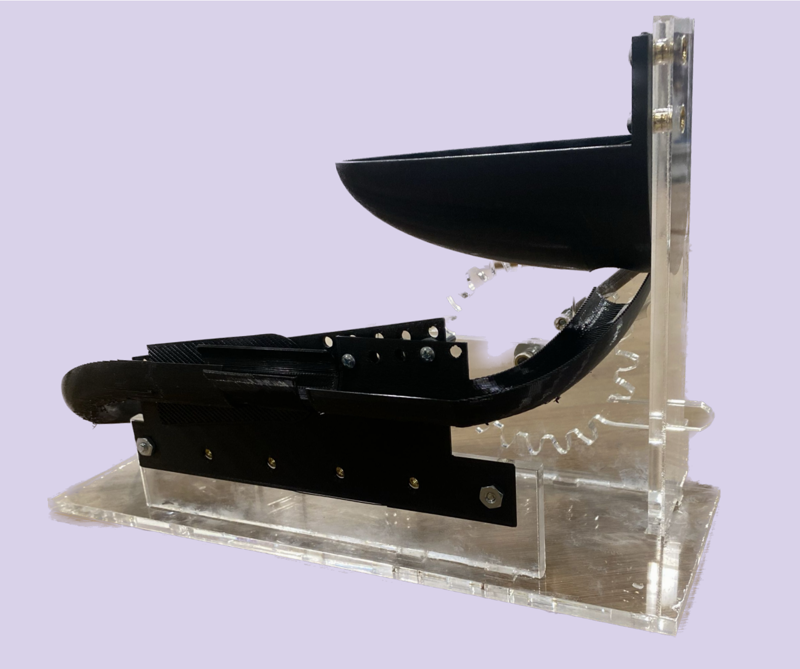
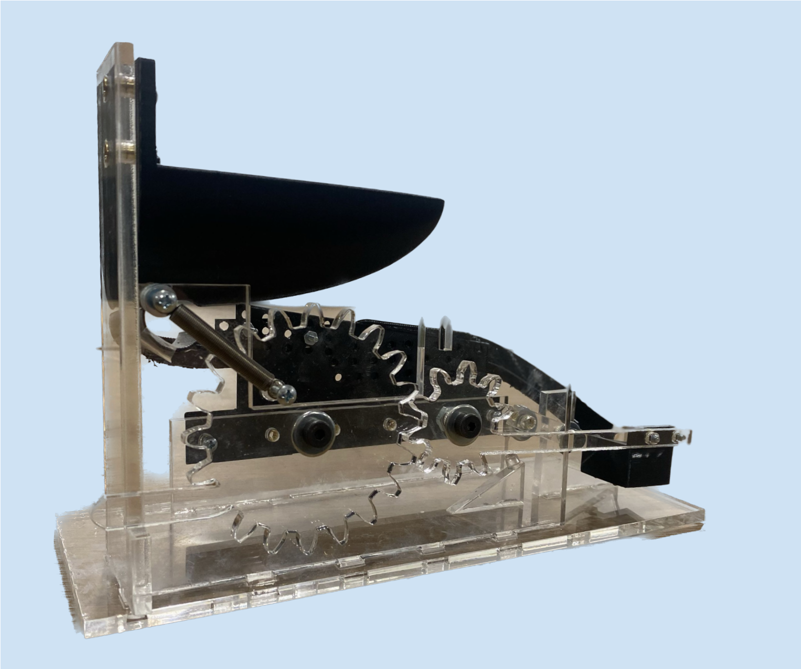




Perpetual Marble Machine

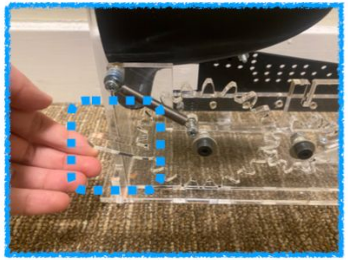
ME102 Winter 2023, May Levin

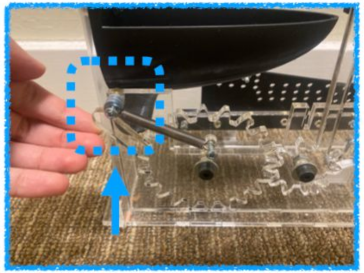
Marble Machine Instructions

May Levin - ME102 Winter 2023

1) Drop the ball in the hopper

2) Push the lever till the top





3) Watch the ball slide down!

Context

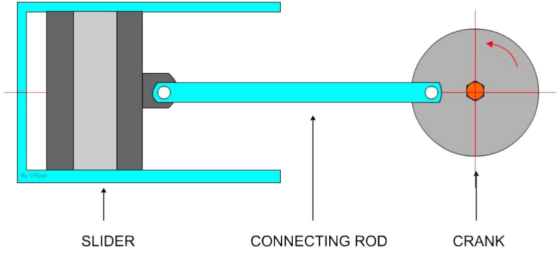
Create a marble machine that:

- Stores 5 balls
- Launches one ball at a time with a 3 inch vertical change
- Resets automatically using a spring
- Rotational Input
- Made with Acrylic/Wood/PLA materials only

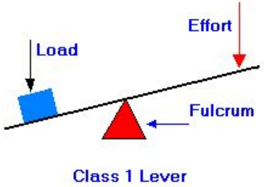
Provided balls, ½” diameter

Inspiration

Looking at hoppers which already use these nerf gun balls. Seem straighter than most funnel designs.



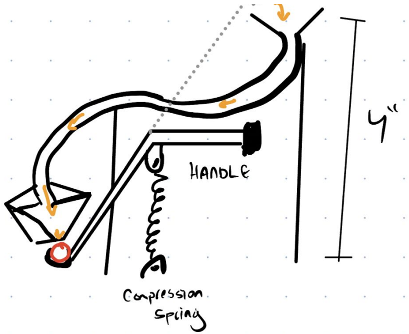
Mechanisms that are able to convert rotational motion to linear motions. Used to inspire initial designs.



Seesaw/Lever mechanism to bring a marble up/down a significant vertical distance.

