Fall 2023

MEMS 411: Pinskee Ball - A Work-Energy Demo

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Mechanical Engineering Design Project
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PinSkee Ball

The Pin-Skee ball project offers an interactive and engaging way to teach children about the principles of work and energy in the contact of a science fair demonstration machine. With the launch mechanism taken from pinball, and the targets from skeeball, the device asks it's users to pull back a light compression spring, load a ball into the tee, and release the spring plunger launching the ball off a ramp towards the targets. The distance the spring is pulled back gets measured by a sensor and sent through a computer program calculating the energy stored within said spring. By providing a live-updating digital display showing this energy number, the player can match the target amounts of energy and make the ball go into each spaced hole. By pulling the plunger and the spring further back, the third and highest target can be reached, and vice versa for the first, closer target. The ramp and launch tee were assumed to have no friction in the case of the computer calculations as a relatively frictionless material, Masonite, was used for their construction. Emphasis was put on experimentally testing the spring constant, the essential value for calculating the mechanical energy added into the system. The launch angle of the ramp was calculated with a specific horizontal shooting distance and vertical heigh of each hole making the device not overly large. Safety elements were taken by adding rails to the side of the device so no balls fly over the top when launched. Additionally, a ball return system was built in under the device so all balls shot would be returned to the user either back down the ramp, or through the return within 8 seconds of launching.

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1 Introduction

The following project is intended to be a Pinball-Based Conservation of Energy Demo/Game for Science Museum. Using both pinball and skeeball characteristics, this device will give kids thorough knowledge on work energy systems in a fun and interactive way. A user will pick an object from ones of varying masses and place it in the spring system. Based on how far back the spring is pulled, a displacement sensor will be used to calculate the total work in the ball at that specific distance. The user will then compete to try to hit three different targets, each requiring a different amount of work to reach the target. The idea is that kids will learn that changing the distance pulled back on the spring, changes the work put into the ball thus changing the target the mass hits each time.

2 Problem Understanding

2.1 Existing Devices

Existing devices inspire our work-energy science museum display by taking the concept of a skee-ball machine shooting balls into multiple spaced holes, the spring-loaded mechanism of a pinball machine, and the different test objects on a car derby track. The three are combined to create a demo where multiple weighted balls will be launched via a spring-loaded plunger toward holes at different heights.

2.1.1 Existing Device #1: Skee-ball Machine

Figure 1: Skee-ball Machine (Source: Skeeball.com)

Link: https://skeeball.com/shop/?campaignid=18392415023&adgroupid=140173895663&keyword=skee%20ball%20machine&device=c&gclid=Cj0KCQjw0vWnBhC6ARIsAJpJM6daCR9d9odhvzlWyCJHzsdMNY2RazkGlVsddrBvTv-kZJ4_rY0KWFYaAmdWEALw_wcB

Description: The skee-ball machine is a classic arcade game where the player rolls multiple balls up a ramped surface into holes associated with point values. The more force the user applies to the ball, the higher the ball flies off the ramp towards the upper more challenging holes. By adjusting this force, and aiming correctly, the player wins by earning as many points as possible. The game makes the user conscious of the force being applied to the ball, and if they miss the hole, they must adjust their next launch to compensate. This translates to our device as our holes will be spaced to require different amounts of energy to hit.

2.1.2 Existing Device #2: Pin-Ball Machine

Figure 2: Pin-ball machine (Source: The Pinball Company)

Link: https://www.thepinballcompany.com/product-category/pinball-machines/
Description: The pinball machine is another arcade game using a spring-loaded launch system to shoot a small metal ball into a series of obstacles in the game. The ball adds points when bouncing off the obstacles, and the user must keep the ball in play with controlled flippers. We will adapt the plunger launch to our work-energy demonstration to add the consistency and dependability of the pre-loaded spring. This will allow us, with the known spring constant values, to display the work the user applies to the plunger when launching the different balls.

2.1.3 Existing Device #3: Derby Track

Figure 3: Derby car track (Source: pinewoodderbycars.com)

Link: https://derbymagic.com/tracks/
Description: The derby car track is a children's toy coming in many different orientations and sizes where the user builds a small wooden car and puts it at the top of a hill. Whichever car is the heaviest and most aerodynamic reaches the end of the track first. This concept will be adapted by using multiple different weighted balls to demonstrate the difference mass makes in the use of energy in a mechanical system. Like the derby track, the heavy ball will not be able to reach the higher holes to visually teach the user about the importance of mass in work-energy models.

2.2 Patents

2.2.1 Skee Ball Game Apparatus (US2724594A)

This patent outlines the usage and building for a skee ball game apparatus. The unit is defined as an indoor games apparatus in which small balls, discs, or other objects are moved from one side of the table to another by being rolled or slid. Additionally, the patent outlines that the small balls or discs are projected into the air by a jump to take aim at a target. The game was first referred to in the patent as "target bowling." As the images below describe, the patent outlines the overall shape and design of a skee ball game. This is helpful for our project because we are designing a game apparatus of "pinskeeball" that combines a pinball machine plunger with a skee ball game apparatus. This patent outlines the overall design of a skee ball machine, including the take-off ramp, the ball collection in the back, and the gutter return.

