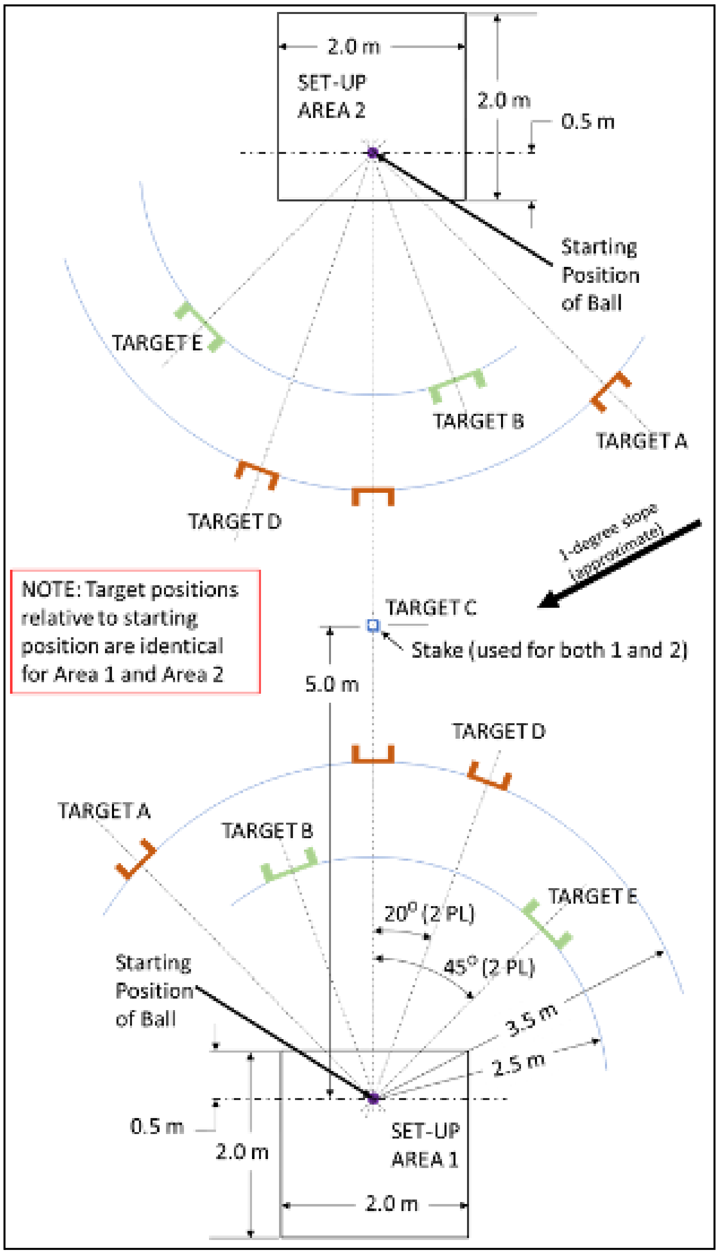
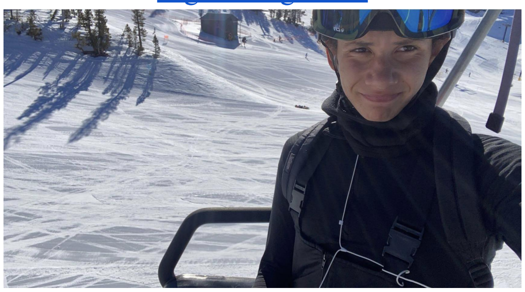
JPL Santa Monica Goats United

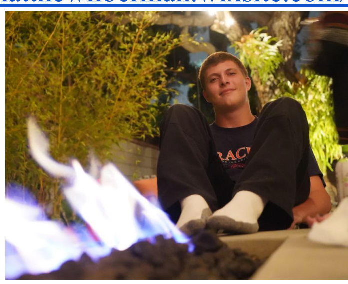


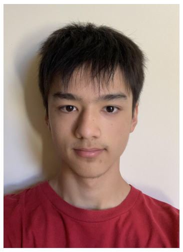
Jacques Barnett, Kaz Bernota, Maximus Bruozis, Thomas Digaetano, Mathew Lieberman, Aurelio Paltera, Lucas Schweighofer, Sebastion Soja, Nikolas Wheeler Quintanilla

JPL Invention Challenge
"Sticky Wicket"

About the Authors

Name & Picture	Bio
Jacques Barnett jwb2526@aol.com https://sites.google.com/smmk12.org/jb-capstone-engineering/home 	Jacques Barnett was born and raised in Santa Monica where he attends Santa Monica High School. Jacques is incredibly interested in engineering and is looking to further his interests in college. He has been a part of a handful of clubs such as Civil Architecture, Surf Club, and more. Captain of the Samohi Surf Team and knowledge enthusiast.
Kazimer Bernota kaz.bernota@gmail.com https://kjb726.wixsite.com/engineering-portfoli 	Kazimer Bernota is a senior set to graduate from Santa Monica High School in 2023. Born in 2005 he would soon attend Edison Elementary where he would grow up bilingual and immersed in other cultures. Kazimer has always found interests with close relations to the core of engineering, whether it be Architecture or Aerospace, it has been an important aspect of his life which has remained prevalent to this day. After graduating John Adams Middle School with the skillset to tackle harder problems, he has since attended PLTW classes every year of his high school career.
Maximus Bruozis mvbruozis@gmail.com https://mvb940.wixsite.com/engineering 	Maximus Bruozis currently attends Santa Monica High School where he will soon graduate. Maximus has been in Project Lead The Way for all four years of high school, learning multiple different engineering fields. Born and raised in Santa Monica, he has always been drawn to nature. Being a part of boy scouts and multiple environmental clubs, he has felt obligated to use his skills to better our environment. After finishing high school, he will attend college in order to further his engineering career to solve environmental problems.

