wobble of the device as a result of the swinging hammer's inertia.

Component 4: Build/Test

Build Progression

Phase 1: Measuring and Cutting

The device is primarily made out of wood, with the base consisting of two horizontal square wood boards with dimensions 24 inches by 24 inches by 0.5 inches. Two vertical wood boards with dimensions 1.5 inches by 5.5 inches by 20 inches, are placed on top of the base. The base planks and the vertical wood boards were cut from 2 large pieces of wood using a buzz saw, and measured using a tape measure. A horizontal plank of wood with dimensions 18 inches by 3.5 inches by 1.5 inches is placed on top of the vertical wood boards. The first two vertical boards hold the hammer's axle. A second pair of vertical wood boards are placed behind the first pair of vertical boards, holding the hammer in place so that it's raised at an angle before its release. The second pair of vertical boards are slightly shorter than the first pair, with dimensions 1.5 inches by 3.5 inches by 18 inches. Both the horizontal plank, and the second pair of vertical boards were measured using a tape measure and cut using a hand-saw. 19 inch long metal rails are placed in between the first two vertical wooden boards and extend out of the device. The rails are placed on top of 5 small horizontal wood pieces. The wooden piece at the center has dimensions 5.5 inches by 1 inch by 0.5 inches, and the rest of the pieces, laid out in pairs of two in front of the first wooden piece, each have dimensions 2 inches by 1 inch by 0.5 inches. All of the pieces were measured using a tape measure and cut using a hand saw. Lastly, a 3D printed cylinder is placed in between the rails in order to keep the ball in place before it's hit by the hammer. The cylinder is 0.7 inches tall, 0.1 inches thick, and has a 2 inch diameter.

Figure 24: A close-up shot of the cutting of the device's vertical wood boards.

Phase 2: Building

First, the wooden base pieces were attached to the top and bottom of a lazy susan with dimensions 6 inches by 6 inches by 0.5 inches, using a screwdriver. Then, the first pair of vertical wood boards were attached to the base, using L braces, screws, and a screwdriver. Two holes were drilled 9.75 inches up the boards in order to fit a 12 inch long metal dowel through. The dowel acts as the hammer's axle. Two rails were then placed on the base, on top of 3 sets of horizontal wood pieces each 0.5 inches tall, so that the rails could be raised slightly above the base. The rails were placed 2.25 inches apart and fixed to the horizontal pieces using velcro. A 3D printed cylinder was placed in between the second set of horizontal pieces, at the exact center of the device. This is so the ball has an initial position to rest on. Afterwards, a second pair of vertical wood boards were attached to the device 3 inches behind the first pair of vertical wood boards, and 0.5 inches from the far end of the device, in order to hold the hammer up at an initial angle. The boards were attached using L braces, screws, and a screwdriver. A dowel was then placed into the boards at a slightly higher height than the dowel in the first pair of boards, so that the hammer is raised 130 degrees from its down position. Finally, an 18 inch long horizontal wood plank was placed on top of the first pair of vertical boards, and attached using velcro.

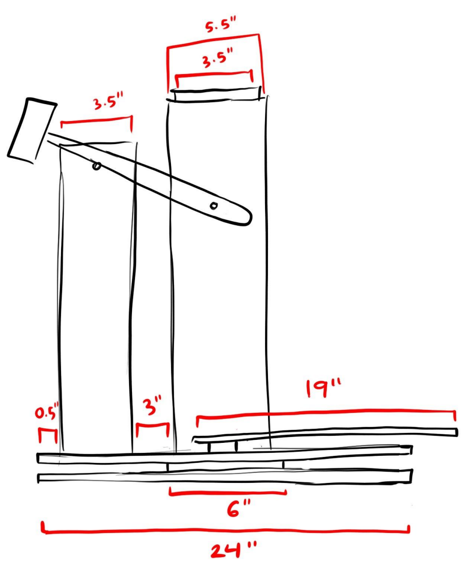


Figure 25: Technical diagram showing the device from the side. Horizontal dimensions are recorded in inches.