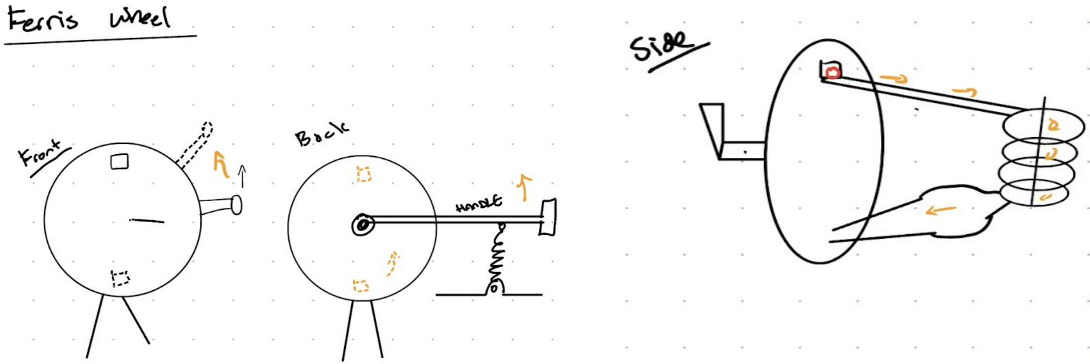
Initial Sketches

#1 Basic Catapult



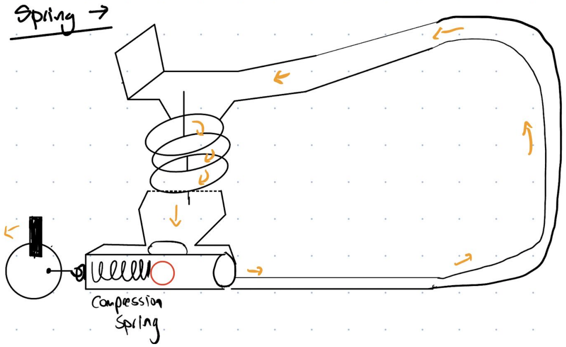
#3 Ferris Wheel

marble taken from bottom to top with ever push of the handle



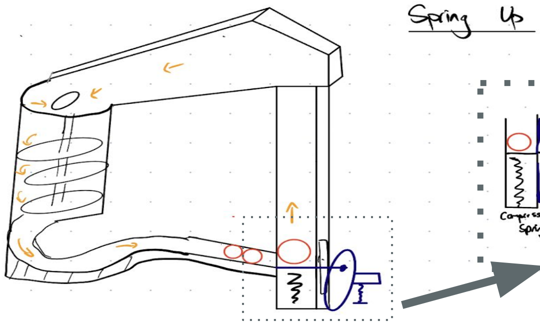
#2 Horizontal Spring

Inspired by crank & slider mechanism

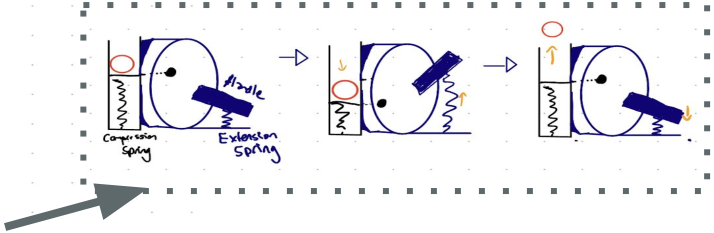


#5 Vertical Spring

Inspired by crank & slider mechanism

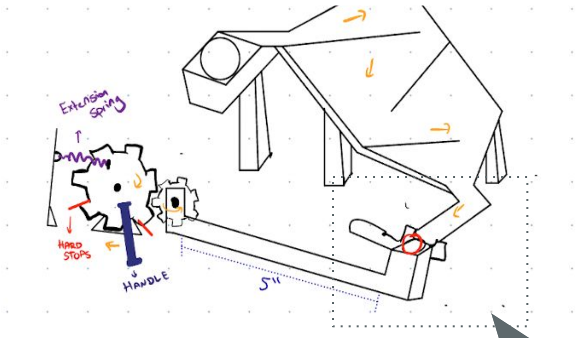


Zoom in of loading + pushing mechanism

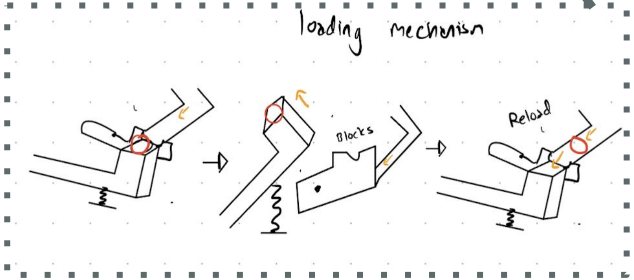


Ranking Sketches 3 & 4 & & 5

#4 Lever, Winning Design



Zoom in of loading + pushing mechanism

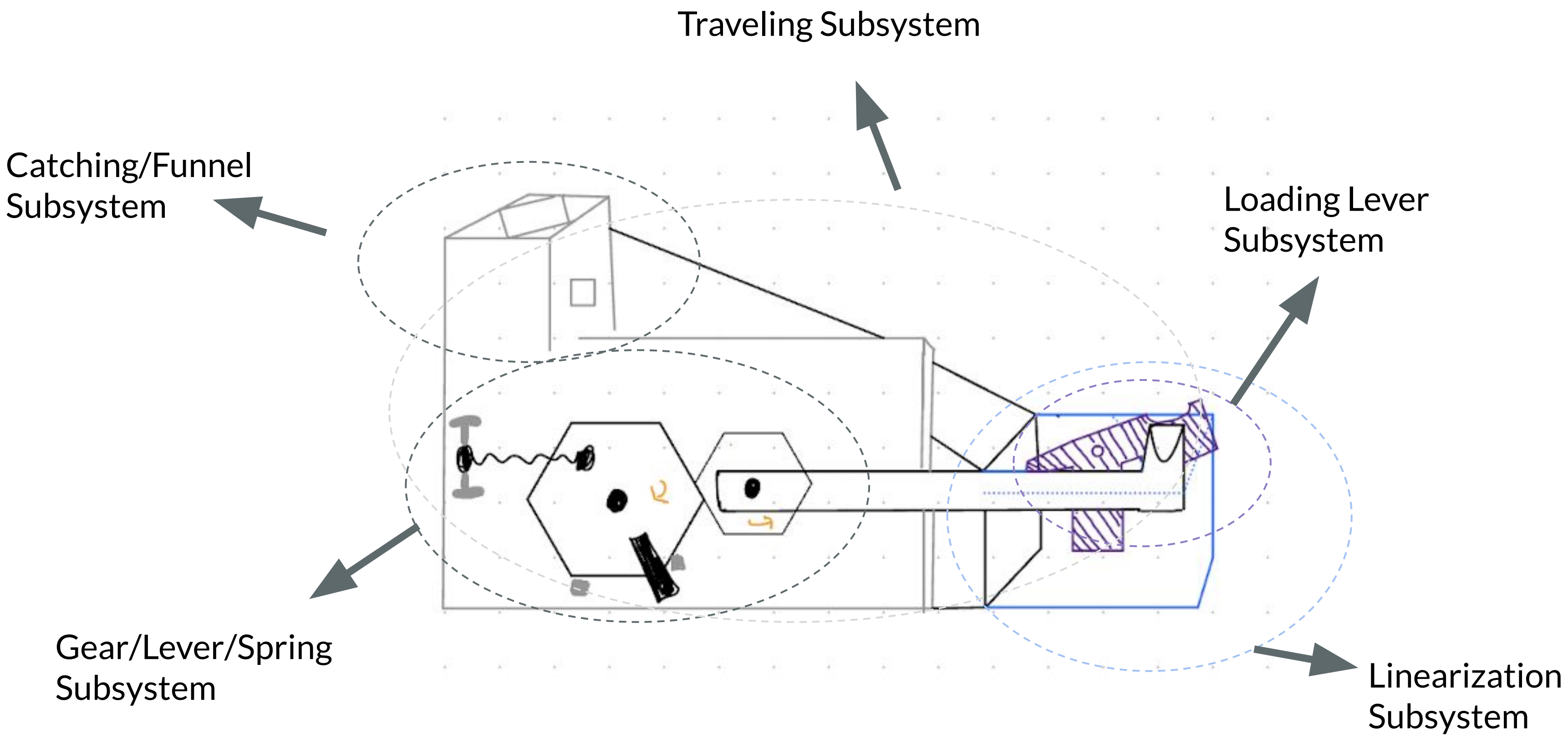


Sketch	Amount of springs needed	Simple loading mechanism	Simple pushing mechanism	Marble varies in where it can land after pushed (adds variability)	Depends heavily on gravity (marbles are not smooth so friction is a factor)	Meets criteria from project description (rotational to linear movement, has spring).
Sketch #3 **Ferris Wheel**	1	Mid, has a funnel loading mechanism that needs to be exact	Yes, push lever down	No, marble led by wheel	Yes, marble expected to fall out of wheel	Yes