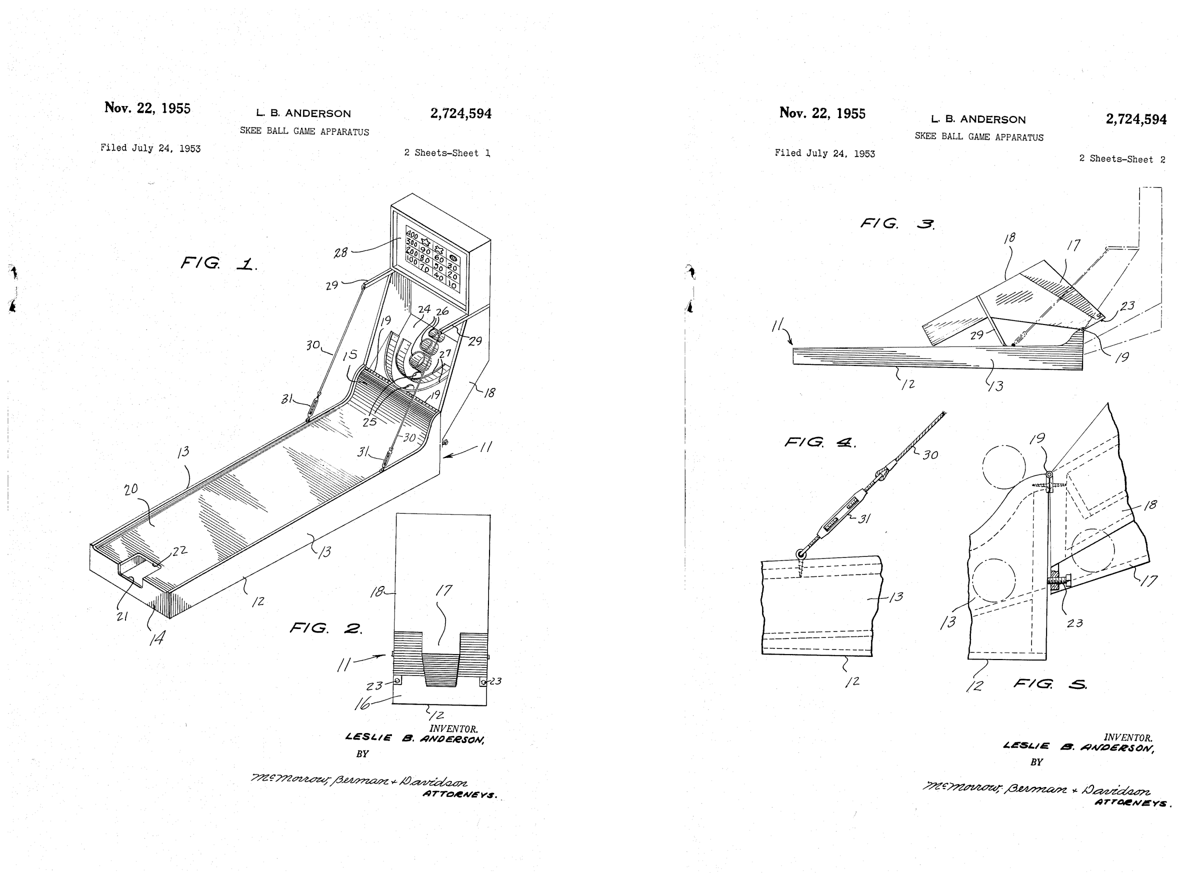


Figure 4: Patent Images for Skee Ball Game Apparatus

2.2.2 Ultrasonic Distance Sensor (US4918672A)

This patent aims to improve current ultrasonic distance sensor technology by utilizing a single element of the sensor to both send and receive the ultrasonic wave in which distance is measured. The transmitting element transmits a single ultrasonic wave. Upon the wave rebounding against the intended object, the ultrasonic wave is then read by the same element that transmitted the initial ultrasonic wave. The device then measures the time between the transmission and the arrival of the wave to determine the distance of the desired object. This patent aims to utilize and improve upon current ultrasonic distance sensor technology by decreasing the "noise" that can occur when used in "busy" areas with their respective machines. The transmitting and receiving element of the ultrasonic distance sensor is driven by a single timing signal.