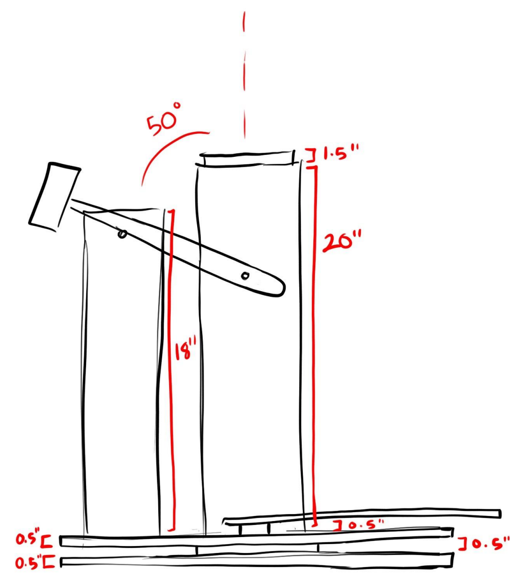


Figure 26: Technical diagram showing the device from the side. Vertical dimensions are recorded in inches.

Figure 27: The lazy susan is being screwed onto one of the base wooden pieces.

Figure 28: The device with the vertical wood boards attached to the base. The hammer has not been attached yet. Placement of the rails is being experimented with.

Figure 29: The second pair of vertical wooden boards is being attached to the device using L braces, screws, and a screwdriver.

<u>Phase 3: Refinement</u>

In this phase, the device was refined in order to improve its accuracy and consistency. To achieve this goal, the device was tested multiple times through trials that simulate the actual competition, as defined by parameters in the official JPL rules. The device was placed on flat ground. A wicket was then placed 3.5 meters away from the device, and a stand-in target was placed 1.5 meters behind the wicket (5 meters away from the device). After the device and wicket were placed, the shooting accuracy of the device was tested by launching the ball multiple times from the device and observing whether the ball would make it through the wicket and/or hit the target. The trials were recorded using a slow motion camera in order to capture the distance the ball would be from the center of the wicket as it passed through, as well as the distance the ball would be from the target. The first few trials showed that the ball would move more to the left than expected. To fix this, the two vertical wood boards holding the hammer's axle were reattached to the base, moving both the hammer and ball backwards in the process. In addition, the metal rails were fixed to the 3 sets of horizontal wood pieces using screws and metal scrap instead of velcro, in order to make the rails more secure. Lastly, the ball's position was adjusted so that its direction would be more influenced by the rails, and a laser pointer was also added to ensure the device lines up with the edges of the wickets upon aiming. As an additional measure to make the device more visually appealing, both sets of vertical wood boards as well as the top base plank were painted gray. Also, a blue viking silhouette along with yellow diagonal stripes were painted on the second set of vertical wood boards.

Figure 30: Device is being set up for shooting accuracy. The wicket is placed the appropriate distance away from the device to mimic the actual competition.

Figure 31: The device's performance is being tested in an environment that mimics the actual competition. Team members practice aiming the device toward the targets with the help of a laser pointer, and releasing the hammer so that it strikes the ball.

Test Criteria

Criteria/Benchmark	Description of data needed	Quantitative or qualitative
Time to fire 5 balls in under 1 minute	Number of seconds between the first ball being fired and the last ball being fired during testing	Quantitative
Device can fire 5 balls into all 5 wickets	Yes/No	Qualitative
Time to set up device in under 3 minutes	Number of seconds needed to set up device during testing	Quantitative
Device fits within 1x1 meter starting area	Yes/No	Qualitative
Device is initiated by a single event	Yes/No	Qualitative
Device strikes ball and does not push ball	Yes/No	Qualitative
Device remains within the set up area during the entire task	Yes/No	Qualitative
Device uses safe energy sources	Yes/No	Qualitative
Device uses non-toxic and safe materials	Yes/No	Qualitative
Device has the official entry number on at least two sides of the device with 3" high numbers or larger	Yes/No	Qualitative
Device isn’t changed significantly after the elimination round	Yes/No	Qualitative
Device can adapt to non-level ground	Yes/No	Qualitative

Device does not use clamps or other means to attach to the ground	Yes/No	Qualitative
Device only strikes each ball once	Yes/No	Qualitative
Device positions ball on/above designated start spot	Yes/No	Qualitative
Device does not alter the balls in any way	Yes/No	Qualitative
Device will not injure or hurt any participants or other devices	Yes/No	Qualitative