Thomas DiGaetano DiGaetanothomas33@gmail.com https://digaetanothomas33.wixsite.com/thomas-engineering-e 	Thomas is a Santa Monica High School student where he will graduate in 2023. Born in New York City, he moved to Los Angeles in 2017 and has been raised there since. He has been in the PLTW program with Ms. Snyder for three years of his HS career and has grown significant interest in Engineering.
Matthew Liberman matthewliberman05@gmail.com https://matthewliberman.wixsite.com/portfolio 	Matthew Liberman was born in Los Angeles and raised in Santa Monica. He has remained in the Santa Monica public education system for his whole life going from McKinley Elementary School to Lincoln Middle School to Santa Monica High School. Throughout school Matthew was fascinated with STEM and his intended major is engineering. He has remained in the engineering pathway for his tenure at Santa Monica High School and remained passionate about his pursuit of knowledge.
Aurelio Paltera aureliopalmmv@gmail.com https://ap9718.wixsite.com/aurelio-p 	Aurelio Paltera was born and raised in Santa Monica. He has been going to school in the Santa Monica public education system for his whole life going from Grant elementary to SMASH to, now, SAMOHI. Throughout his school journey Aurelio was fascinated with anything STEM and his intended major is aerospace engineering. He has remained in the engineering pathway since middle school and for his time at Santa Monica High School and has remained passionate about aerospace engineering.

Lucas Schweighofer lucas_s_29@icloud.com https://ls6860.wixsite.com/engineer 	Lucas Schweighofer grew up in Santa Monica and has been going to schools in this district throughout his life. Lucas is currently in his senior year of high school at Santa Monica High School (SAMOHI) and has been involved with many STEM courses, including the PLTW engineering course and high level math and science classes.
Sebastian Soja sebastianwsoja@gmail.com https://sebastianwsoja.wixsite.com/sebastian-soja 	Sebastian Soja is a senior at Santa Monica High school and is graduating in the class of 2023. Throughout his life he's been fascinated with learning how things work, everything and anything was taken apart, reassembled and eventually improved. His interest in engineering is being continued into his post high school years as he attends a college for environmental engineering.
Nikolas Wheeler-Quintanilla nikolaswheeler1@gmail.com https://nikolaswheeler1.wixsite.com/samohi-12th-grade-en/blog 	Nikolas Wheeler-Quintanilla was born on April 28th 2005 in Santa Monica California. He started at Edison Elementary where he first joined the Spanish immersion program. He has stayed with the Spanish immersion program all through his schooling career helping him become a well rounded student. These attributes have been especially helpful in PLTW, the engineering program at Samohi.

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Component 1: Rules/Research

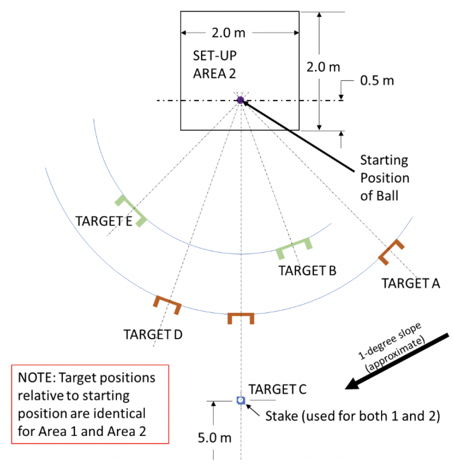
Problem Statement:

To design, build, and test a machine that propels 5 rubber balls into polo-esque wickets. The goal is to score the most points possible by creating a strategy, as each ball and wicket vary in points as well as difficulty, and sending the balls into the wickets.

Rules/Considerations:

- There are 5 wickets (miniature soccer goals), which are the targets.
- Each wicket is worth different amounts of points (see figure 1):
    - Targets B and E are worth 10 points each.
    - Targets A and D are worth 20 points each.
    - Target C is worth 30 points but most go through the wicket and hit the stake.
- Each ball has a differing multiplier:
    - Blue ball has a 3x multiplier.
    - Red and Yellow balls have a 2x multiplier.
    - Green and Orange balls have a 1x multiplier.
- The balls must be used in a specific order from the highest multiplier to the lowest.
- Balls must be launched without any external force (striking motion, no physical push from a person).

Figure 1: Structural layout by JPL



Initial Research:

Figure 2: Kazimer Bernota Design

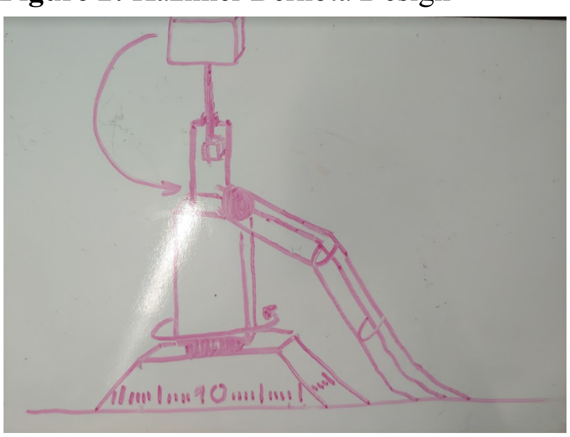


Figure 3: Nikolas Wheeler-Quintanilla Design

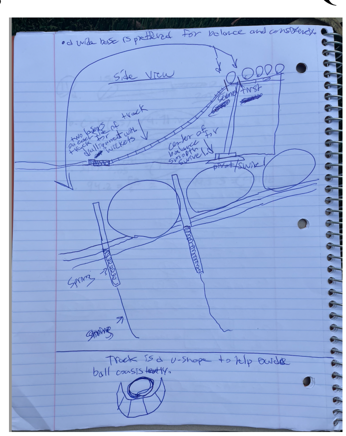


Figure 4: Lucas Schweighofer Design

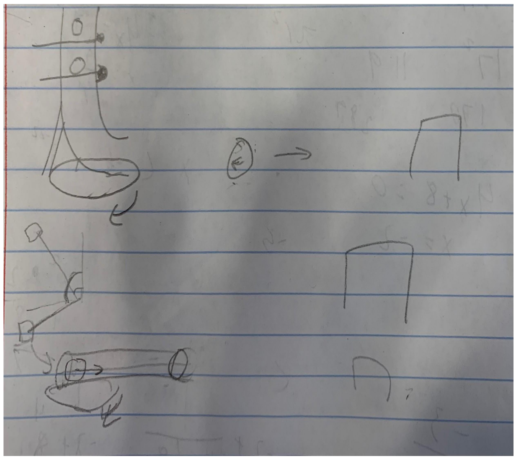


Figure 5: Jacques Barnett Design

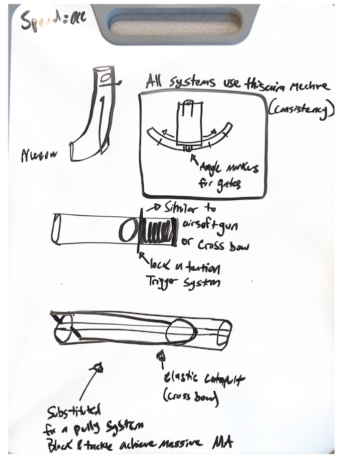


Figure 6: Maximus Bruozis Design

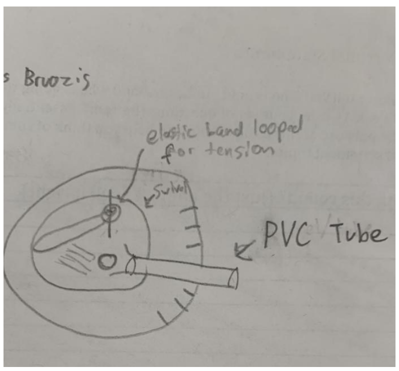


Figure 7: Thomas DiGaetano Design

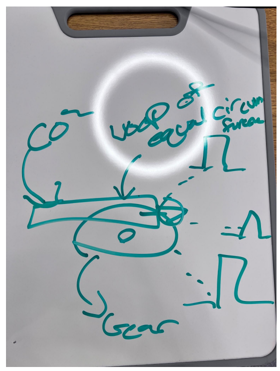


Figure 8: Matthew Lieberman

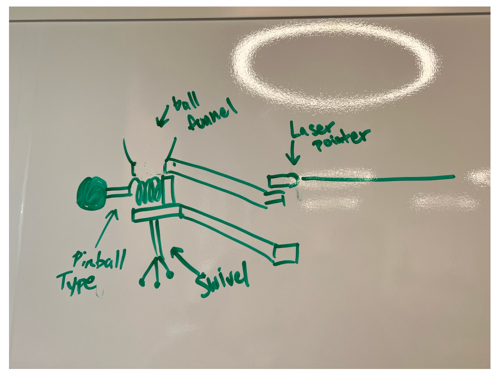


Figure 9: Sebastian Soja Design

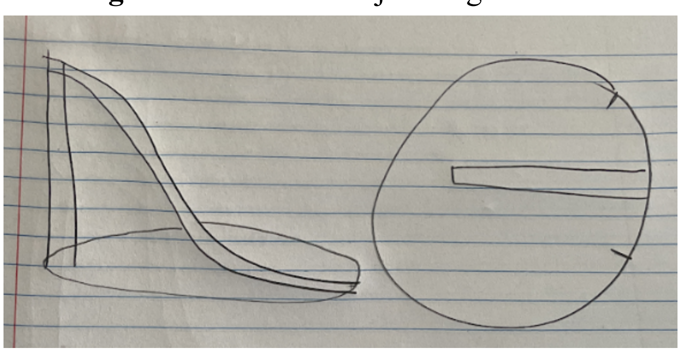
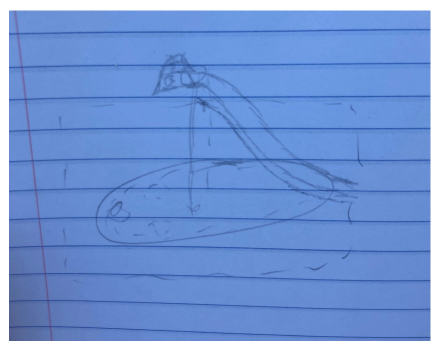


Figure 10: Aurelio Paltera Design



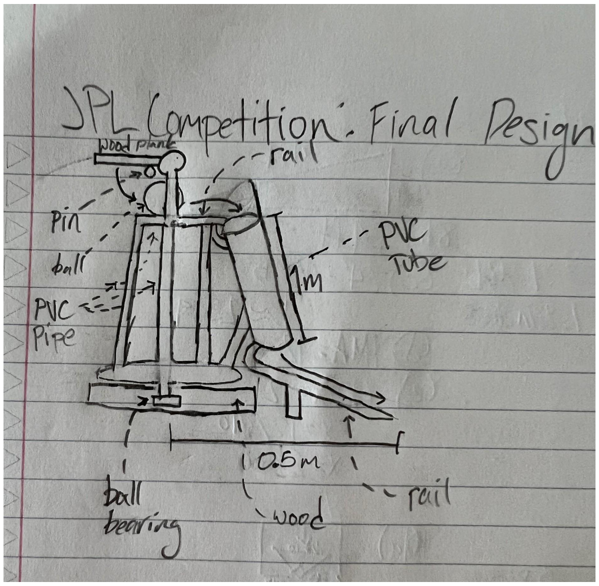
Conclusion:

A PVC pipe with the approximate diameter of 6 inches leading into a bike ramp to stabilize the ball would prove to be an effective design. The ball will be set into motion by a swing mechanism that will strike the ball lightly, taking advantage of the consistency of gravity. The rest of the work will be done by the potential gravitational energy. The ball will start one meter above the starting point and ride down a track of about 5 meters in length. The ramp will be on a swiveling base with holes to lock in the appropriate angles and to launch the ball through the wicket.

Component 2: Design

Initial Design Concept:

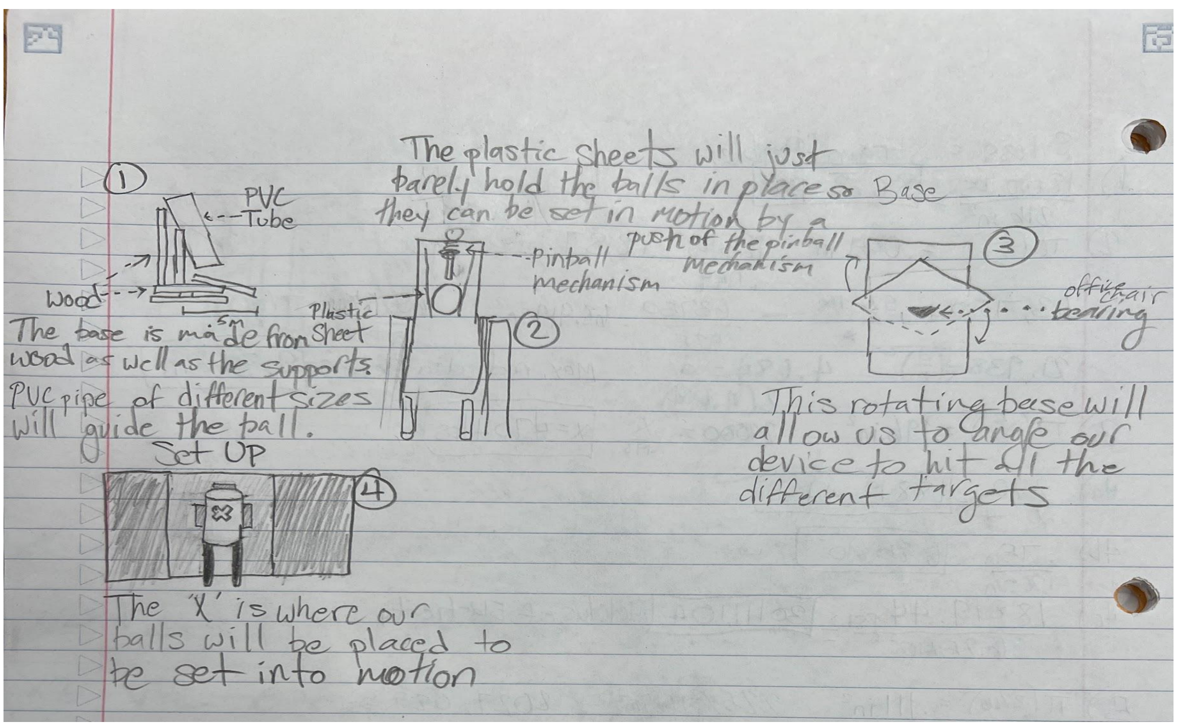
Figure 11: Initial group design concept



An inclined tube was the initial design in order to use gravity to roll the ball. The ball would then move onto the rails after the tube ends to make a clean transition from the machine to the ground. It also included a rotating wheel-like base with a bearing in order to change the direction that the ball was rolling to be able to aim at the wickets. Lastly, there is a 'hammer' on top of the launch pad, which is supported through multiple beams of PVC pipes, that allows the ball to be set in motion through a striking action with the activation of a pin.

Revised Design Concept:

Figure 12: (1) Side view of design. (**2)** Striking mechanism. **(3)** Bearing mechanism. **(4)** Set up placement.



The measurements and structure were finalized for the revised design concept, with a better understanding of how the bearing rotates the base (figure 12.3). The starting mechanism was also changed to include a pinball mechanism pushing through plastic sheets instead of a hammer so as to not worry about creating a supporting base (figure 12.2). This also allows more room to work with since the design is constrained within a limited space (figure 12.4).

Prototype Design Model:

Figure 13: Side View design with measurement and materials

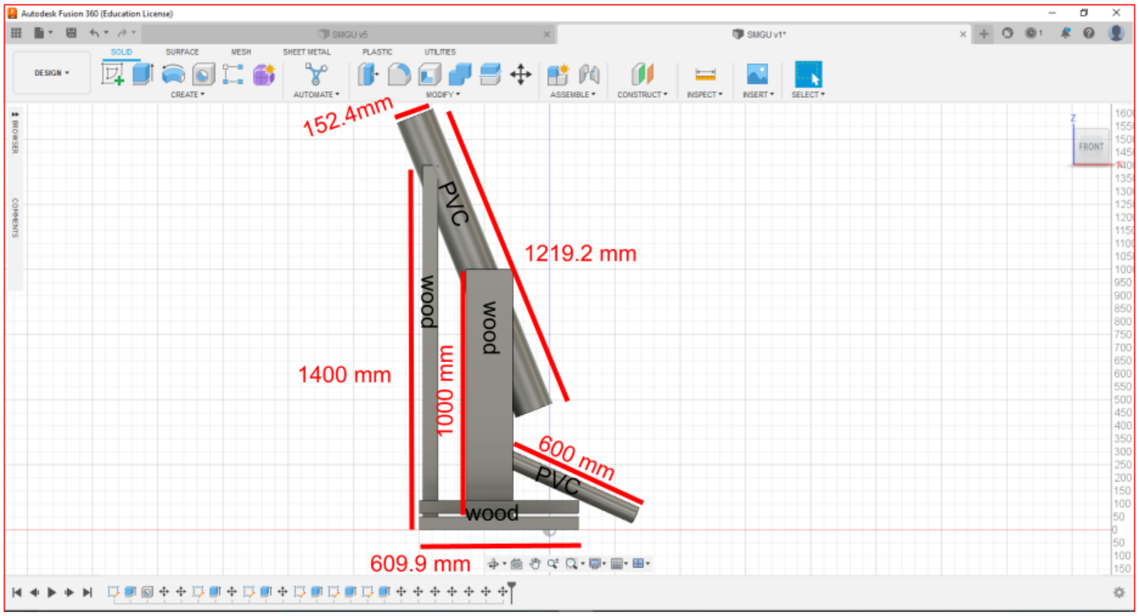


Figure 14: Front View

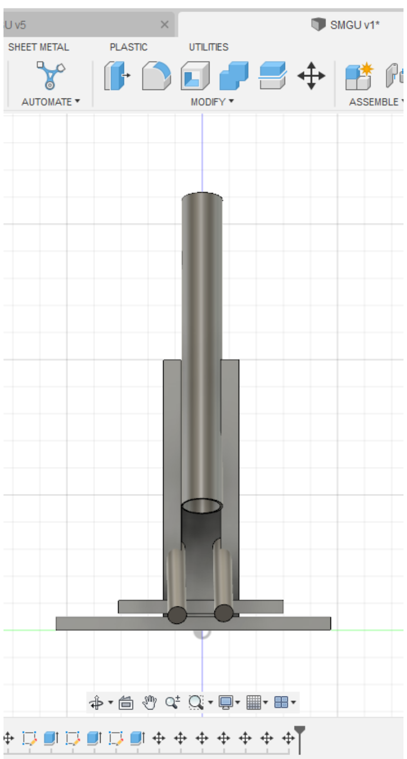


Figure 15: Birds-eye View

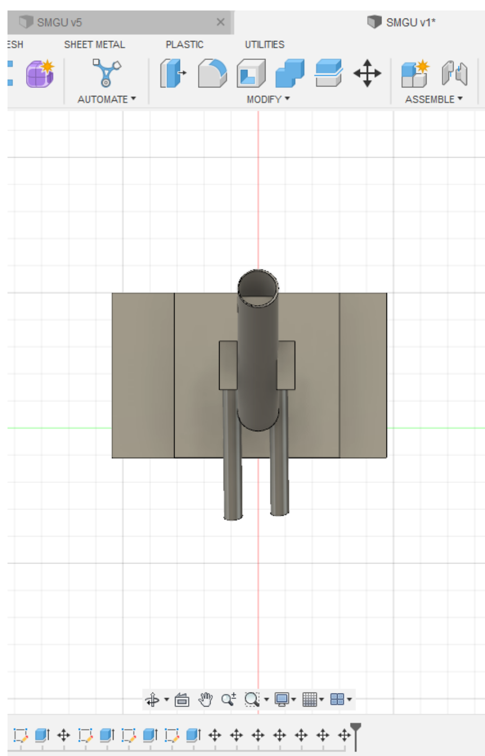
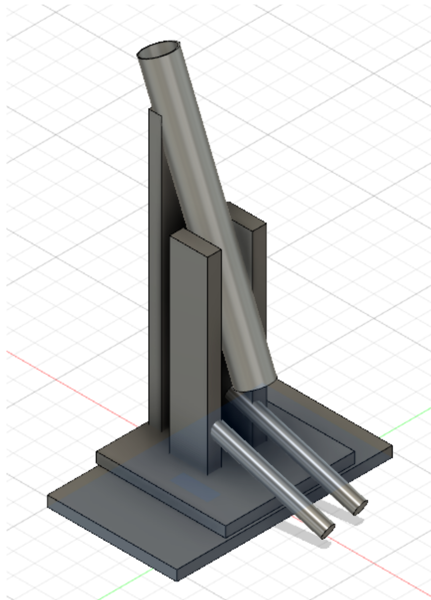


Figure 16: ISO View



Details Necessary to Build Prototype:

In order to construct a prototype the equipment needed is PVC pipe, a barring, and wood. The design is not very complicated however, it will certainly get the job done. Most of the construction process involves teamwork on ironing out the kinks going from the concept to the prototype.