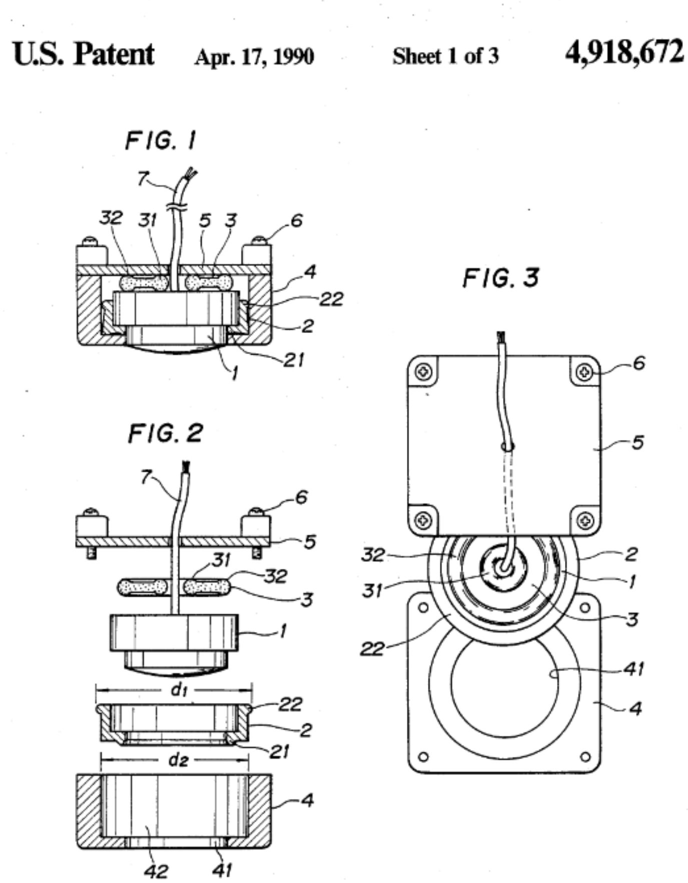


Figure 5: Patent Images for Ultrasonic Distance Sensor

2.3 Codes & Standards

2.3.1 Toy safety specification - Consumer safety (ASTM F963-17)

This ASTM international standard gives the safety specifications for toys in the US. It ensures that any toys used are not choking hazards for young kids. This is relevant because we will be using marbles or other small objects for the science demonstration. The idea is that kids will be testing the device, so it is important to have safety standards for the objects used. This specification covers the necessary guidelines for the requirements and test methods for toys meant for children less than

14 years old.

2.3.2 Electrical Safety Standard (UL 60950-1)

This electrical safety standard is intended to give the safety guidelines for the use of any electrical devices in the project. If we choose to add any sensors or other devices that need electricity, this standard is relevant and important. This specific standard gives a guide for the safety of information technology equipment. It gives benchmark requirements for the electrical components and systems of our device for all components under 600V.

2.4 User Needs

2.4.1 Customer Interview

Interviewee: Dr. James Jackson Potter
Location: Jolley 110, Washington University in St. Louis, Danforth Campus
Date: September 8^{th}, 2023
Setting: We presented our idea for a work and energy demonstration based on pinball and skeeball. The customer listened to a few different ideas and drew them on the whiteboard. We discussed competitive elements and specifications for a design that showed our concepts while being fun for kids. The whole interview took place over an hour in Jolley 110.

Interview Notes:
What safety parameters should we consider for the museum? Any specific testing requirements?

- There should be guardrails in place to keep the ball from flying off the device.
- It is not necessary to enclose the skeeball area.

What ages should the device target?

- 6-8 year olds

Would it be beneficial to incorporate a competition/arcade-like element?

- Yes, it should be fun and engaging. Kids like to win.

Are there any size constraints for the device?

- The size of a Jolley 110 table seems right.

How many different values should we incorporate for each variable (friction, mass, spring constant)?

- Do not vary friction
- You only really need to vary the mass of the balls

Does it need to be portable?

- It should be able to be moved by 2 people.

2.4.2 Interpreted User Needs

The users need the device to be fun and engaging while demonstrating the concepts in a way that is easy to understand. The device also needs to be safe and easy to use for kids aged 6-8.

Table 1: Interpreted Customer Needs

Need Number	Need	Importance
1	The device is easy to transport	3
2	The device demonstrates the transfer of work to kinetic energy	5
3	The device is visually appealing	3
4	The device is easy to use	4
5	The device has a fun competitive element that is engaging	4
6	The device is safe for children	5

2.5 Design Metrics

Table 2: Target Specifications

Metric Number	Associated Needs	Metric	Units	Acceptable	Ideal
1	1	Total weight	lb	150	100
2	1	Total surface area	ft^2	< 24	< 20
3	3,5	Rating of "entertainment" by class focus group	avg. score	$> 3/5$	$> 4/5$
4	4	"user-friendly" rating from class focus group	avg. score	$> 3/5$	$> 4/5$
5	2	Number of balls of different masses	integer	2	3
6	2,4	Range of work necessary for "goal"	J	2-50	5-25
7	6	Number of times ball falls out of device in 10 tests	integer	1	0
8	6	Diameter of the balls – Toy safety specification - Consumer safety (ASTM F963-17)	in	> 1.25	> 1.25

2.6 Project Management

The Gantt chart in Figure 6 gives an overview of the project schedule.