Test Procedure

- Create a 1x1 meter box using tape on a level floor. Add a starting point for the ball, as well as points for the wickets and target at the appropriate distance according to the JPL competition rules. Measure using a tape measure and protractor.
- Place the device on the box such that the ball's resting place is over the designated starting point and within the 1x1 meter box.
- Place all of the wickets on the designated points (and the stake behind target C), with the front of the wicket facing the device.
- Receive 5 balls (inflated to 10 psi) and place them next to the device in order of blue, red, yellow, green, and orange. The first ball launched must be the blue ball, the second ball must be the red ball, the third ball must be the yellow ball, the fourth ball must be the green ball, and the fifth ball must be the orange ball.
- For each wicket (the first ball should be fired towards target C and its stake in the center, the second ball should be fired towards target A on the far left from the perspective of the device, the third ball should be fired towards target D just right of center from the perspective of the device, the fourth ball should be fired towards target E on the far right from the perspective of the device, the fifth ball should be fired towards target B just left of center from the perspective of the device):
    1. Aim the device towards the wicket (based on the aforementioned order)
    2. Prepare a stopwatch
    3. Place the ball on the small cylinder in the center of the device so that it doesn’t move.
    4. Once the timekeeper yells “start,” pull the metal rod out of the dowel near the back of the device, which will fire the ball (if this is the first ball, start the stopwatch).
    5. Repeat steps 1-4 with a new aiming direction until all five balls have been launched.
- Stop the stopwatch, recording the time interval required to fire all five balls on paper.
- Calculate score achieved for the trial based on which balls successfully pass through their wickets, and record the score on paper.

Component 5: Results/Conclusion

Testing Results

Criteria/Benchmark	Description of data needed	Quantitative or qualitative	Results Upon Testing	Criteria Pass/Fail
Time to fire 5 balls in under 1 minute	Number of seconds between the first ball being fired and the last ball being fired during testing	Quantitative	30 seconds	Pass
Device can fire 5 balls into all 5 wickets	Yes/No	Qualitative	Yes	Pass
Time to set up device in under 3 minutes	Number of seconds needed to set up device during testing	Quantitative	15 seconds	Pass
Device fits within 1x1 meter starting area	Yes/No	Qualitative	Yes	Pass
Device is initiated by a single event	Yes/No	Qualitative	Yes	Pass
Device is loaded with a ball	Yes/No	Qualitative	Yes	Pass
Device strikes ball and does not push ball	Yes/No	Qualitative	Yes	Pass
Device remains within the set up area during the entire task	Yes/No	Qualitative	Yes	Pass

Device uses safe energy sources	Yes/No	Qualitative	Yes	Pass
Device uses non-toxic and safe materials	Yes/No	Qualitative	Yes	Pass
Device has the official entry number on at least two sides of the device with 3" high numbers or larger	Yes/No	Qualitative	Yes	Pass
Device isn't changed significantly after the elimination round	Yes/No	Qualitative	Yes	Pass
Device can adapt to non-level ground	Yes/No	Qualitative	Yes	Pass
Device does not use clamps or other means to attach to the ground	Yes/No	Qualitative	Yes	Pass
Device only strikes each ball once	Yes/No	Qualitative	Yes	Pass
Device positions ball on/above designated start spot	Yes/No	Qualitative	Yes	Pass

Device does not alter the balls in any way	Yes/No	Qualitative	Yes	Pass
Device will not injure or hurt any participants or other devices	Yes/No	Qualitative	Yes	Pass

Points Earned & Time Elapsed per Trial

Trial	Time (seconds)	Points Earned (Max: 190)
1	42	190
2	38	100
3	37	190
4	33	130
5	47	190
6	30	190
7	42	150
8	39	190
9	33	190
10	29	190
11	26	190
12	30	190
13	33	190
14	33	130
15	32	190
16	34	100
17	28	190
18	28	160