Sketch #4 **Catapult with lever**	1	Yes, you have a stoppage that changes based on lever position	Yes, push lever down	No, marble is always led by catapult	No, marble led by catapult	Yes
Sketch #5 **Spring Vertical**	2	Mid, has a funnel loading mechanism that needs to be exact	Yes, push lever down	Yes, marble constrained by walls but still pushed by spring	No, marble will fall down if pushed high enough	Yes

Sketches 1 & 2 seem harder to create (need more precise measurements) and less clean

Sketch #4 seems the most dependable, not depending on gravity or other forces to lead the marble. It is always in contact with the machine.

Prototyping - Splitting into subsystems

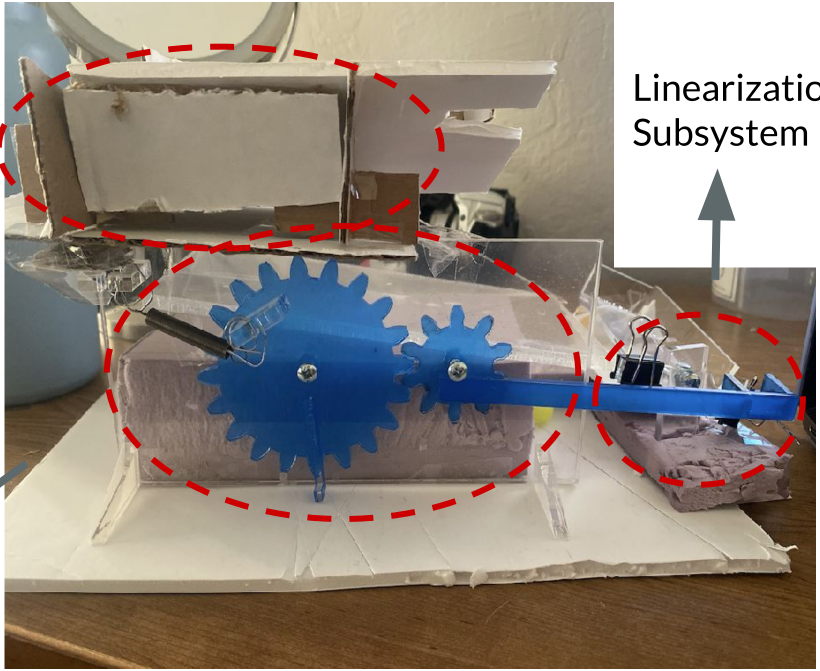


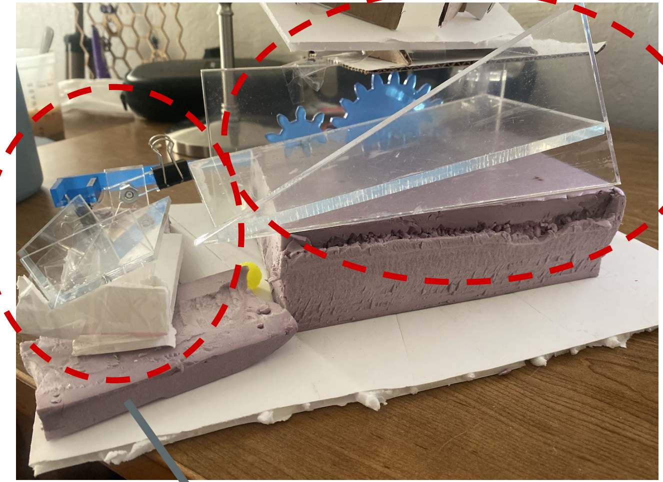
Prototyping - splitting into subsystems

Catching/Funnel Subsystem

Linearization Subsystem

Traveling Subsystem





Gear/Lever/Spring Subsystem

Loading Lever Subsystem

Gear/Lever/Spring Subsystem V1

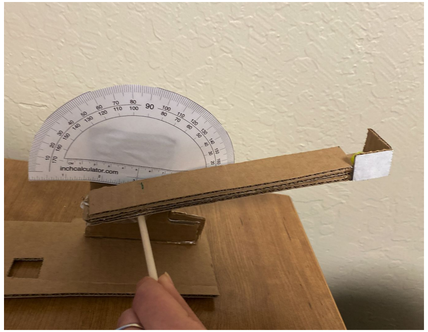
Driver Question

What range of angles will have my catapult move a marble 3.5 inches vertically?