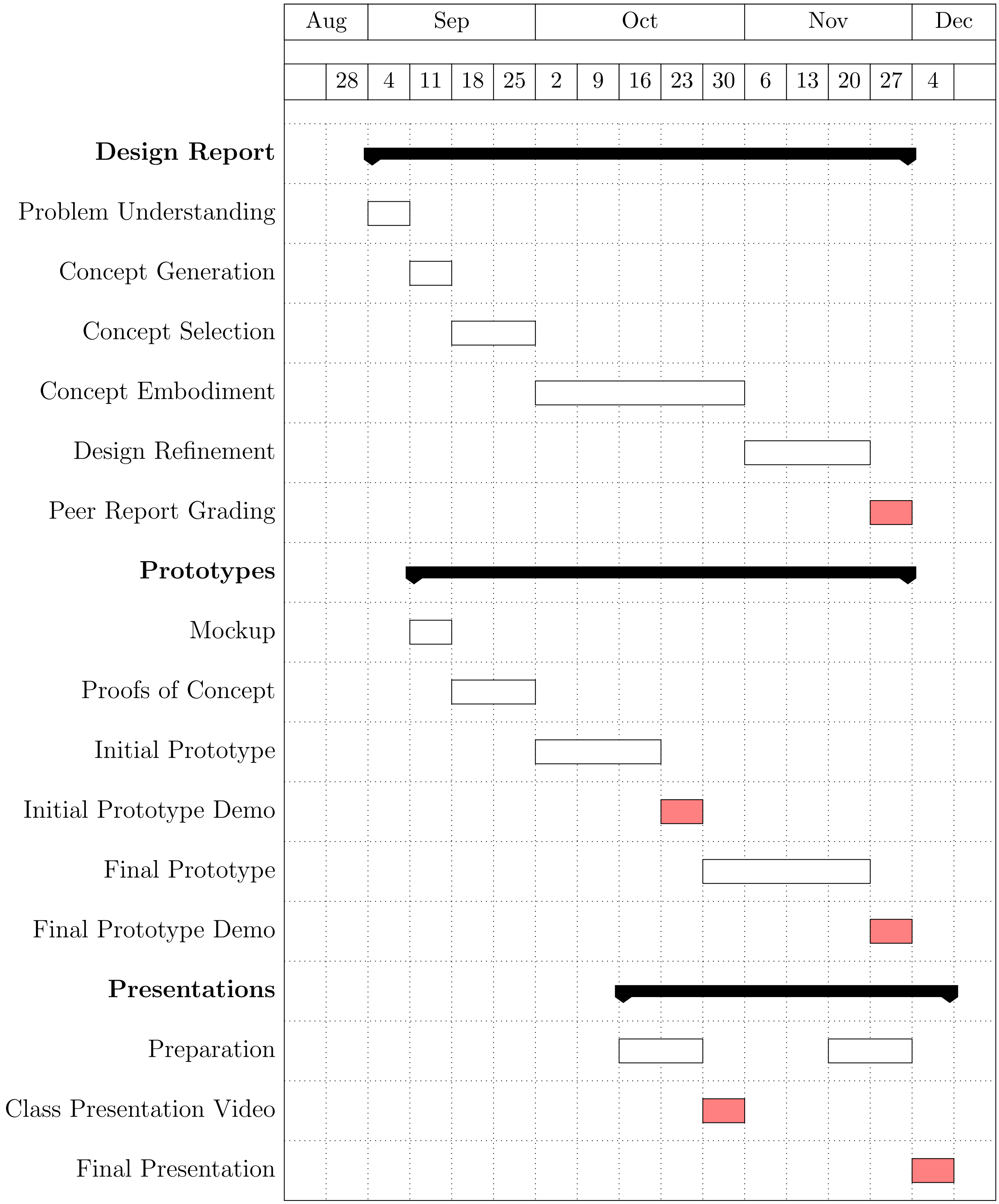


Figure 6: Gantt chart for design project

3 Concept Generation

3.1 Mockup Prototype

Our mockup was a great initial concept generation. It allowed us to test different masses and learn how much work goes into hitting each of them. With the mock up, we were able to play with the height of the ramp and learned that a steeper slope is better for hitting the higher targets as long as enough work was applied. Consistency is going to be a big factor in our design and we are going to have to create a sound spring system with little inconsistencies when hitting targets.