19	32	190
20	25	190
21	25	190
22	18	150
23	27	100
AVERAGE	**32.2**	**168.2**

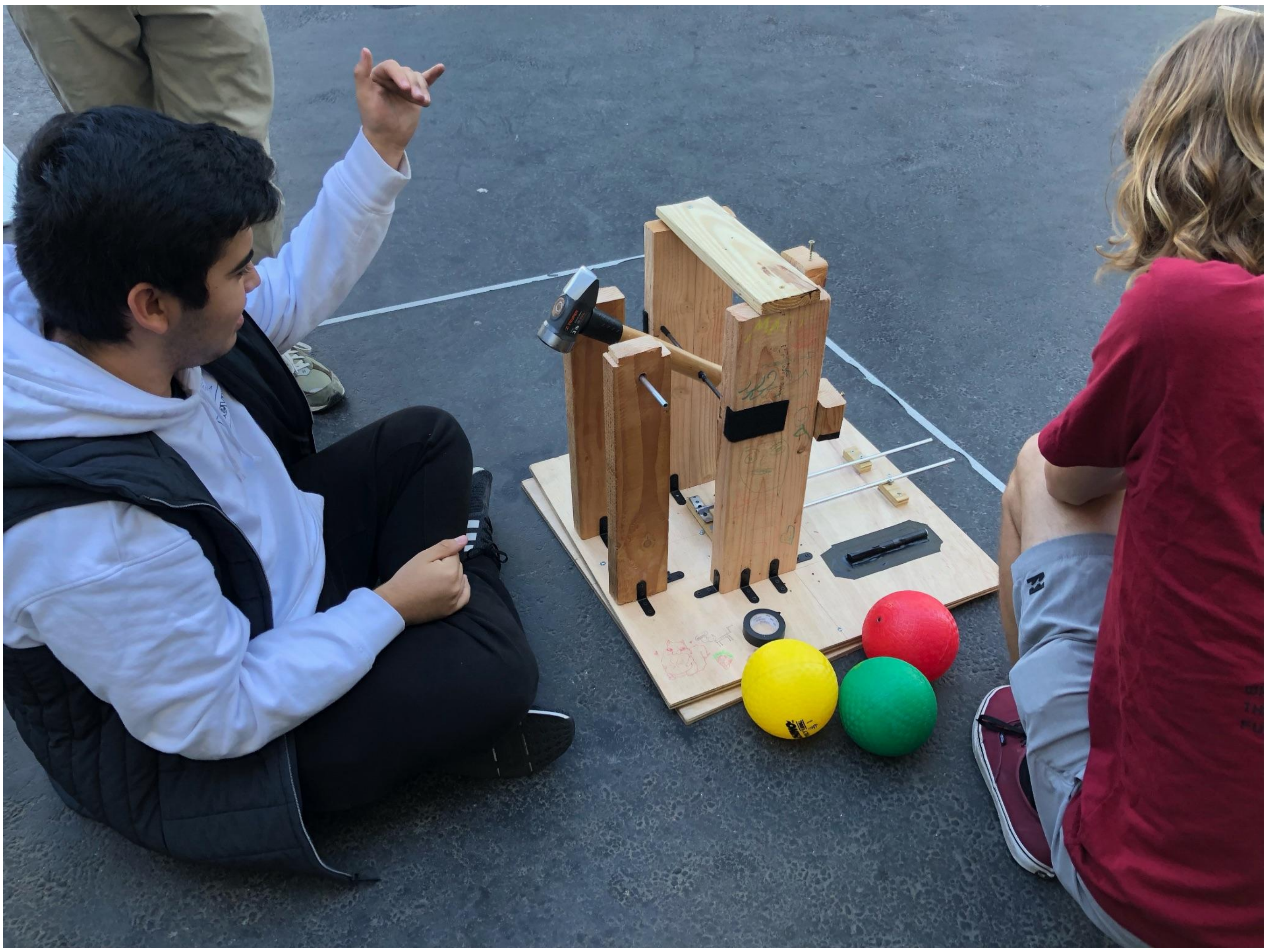


Figure 32: The device in the designated starting position with three balls to the side of it. Team members decide on the best protocol for aiming and initiating the device in order to get the max possible score.