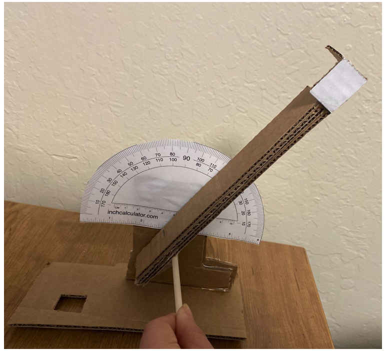
Metrics of success:

- Was the marble moved 3.5 inches up vertically?
- Did the marble remain inside the catapult until the last moment?
- Did the marble fall at the top of the catapult?

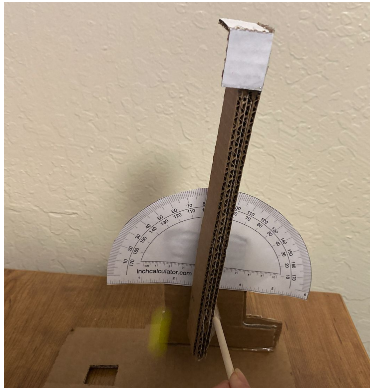
Stage 1



Stage 2



Stage 3 - Action shot of ball falling

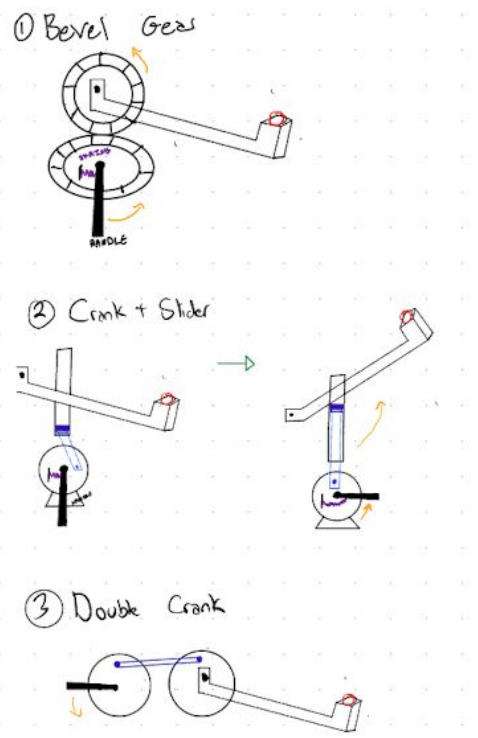


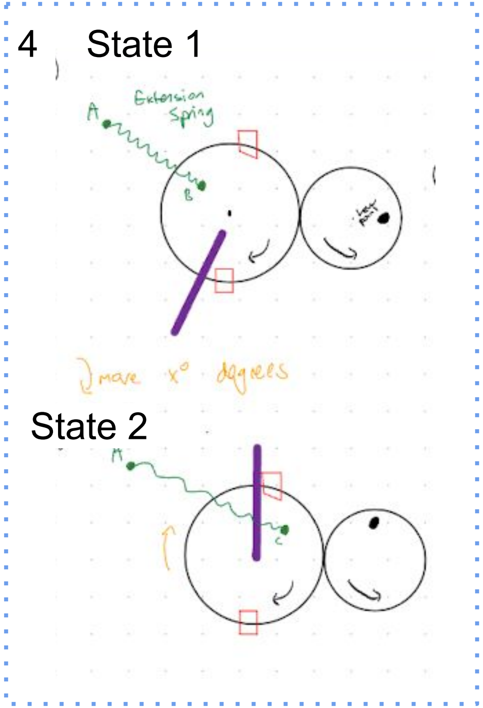
Angle (degrees)	80	85	90	95	100	105	110
Works?	No	No	No	Falls (barely)	Falls	Falls	Already fell (pretty flipped)

Seems optimal angle range is between 100-105 degrees to have the ball fall. This means the rotational handle should reach up to this point and then push back.

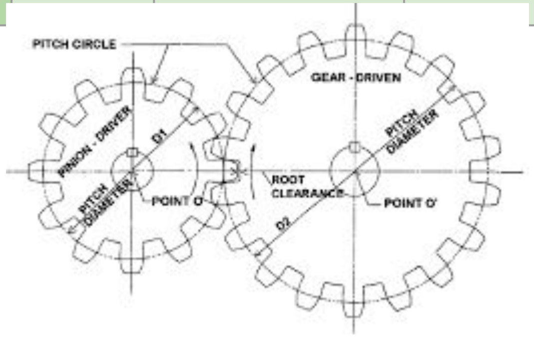
Gear/Lever/Spring Subsystem V2

How to move the lever?





Sketch	Num. of axes	Complexity	Likelihood to jam/break
1: Bevel Gear	2	Bevel Gears	Need to get reversible bevel gears
2: Crank + Slide	1	Need to push up linear motion and align with lever	Backwards motion might jam?
3: Double crank	1	Need to align cranks	Connector might jam when going back
4: Two gears	1	Simple gears	Unlikely



Gear/Lever/Spring Subsystem V2

Gear Assumptions:

- *Output angle must be around 95 degrees (determined by prototype #1)*
- *Input gear > output gear by around ½*
- *Input gear will be holding spring > 1.875", and moving it to a point < 3.025"*
- *input gear was given 20 teeth, input teeth was given 10 teeth.*

Calculations:

Gear ratio = 20/10 = 2

For every 2 revolutions of the smaller gear, the larger gear will make one revolution.

Angle rotated by larger gear = Angle rotated by smaller gear / Gear ratio

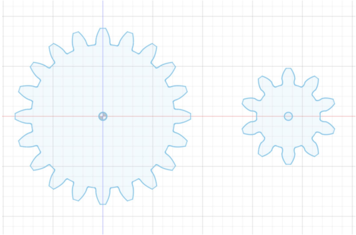
Angle rotated by larger gear = 95 degrees / 2 = 47.5 degrees

So the larger gear needs to move approximately 47.5 degrees for the smaller gear to move 95 degrees.