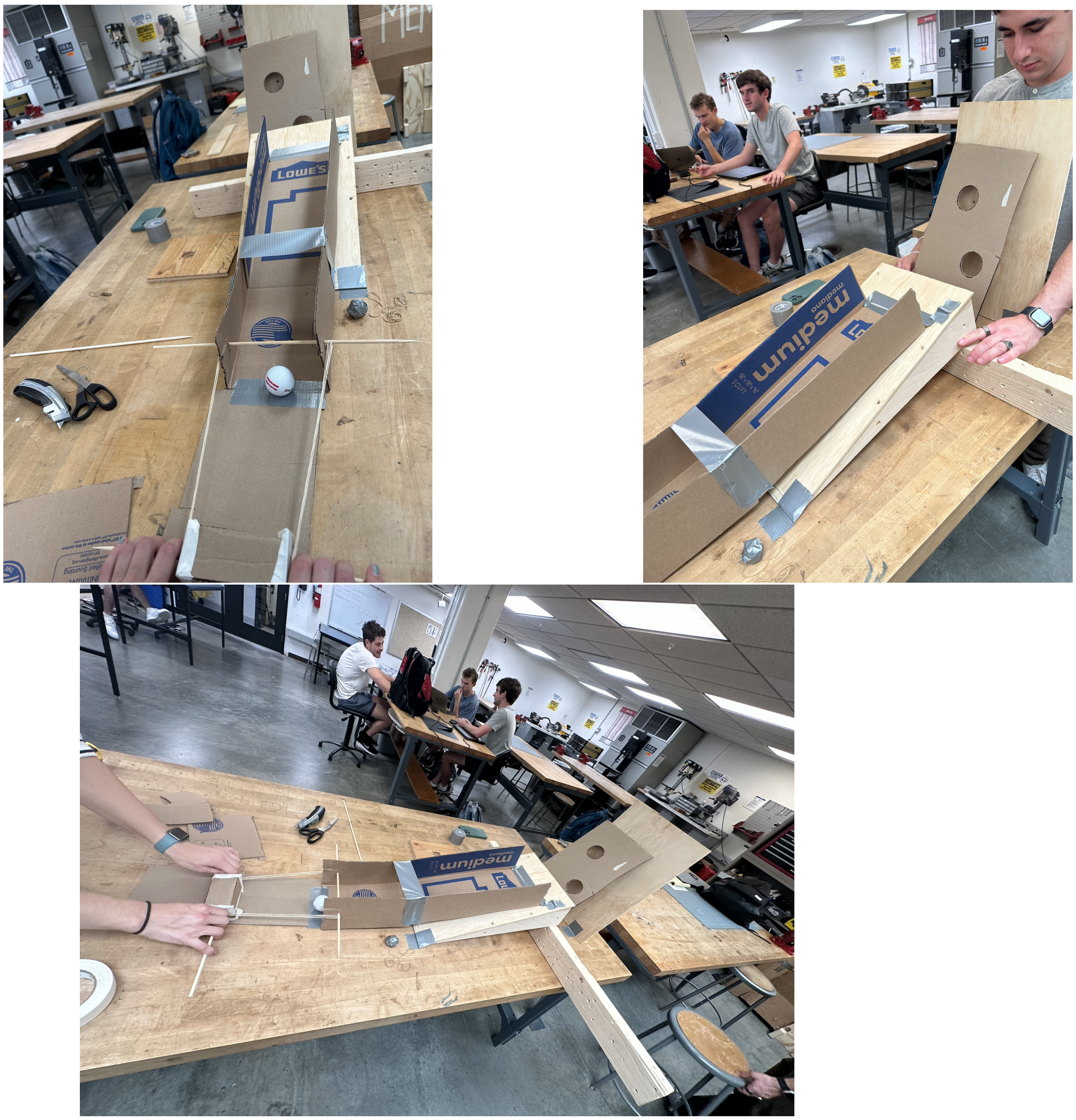


Figure 7: Images of Mockup Prototype

3.2 Functional Decomposition

The overall goal of this device is to teach about work-energy systems. Users will learn how changing different masses changes the work needed to push the object to hit different targets. The main sub functions of the device include hitting a ball towards a target, having a goal for the ball to hit, displaying the work put into the system, launching the ball towards the goal as a projectile, and keeping the ball on the ramp.