Parts List

Material	QTY	Price
Wood, Plywood	1	In Shop
PVC Tube 6in	2	$18
Bearing	1	$21
PVC Pipe .5in	2	$6
Screws	12	In Shop
Wood, 2-4	4	In Shop
Bolts	4	In Shop
Washers	8	In Shop
Nuts	4	In Shop
Wooden Dowel	1	4

Cost Analysis:

Figure 17: Cost Analysis Graph (Materials)

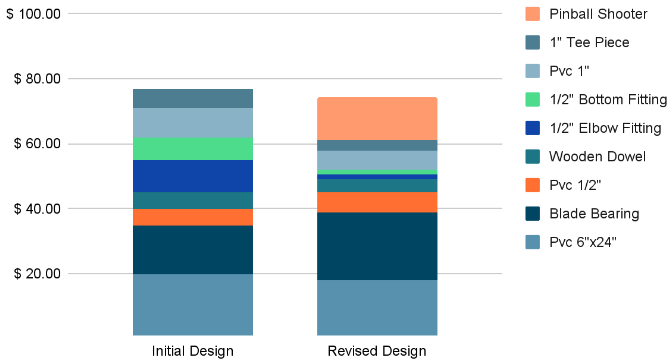
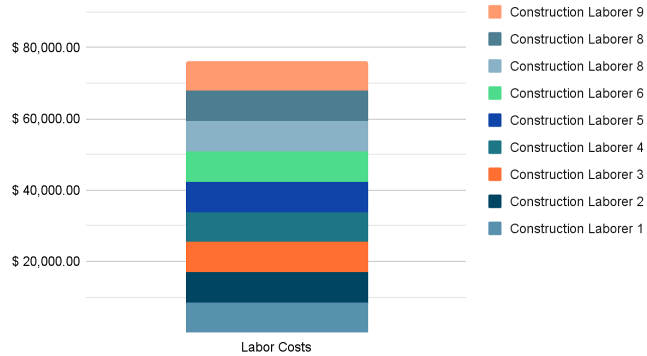


Figure 18: Cost Analysis Graph (Labor)



The average salary for a Construction Laborer is $50,868 (Payscale 2022)
$50,868 divided by 12 Months = $4,239 per Month
Project ends on Nov 19, 2022 = 2 months of work
$4,239 x 2 Months = $8,478 per Person
(5 laborers x $8,478 per Person) + (Materials Cost of $75) = Net Cost
Net Cost would cost = $42,465

Equipment and Technology:

A model was made in a 3D computer design program called Fusion 360. This created a referenceable blueprint for the more complex stages of development (Figure 13-16). Pencils, rulers, and measuring tapes were used to help plan out the initial stages of construction to align it with the 3D design. This kept the design symmetrical to avoid stability issues in the future. With this project being primarily made out of wood and PVC piping, it was found that the most common array of tools used were saws to cut the wood into the necessary shapes and sizes needed as well as electronically powered tools. These powered tools include drills to make holes in the building and screwdrivers to screw in screws and take advantage of the soft wood surface opposed to needing to weld metal. This can be seen through the process of constructing the base mentioned previously. Wood was used to connect two platforms to a blade bearing, the reasons are stated above (figure 12). It is expected to follow similar patterns in the approach to the next components, with heavy use of wood and PVC for their versatility and as a result screwdrivers and saws (Figure 13). However the ideas and design may evolve over time and in the future a completely different approach to the manufacturing process may be inevitable.

Component 3: Physics Analysis

Equations:

$$E_0 = E_1 \qquad (1)$$

The initial energy (E_0) equals the final energy (E_1) as energy is conserved.

$$U_g = mgh_0 \qquad (2)$$

Gravitational potential energy (U_g) is used because the ball with mass (m) is being affected by gravity (g) from an initial height (h_0).

$$U_s = \frac{1}{2}kx^2 \qquad (3)$$

Spring potential energy (U_s) is used because the device has a spring with a spring constant (k) and the length pulled back (x).

$$K = \frac{1}{2}mv^2 \qquad (4)$$

Linear kinetic energy (K) is created as the ball moves with some velocity (v).

$$K_r = \frac{1}{2}Iw^2 \qquad (5)$$

Rotational, or angular, kinetic energy (K_r) is amassed as the ball with some moment of inertia (I) starts rolling with an angular velocity (w).

$$U_g + U_s = K + K_r \qquad (6)$$

The initial energy and final energy from equation (1) can be substituted with the initial potential energies and final kinetic energy respectively.

$$mgh_0 + \frac{1}{2}kx^2 = \frac{1}{2}mv^2 + \frac{1}{2}Iw^2 \qquad (7)$$

The equations from (2), (3), (4), and (5) are used to substitute their respective variables from equation (6).

$$I = \frac{2}{5}mr^2 \qquad (8)$$

The moment of inertia of a sphere, or the ball that is being used, is related to its mass and radius (r).

$$w = \frac{v}{r} \qquad (9)$$

The angular velocity is directly proportional to the linear velocity and radius of the sphere.

$$mgh_0 + \frac{1}{2}kx^2 = \frac{1}{2}mv^2 + \frac{1}{2}(\frac{2}{5}mr^2)(\frac{v}{r})^2 \qquad (10)$$

Equation (7) is simplified by substituting I and w with equation (8) and (9).

$$mgh_0 + \frac{1}{2}kx^2 = \frac{1}{2}mv^2 + \frac{1}{5}mv^2$$

$$mgh_0 + \frac{1}{2}kx^2 = \frac{7}{10}mv^2$$

$$v^2 = \frac{10gh_0}{7} + \frac{5kx^2}{7m} \quad (11)$$

The equation is further simplified by combining like terms and isolating velocity.

$$v = \sqrt{\frac{10gh_0}{7} + \frac{5kx^2}{7m}} \quad (12)$$

The final equation with the velocity with respect to the initial height.