Create Gear using:
https://evolventdesign.com/pages/spur-gear-generator

Parameters (all lengths in millimeters)

Gear 1 Tooth Count (n1 > 0: external gear; n1 = 0: rack; n1 < 0: internal gear):	20
Gear 2 Tooth Count:	10
Module (Module = 25.4/Pitch):	4
Pressure Angle (common values are 14.5, 20 and 25 degrees):	20
Profile Shift (positive values increase backlash, default is 0; mm):	0
Clearance (minimal distance between the apex of a tooth and the trough of the other gear; mm):	0.05
Gear 1 Center Hole Diameter (mm), 0 for no hole:	4
Gear 2 Center Hole Diameter (mm), 0 for no hole:	4
Gear Center Distance (distance between shaft centers; mm)	60.000
Gear 1 Pitch Circle Diameter	80.000
Gear 1 Outer Circle Diameter	88.000
Gear 2 Pitch Circle Diameter	40.000
Gear 2 Outer Circle Diameter	48.000

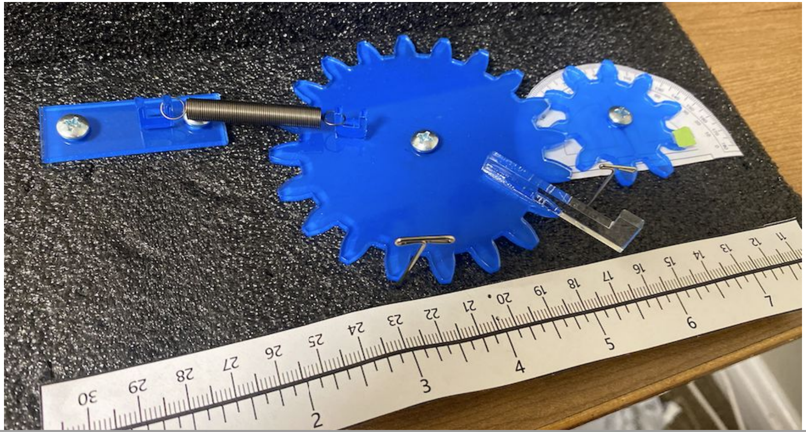


Driver Question

Given the gear sizes, and extension spring, what range of possible hardstops can I have to have my input reload properly?

Metrics of success:

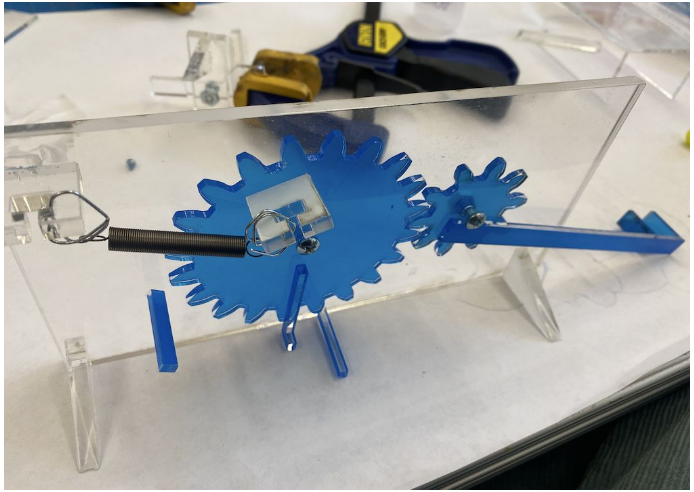
- Did my output gear move 95 degrees?
- Is my spring tense at every constant?
- Is my spring under the maximum load length?



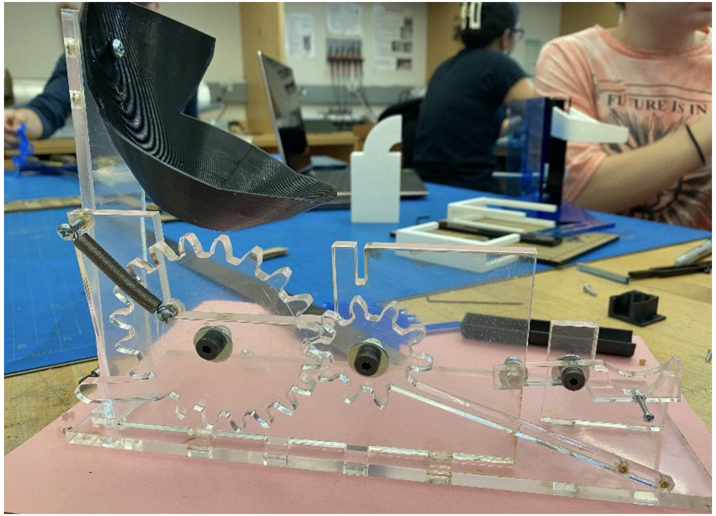
Hardstop Length	2”	2.15”	2.3”	2.5”	2.6”	2.8”
Works?	Not enough	Not enough	Closer to 90 degrees	95 degrees	Past 95 degrees	Spring overstretch ed

Gear/Lever/Spring Subsystem V3 + V4

Prototype V3



Prototype V4 (final)



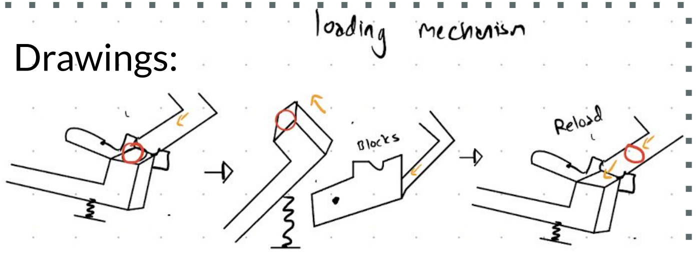
V3 was built upon V2 version, made vertical, and included lever on the gear.