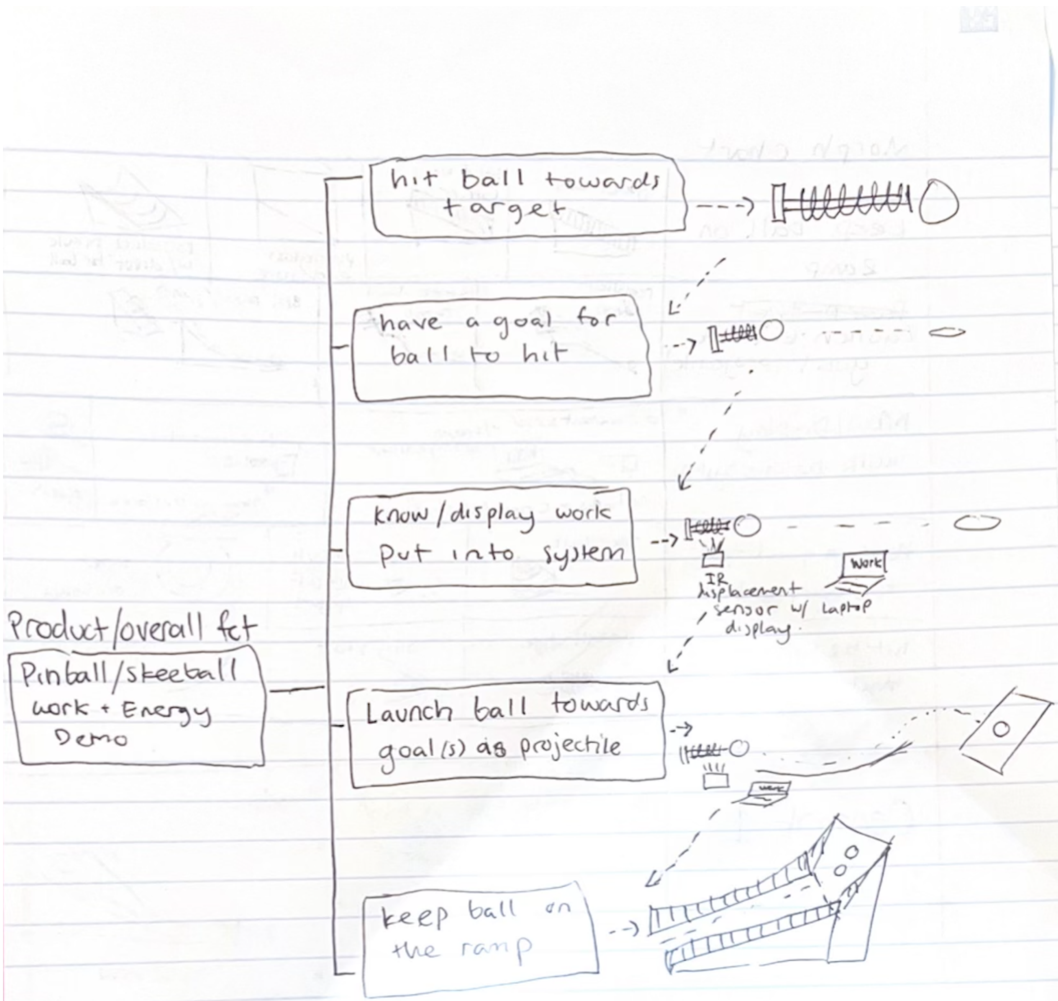


Figure 8: Function tree for Pinball/Skeeball device, hand-drawn and scanned

3.3 Morphological Chart

The morphological chart extends from the function tree. For each of the sub functions, 3 different solutions are present. The different solutions show different ways of configuring the device. Later on, one solution from each category will be picked for the final prototype.

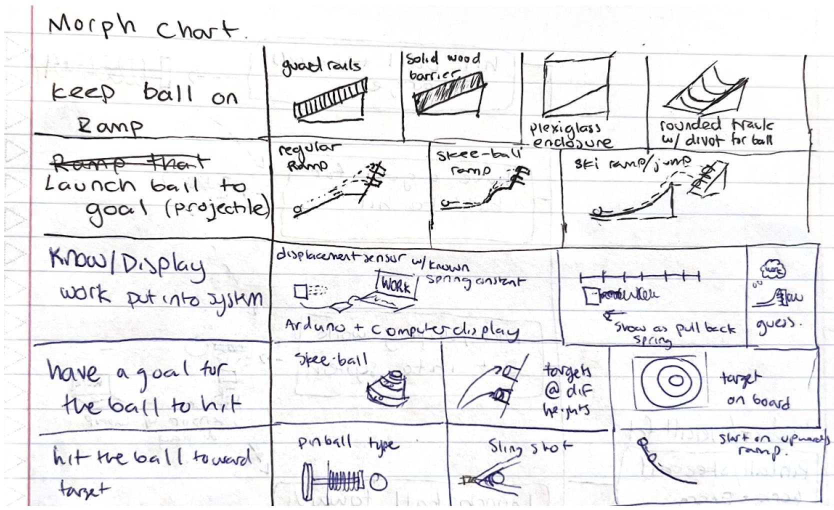


Figure 9: Morphological Chart for Pinball/Skeeball device

3.4 Alternative Design Concepts

3.4.1 Concept #1: Jump Ball

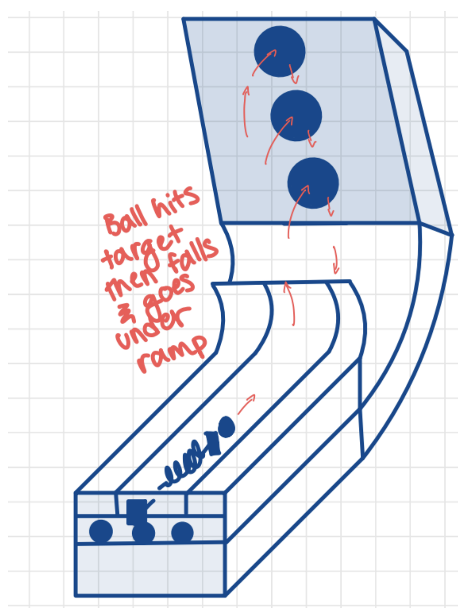


Figure 10: Sketch of the device with a hittable target

<u>Description</u>: A spring system device pushes a ball on a ramp which slopes up and launches the ball into the air to hit three different targets. A user initially pulls back the spring and releases it to hit

the ball up the ramp. The ramp is slightly angled and then goes off an steep jump to fly up and hopefully hit one of three targets. The targets are stationary in this concept so after the ball hits the target, it falls down into a 'catch shoot' and rolls back to the front of the device.