Theoretical Device Performance:

Figure 19: Diagram of Device Analysis Geometry

Variables from figure 19:
D_1 = 796.5 mm
D_2 = 1219.2 mm
D_3 = 600 mm
D_4 = 914.4 mm

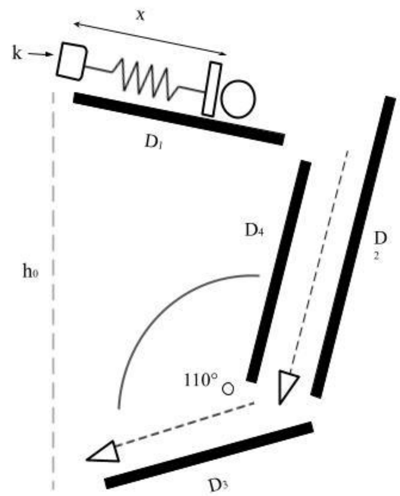
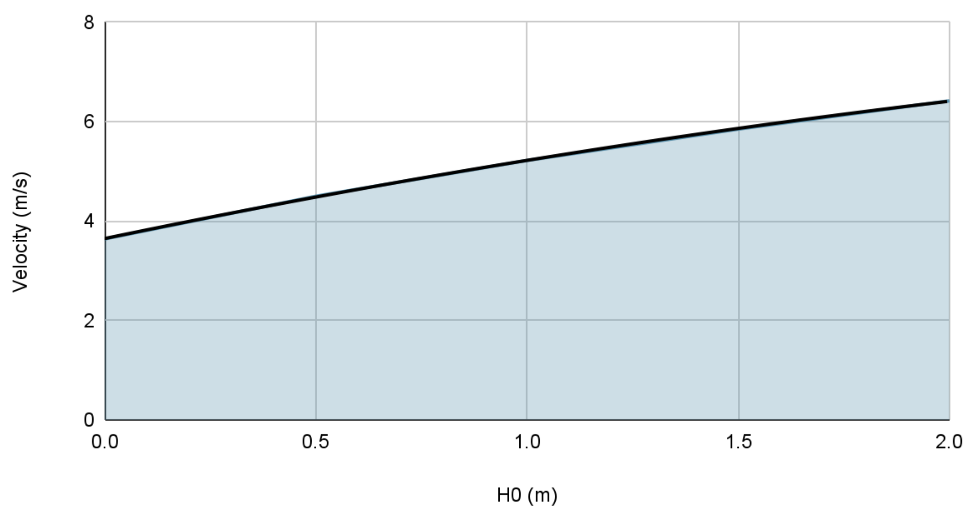


Figure 20: Graph of Theoretical Performance with Initial Height (H0) and Velocity (V)



Using equation (12) found above and using the constants g = 9.8 m/s^2, m = 0.119 kg, x = 0.047m, k = 1000 N/m (With an error of ± 150 N/m), a nonlinear, square root graph was made. The graph represents the final velocity obtained given a certain initial height. The y-intercept represents the machine with just the pinball mechanism, which will produce at most 3.64 m/s.

Device Limitations:

There are some limiting factors in the device. For example, attain a certain speed without increasing the height, might be impractical after a certain height (material cost would increase, build time would lengthen, and the device may be unable to start if the ball is too high up). Along with this, friction was not included in equation (1), as calculating the coefficient of friction would be challenging without testing. Thus, the theoretical velocity found in figure 20 should always be less than the velocity found by the line that best fits due to the friction reducing the energy conserved.

Note*: The design has changed to not include a pinball mechanism. Thus, the spring potential energy and spring constant considered in the equations, the spring on the diagram (figure 19), and graph will not be applicable to the new design.

Component 4: Build and test

Build Progression:

Figure 21: Phase One
The base of the design is constructed using a wooden floor, support, and bearing. The bearing allows for the structure to rotate without moving the entire base. The bearing is attached to the wooden board using an electronic screwdriver.

Figure 22: Phase Two
Testing the addition of the halfpipe slope and how the ball exited the rails on the bottom. The testing was looking to see if the ball's trajectory was consistent and how smoothly the ball rolled throughout the system. The structure used wooden beams to provide support for the design and halfpipe. The connection was possible by using a drill to fasten the half pipe to the back piece of wood.

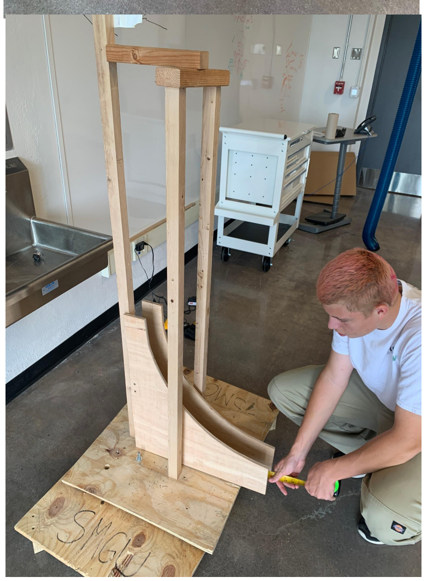


Figure 23: Phase Three
After realizing that the ball's bounce affected its trajectory and accuracy, the team reassessed how to mediate the issue. Here a team member measures how far the lip of the slope goes out to ensure that the design is within the constraints of the rules. The slope was lowered to the floor, so the ball dropped less when it fell and rolled smoother through the device. The blocks the base was on were replaced to reduce the overall drop of the ball.

Figure 24: Phase Four
The group tested an earlier design's accuracy and consistency. The new lowered design had a massive improvement on the bounce and accuracy of the ball, but the issue arose of the pipe being an inconsistent launch method. The ball was unstable when exiting the rail but much smoother than before.

Figure 25: Phase Five
Addressing the issue of the pipe's inaccuracy by replacing the pipe with rails would increase accuracy as the ball would have two points connected to the slope instead of one in the tube. The ball will not bounce off the pipe walls but stay consistent on the rails. The transition between them was smoother and the ball was more consistent and accurate when testing. This design was achieved by taking off the previous PVC pipes and using hot glue guns to attach the rails to the wooden ramp.