Lessons Learned from V3 and applied to V4:

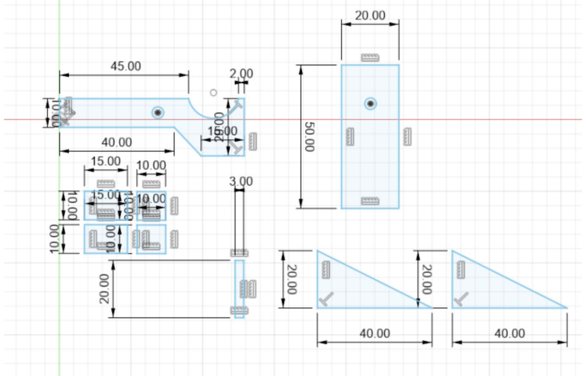
- Connect spring to subsystem using screws not acrylic holders (they are not strong enough).
- Make hardstrops screws as well.
- Make cage longer in higher to give enough space for lever to move down.
- Add a plastic sheet on top to hold gear down
- Use shoulder screws!
- Use heat inserts

Loading Lever Subsystem V1

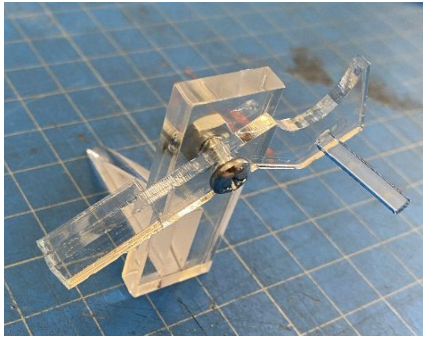
Drawings:



Laser Cut Files:



V1



For V2 (final), learned to use thicker material, utilized screws to add weights, and shoulder screws for rotation

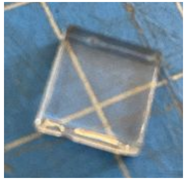
Driver Question

What range of weights will allow the loading mini lever to block the ball when the lever is up, and be pushed down when the lever is on it?

Metrics of success:

- Is the mini lever blocking the ball?
- Can the mini lever be pushed down by the big lever?
- When the mini lever is pushed down, is another ball loaded?

Test:
Adding 10mmx10mm acrylic squares to the end piece

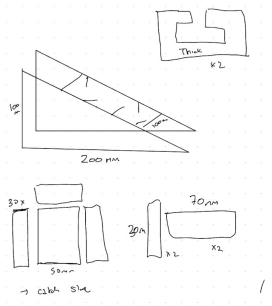


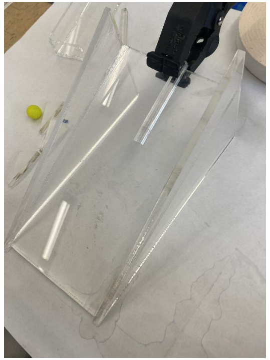
Square Number	1	2	3	4	5
Works?	Not enough weight	Falls to Left	Falls to Left	Falls to Left	Falls to Left (Getting bulky)

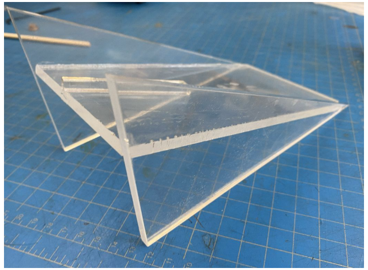
Travel Subsystem V1 + V2

Drawings: | Real Life Prototype: | Lessons learned:

V1

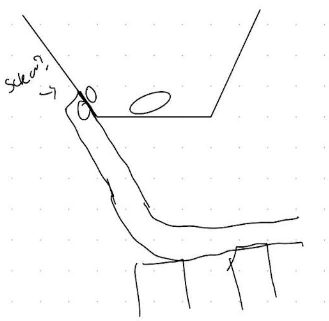






- Hard to connect + prototype
- Slide will work better

V2



Decided that this subsystem should also become part of the slide. Details in upcoming slide.

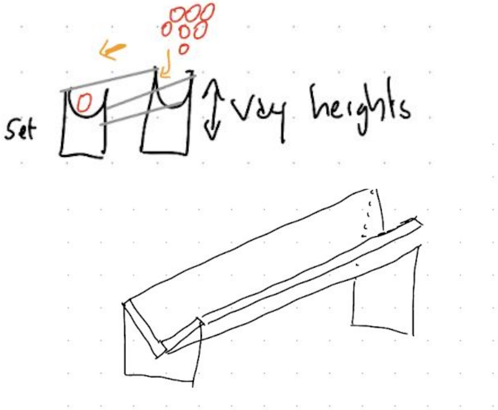
Linearization Prototype V1

Drawings:

Real Life Prototype:

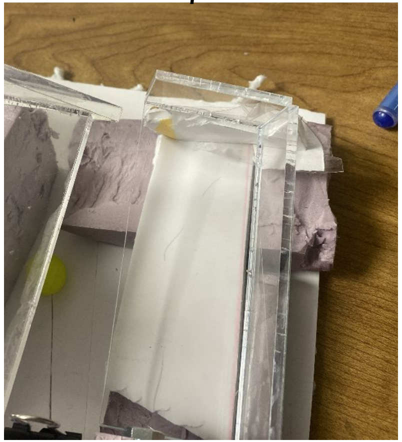
Lessons learned:

V1



Back

Top



- Must have angle of 45 degrees to flow down
- 3D print
- Connect by slide?

V2

This should also become part of the slide. Details in upcoming slide.

Travel + Linearization Subsystem V2

Travel + Linearization subsystems should be combined into a larger slide piece.

Driver Question - Travel
Given the length constraints of the system, what range of curves does my slide need for the ball to leave the hoop and continue down?

Metrics of success:

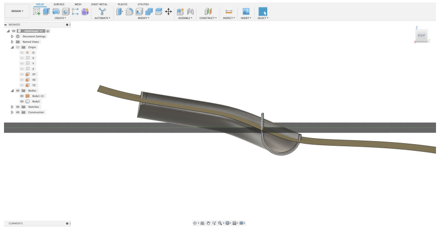
- Did my ball fall along the slide?

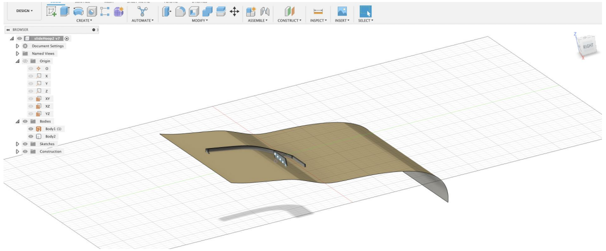
Driver Question - Linearization
Given the length constraints of the system, what range of curves does my slide need for the ball to leave the slide and continue down to the lever loader?