3.4.2 Concept #2: Pinskee Ball

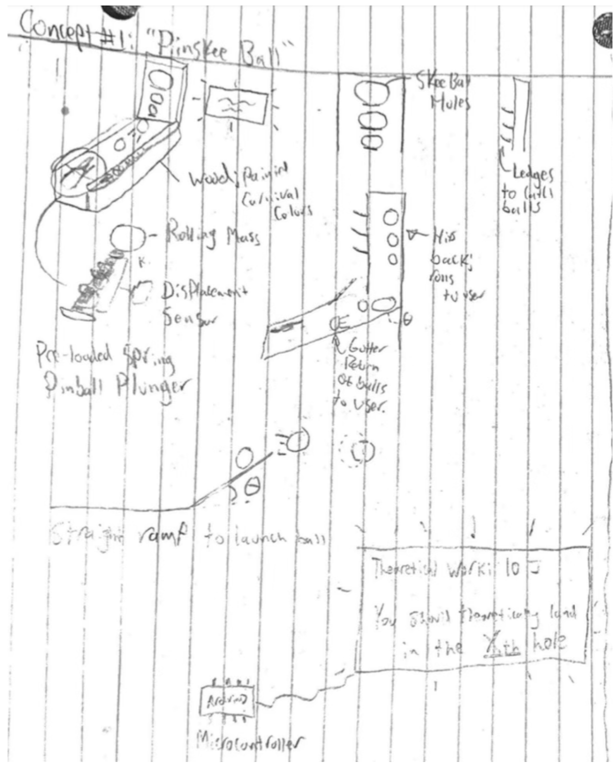


Figure 11

Description: The Pinskee Ball concept uses a pre-loaded pinball plunger to propel a skee ball across the skee ball machine apparatus and into skee ball target holes. By building the target holes at specific heights, we can calculate the theoretical potential energy generated by the displacement of the pre-loaded spring of the pinball plunger. We will display the "sweet spot" in which the user could theoretically provide enough spring potential energy to the skee ball to make it into the respective hole. This is possible because we know the stiffness of the spring, the mass of the skee ball, and the displacement of the spring using a displacement sensor. The pinball plunger propels the skee ball up the ramp and into the targets. The balls are returned via an angled gutter system using no extra mechanical energy. The device also has an associated screen to display the target the user should theoretically be able to "score" in, as well as displaying the ever-coveted "You Win!" or the dreadful "You Lose!".

3.4.3 Concept #3: Funnel Ball

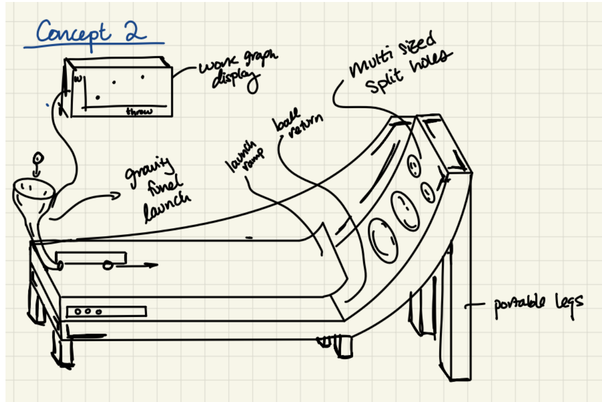


Figure 12: Funnel Ball Machine Set Up

<u>Description</u>: The funnel concept uses a multi-stage raised funnel tube to provide the initial energy push to the ball. By building the inputs at specific heights, the concept that the ball needs certain amounts of potential energy to make the shot in each hole can be further demonstrated to the user. The funnel also eliminates the potential for the spring system to be too hard for the user to pull back and release. The device also has an attached screen plotting the work applied to the ball for a series of the user's shots. The ball will fly through the hole into a return pipe under the main ramp.

3.4.4 Concept #4: Instant Digital Display With Spring

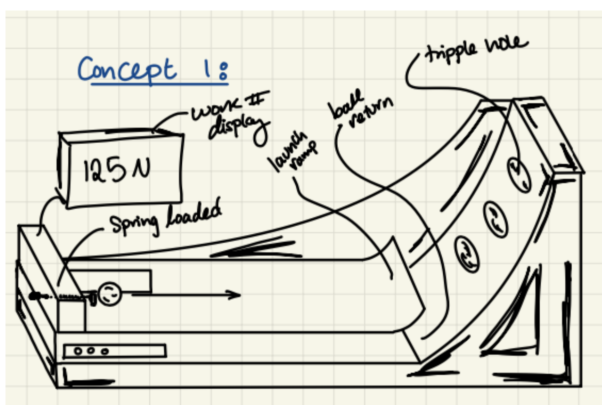


Figure 13: Instant Digital Display Machine Setup

<u>Description</u>: The instant digital display uses a spring-loaded device with a measured spring constant. The device will know the travel of the spring as the user pulls the plunger back, therefore knowing the force being applied to the ball in conjunction with collision equations. With a sensor mounted checking the velocity of the ball, the device will be able to display the work applied to the ball after each shot the user takes. The ball will fly through the hole into a ball and return under the main ramp. When the ball flies through the hole, this system uses the same ball-return as the funnel machine.