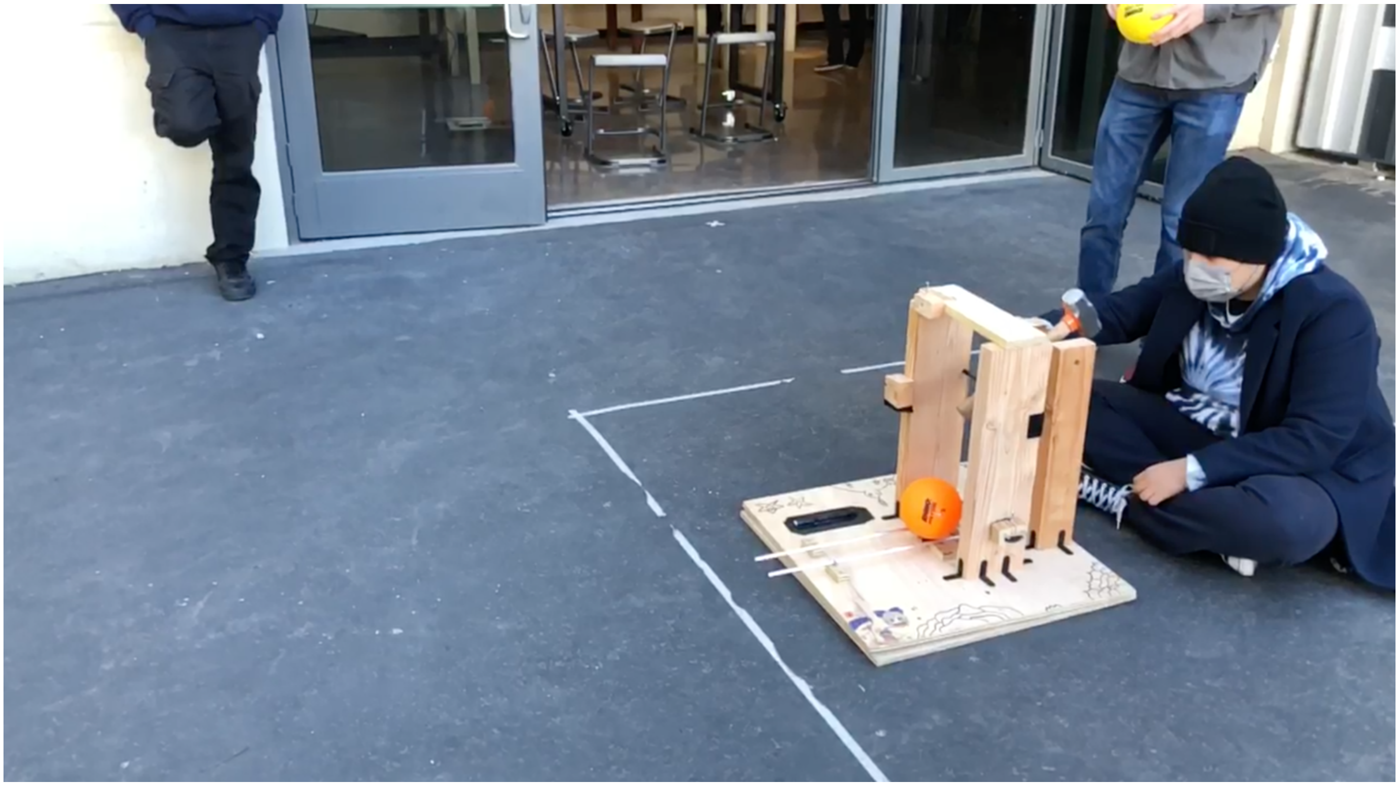


Figure 33: The ball in its designated starting position before being struck by the hammer.

Figure 34: The ball after it has made it through the wicket.

Prototype Evaluation

The design solution was a success. Across 23 trials, the device achieved an average of 168.2 points in an average time of 32.2 seconds. As the max possible score is 190 points, 168.2 points is a sufficiently good score. Likewise, as the task needs to be completed in 60 seconds or less, 32.2 seconds is a sufficiently good time. If the device manages to get a perfect score in the actual competition, a low average of 32.2 seconds could guarantee a winning time.

Figure 35: A photo of the final device with a finished paint job.

<u>Do the results reflect a problem with the materials used for the prototype?</u>

The results do not reflect a problem with the materials used for the prototype. This is because during testing the machine never had any structural failures, and shaking was minimal. In fact, most of the lost points were due to inaccurate aiming during the trials. This shows that none of the materials used failed, and thus there were no problems with the materials used for the prototype.

<u>Do the results reflect a problem with the quality of the building process of the prototype?</u>

The results somewhat reflect a problem with the quality of the building process. Due to the device being more heavy than optimal, the turning speed is reduced. In addition, the stabilizers in between the two wooden boards at the base aren’t level, reducing their efficacy and slightly reducing accuracy. This is reflected in slightly slower times and slightly lower point averages. Ultimately, the device’s weight and reduced speed wasn’t a huge issue, as the device still managed nearly perfect scores.

<u>Do the results reflect a problem with the design of the prototype?</u>

The results do not reflect a problem with the design of the prototype. The main objective is for the device to get all five balls into all five wickets in the order that maximizes the amount of points earned. As shown by the trial data, 15 out of 23 trials achieved a perfect score (190 points), and 5 of these perfect scores were achieved in under 30 seconds (half the allotted time). Since the device accomplished what it was set out to do, it is sufficient to say that the prototype’s design was effective.

Supporting Materials

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