Figure 26: Final Phase

Although the device in phase five (figure 25) was more consistent than phase four (figure 24), the design still had inconsistencies and problems within it. To try to make it more consistent, the design team tried sanding the downward slope of the wood to create a smoother path for the ball to roll. They also filled holes in the wood that disrupted the ball with hot glue. The design from phase five (figure 25) also did not follow the rules of needing a striking motion (see Rules/Considerations). The team addressed this by adding an adjustable zip tie to hold the ball in place before the new metal rod would drop and hit the ball. The metal drop rod had to be secured with a drill bit to drop the rod and start the mechanism. The laser was inaccurate, so the team moved to the middle of the wooden slopes instead of the side to maximize accuracy. Drilling a hole in the back support secured the laser, and they fitted a PPC pipe around it to hold the on-button when aiming.

Test Criteria:

Criteria/Benchmark	Description of data needed	Quantitative or Qualitative
Make sure the ball has traveled from the front of the device through the wicket.	Distance traveled in meters (m)	Quantitative
The device can change direction consistently.	Compare the anticipated angles (degrees) needed to the actual angle produced by the device.	Quantitative
Each ball should go from the start (including changing the direction of the building and 'striking' the ball) to finish in under 12 seconds.	Time (seconds) obtained from using a stopwatch.	Quantitative
The device is within the setup area and the ball is always over the starting area.	Measure device size (m) and position of ball starting (m).	Quantitative
Each ball can go through each wicket and hit the stake as well to maximize point collection.	Total points earned.	Quantitative

Test Procedure:

(Refer to figure 1 for building and wicket placement)

1. Put the device within the setup area.
2. Put the ball on top of the starting position and make sure it remains on top of it until in motion.
3. Aim the device to one of the wicket targets or stake at angle theta.
4. Release the pin.
5. Start a stopwatch at the same time as the ball is released.
6. Make sure the ball has traveled from the front of the device through the wicket.
7. Repeat steps 2, 3, and 4 and observe if the ball goes through the stake or hits the stake and record the time it took to reach the object.
8. Correct laser angle to account for the ball favoring a specific trajectory.
9. Repeat steps 3 and 7 using different targets, or angles, to check consistency.
10. If all stakes/wickets were hit or passed and the time recorded were all below 12 seconds, then do a trial run from start to finish with all the balls launched and see if everything works out in under 60 seconds.

Component 5: Results/Conclusion

Testing Results:

Criteria/Benchmark	Description of data needed	Quantitative or Qualitative	Pass or fail?
Make sure the ball has traveled from the front of the device through the wicket.	Distance traveled in meters (m)	Quantitative	Pass
The device can change direction consistently.	Compare the anticipated angles (degrees) needed to the actual angle produced by the device.	Quantitative	Pass
Each ball should go from the start (including changing the direction of the building and ‘striking’ the ball) to finish the entire course in under 60 seconds.	Time (seconds) obtained from using a stopwatch.	Quantitative	Pass
The device is within the setup area and the ball is always over the starting area.	Measure device size (m) and position of ball starting (m).	Quantitative	Pass
Each ball can go through each wicket and hit the stake as well to maximize point collection.	Total points earned.	Quantitative	Fail

Criteria/Benchmark	Score	Time
Trial 1	150	57 seconds
Trial 2	150	46 seconds
Trial 3	90	64 seconds
Trial 4	30	60 seconds

Figure 27: Loaded ball for testing

Figure 28: Ball being launched

Figure 29: Ball striking the stake

Evaluate Prototype:

1. Was the design solution a success?

The design was a failure. The failure is in the inconsistency of the ball, which is shown by the poor score data. The ball would go in different directions, even if the aiming of the device didn't change. This means that even the smallest of changes would change the direction. Although the ball is inconsistent, testing has shown it is possible to make all three far wickets. Because our device is very sensitive to the smallest changes outside our control, with enough luck our design could still pass every wicket and the stake.

2.
   a. Do the results reflect a problem with the testing procedure?

No, the problem didn't come from the testing procedure, but it perpetuated the issue. By precisely correcting the aim of the laser and testing the device with adjustments, we could have aimed the laser more accurately.

   b. Do the results reflect a problem with the testing criteria?

No, the testing criteria allowed us to find mistakes in the quality of the building process and possibly the materials used, but it didn't have any problem itself. This is because we used a testing criteria tested for all the factors needed to make a device successful.

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

Yes, the materials used were inconsistent. Wood as our ramp was a good idea because it is easily workable, but wood has issues. The wood we used had knots and imperfections, and as we sanded it down, it became apparent they were affecting the ball's trajectory. The choice of wood as our material may have also made it harder to spot bumps and areas the ball bounced.

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

Yes, the building process was arduous. The team faced many trials and failures before reining in the inconsistency, which never wholly left the design. The striking mechanism of our pipe sometimes caused the ball to bounce. The tool that held the ball to the ramp was changed a lot and finalized with an adjustable zip tie. The PPC pide ramp leads to a drop and bumps when transitioning into the circular wooden ramp. The wooden ramp has bumps, holes, and areas where the edges are wavy.

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

Yes, most of the design had the possibility of inconsistencies. The drop pin, the ball holding mechanism, and the ramp provide a lot of variables. In contrast, more straightforward designs with fewer variables would have allowed us to manipulate each more to refine the consistency. The prototype design (figure 26) was inconsistent when it came to setting of the ball; the adjustable zip tie being too loose and the ball rolling off or too tight and the striking mechanism didn’t start the ball. This could have been modified by having the ball on a platform as originally proposed (figure 11) instead of a zip tie. The wooden slope could have also had a smooth transition to the ground instead of a small drop, which made the ball bounce and could have given its inconsistency.

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