Metrics of success:

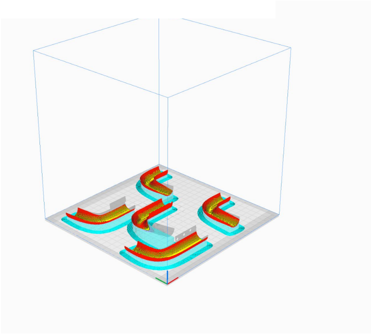
- Did my ball fall along the slide into the lever loader?
- Does this work for more than one ball?

CAD: Created angled + curved slides by projecting a sweep on a curved plane, **varying angles from 20-45 degrees**, up or down





Ultimaker Cura



3D Printed

The pieces

20 degrees was the best fit for linearization piece, and 25 degrees was best fit for travel corner piece

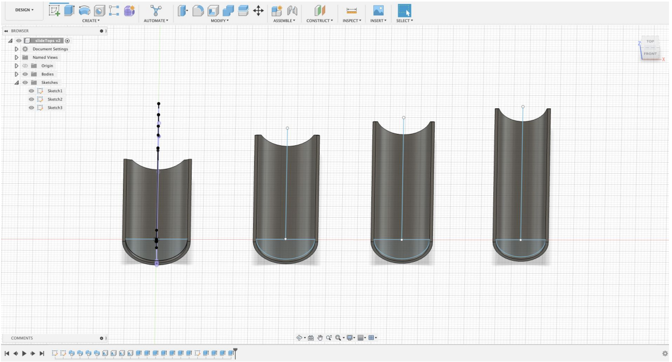
Travel + Linearization Subsystem V2

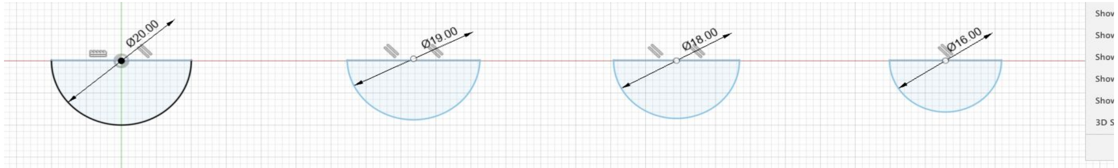
Driver Question - Travel
Given the width constraints of the lever loading system, what range of diameters does my slide need for the ball to enter the lever loading system?

Metrics of success:

- Did my ball fall into the lever loading system?
- Does the slide fit tightly into the lever loading part?

CAD
Ranging values of diameters with a 1” PLA thickness



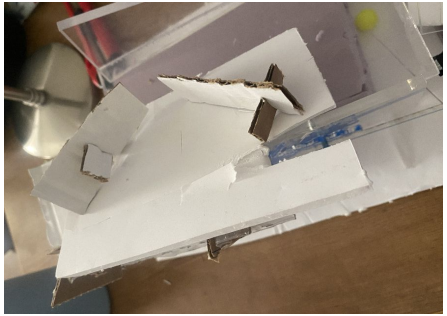


20mm was the best fit for diameter. <20mm was too loose.

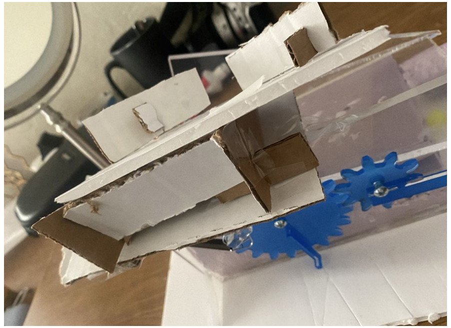
Catching & Funnel Subsystem

Prototype V1

Top



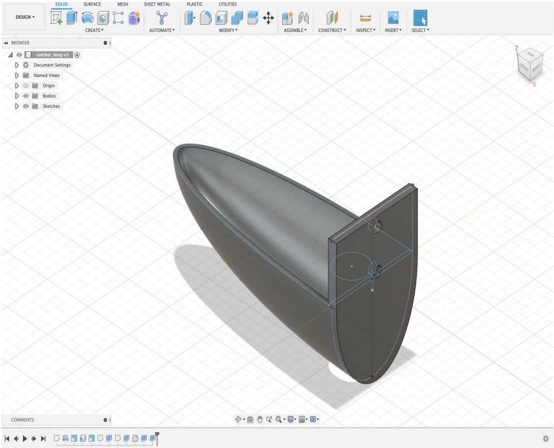
Back



**Tried to print this out of acrylic initially but it did not fit/work*

Prototype V2

Prototype V3



Driver Question:
What range of height does this need to be on the backboard for the lever to drop ball into it?

Measure of success:

- The ball was dropped into hopper with no gaps

Base holes needed to be 1.5 to 2.5 inch above baseboard.
Also hopper needed to be longer and was lengthened in V3

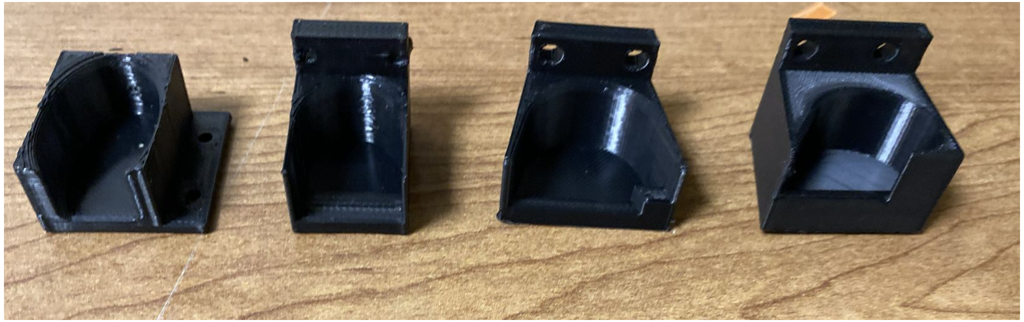
Lever Ball Holder – Extra subsystem!

Prototype levers had acrylic walls glued together as a ball catcher however this made it hard for ball to stick + insert. **Decided to 3D print the lever ball holder**

Driver Question:
- What range of angle opening does the holder need to let the ball enter but still stay during vertical rotation?

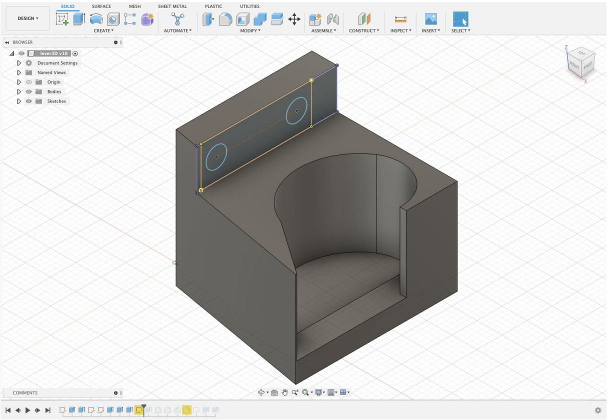
Metrics of success:
- The ball can enter the holder
- The ball does not fall out of the right edge when turned

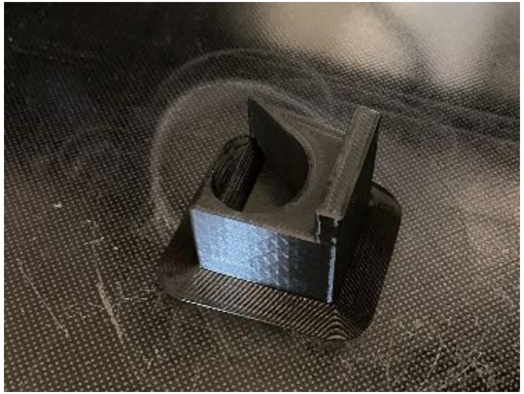
V1 V2 V3 V4 (Final)



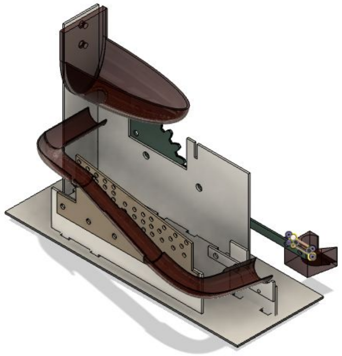
The angle needed to be curved 25 degrees each outwards. An extra inward wing was added to keep the ball in. Each version was printed iteratively

V4, CAD & 3D print

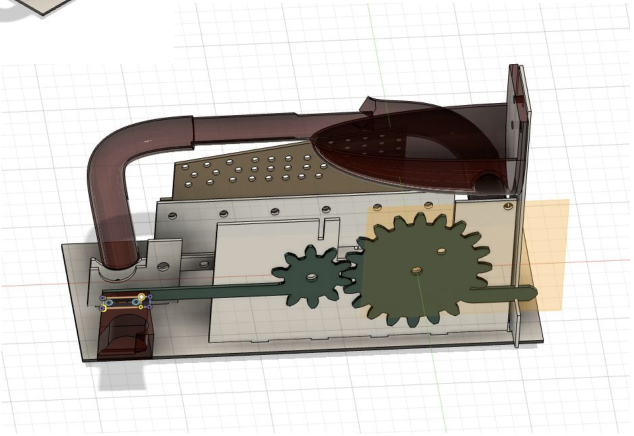


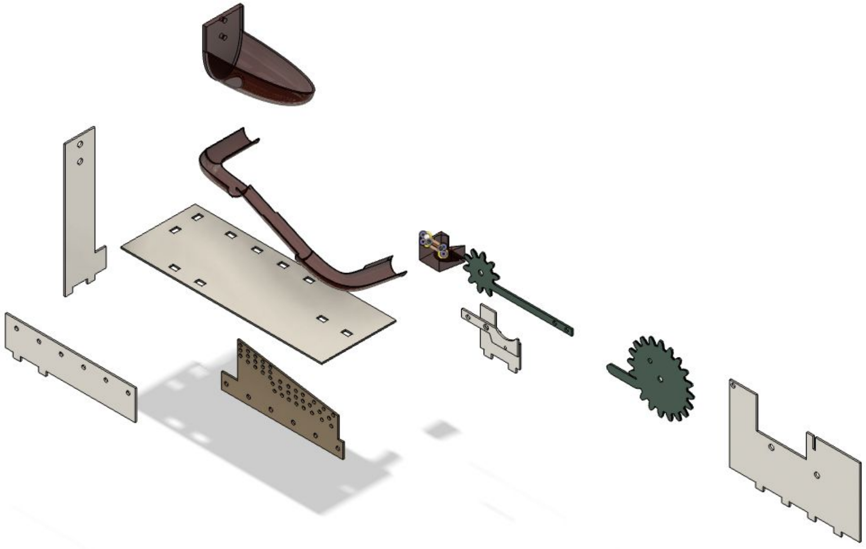


Final CAD Exploded View



All final versions prototypes were combined into one final piece and combined. Additionally a base board and bottom were created to hold everything together. The final versions of the prototypes were just repurposed for the final version (not reprinted/cut) and combined together.





Bill of Materials

Item	Item Detail	Quantity	Price per item	Total Price
Small washers	N0.10 flat washer	7	0.03	0.21
Large washers	1/4 flat washers	5	0.05	0.25
Shoulder screws	1/4 , 10-24 thread	3	1.4	4.2
Heat Inserts - Small	6-32 Brass heat-set insert	8	0.2	1.6
Heat Inserts - Large	10-24 Brass heat-insert	5	0.3	1.5
Screw - small	4-40, 1inch	1	0.04	0.04
Screw - Large	8-32, 1/2	12	0.04	0.48
Nuts - Large	8-12 hex lock nut	5	0.04	0.2
1/4 Acrylic + Scrap	Clear Acrylic	2	4	8
**3D printing was done on a personal machine*				
				16.48

Prototyping		Quantity	Price per Item	Total Price
1/8 thin acrylic		2	2.45	4.9
*Nuts + Screws used in prototyping were later transferred to real product				
**3D printing was done on personal machine*				

Total = $21.38

Next Steps...?

Remaining Gaps:

- Slide is not one piece (had to glue the prototype pieces together due to 3D Printer malfunction in the final slide)
- Machine cannot function with more than two balls (the weight of the balls overwhelmed the loading lever mechanism)

To do:

- Make slide one cohesive piece by combining the working slide pieces
- Make loading lever thinner so it will be able hold the weight of more than 2 balls (now it gets pushed down). Also make the lever handle smaller in order to have the loaded ball push against the other balls.
- Connect pieces to baseboard using screws, not glue.