4 Concept Selection

4.1 Selection Criteria

The following selection guide compares each criterion to the others determining which parameters are most important when designing and selecting the final concept. The data can be read as row factor is the displayed number of times more important as the column factor.

	Easy to Transport	Demonstrates transfer work to kinetic energy	visually appealing	Easy to Use	Fun and competitive	Safe to use	Row Total	Weight Value	Weight (%)
Easy to Transport	1.00	0.14	3.00	0.33	0.20	0.33	5.01	0.07	7.25
Demonstrates transfer work to kinetic energy	7.00	1.00	5.00	5.00	3.00	3.00	24.00	0.35	34.71
visually appealing	0.33	0.20	1.00	0.33	0.20	0.33	2.40	0.03	3.47
Easy to Use	3.00	0.20	3.00	1.00	0.20	0.33	7.73	0.11	11.18
Fun and competitive	5.00	0.33	5.00	5.00	1.00	0.33	16.67	0.24	24.10
Safe to use	3.00	0.33	3.00	3.00	3.00	1.00	13.33	0.19	19.28
						Column Total:	**69.14**	**1.00**	**100.00**

Figure 14: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

The following weighted scoring matrix uses the weights determined in 14. Demonstrating transfer work to kinetic energy has the highest weight and fun and competitive is a close second. The first and second placed concept were very close in score. Concept #2 scored slightly higher at 1.783 with concept #4 at 1.735.

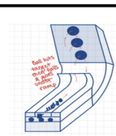
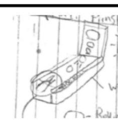
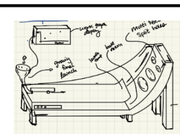
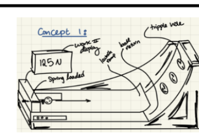
Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Easy to Transport	7.25	3	0.22	2	0.15	2	0.15	3	0.22
Demonstrates transfer work to kinetic energy	34.71	4	1.39	5	1.74	2	0.69	5	1.74
visually appealing	3.47	3	0.10	3	0.10	4	0.14	4	0.14
Easy to Use	11.18	4	0.45	3	0.34	4	0.45	3	0.34
Fun and competitive	24.10	4	0.96	5	1.21	2	0.48	4	0.96
Safe to use	19.28	3	0.58	3	0.58	4	0.77	4	0.77
	Total score	**1.542**		**1.783**		**1.253**		**1.735**	
	Rank	**3**		**1**		**4**		**2**	

Figure 15: Weighted Scoring Matrix (WSM) for choosing between alternative concepts

4.3 Evaluation Results

We selected the following criteria to be critical aspects of our concept that design: Easy to Transport, Demonstrates transfer work to kinetic energy, visually appealing, Easy to Use, Fun and competitive, and Safe to use. Using the Analytical Hierarchy Process (AHP), we determined the scoring matrix weights for our Weighted Scoring Matrix (WSM) by comparing the importance of concept aspect against one another. As outlined in the "Weight (%)" column of our AHP, we should prioritize that our concept demonstrates transfer work to kinetic energy as the most important concept design which makes sense because our device is designed to be a museum exhibition to teach young children about work and energy. Next, our AHP determined that we should prioritize fun and competitive aspects of our concept as the second most important thing. Children tend to be competitive and want to win, so designing an exhibition that serves as a game taps into their competitive natures to teach them about work-energy. Next, our AHP determined that our concept should be safe to use. This is also very important because users will be shooting metal balls at targets with an electronic display stating if they win or lose. Safety is very important, especially in a children's demo. Next, our AHP determined that ease of transport should be our second least important design factor. Our exhibition will not be moved often as it's designed to stay in a children's museum or science museum, so this weight makes sense. Finally, our AHP determined that our concept design should be visually appealing. We were a little surprised this ranked this low, as we feel that visual appeal is a large factor in children's games.
Based on these weights produced by our AHP, we applied them in our WSM for our alternative design concepts. Based on our selection criterion and AHP determined weights of our selection criterion, concept 2 is the design we'll be using. Concept 2, or "Pinskee Ball" is a visually appealing concept based on the original design of a skeeball ramp and a pinball machine. The device is appealing and has safety mechanisms in place by creating a gap between the ramp and the targets so the call does not rebound back at the user as the gap will be designed to be large enough to catch balls that richocet. Additionally, the concept embodies all of our selection criteria and prioritizes functionality over aesthetics. The device uses a metal ball and a spring to demonstrate transfer of energy from potential elastic energy to kinetic energy of the ball and then shooting it into the target. We can demonstrate work of the ball and spring and energy transfer of the ball in this demo using a fun, game like element for a children's demo of work-energy.

4.4 Engineering Models/Relationships

The following four criteria govern our final concept selection in the way of the motion of the ball, the projectile launch of the ball off the ramp, the work displayed to the user, and the estimated spring constant.

Model 1 discusses the spring equations used to select our plunger. Using the following equation, we will find the right spring that isn't too hard to pull back for the user but will still have enough power to launch the ball through the holes on the backboard. We will use the correct balance between the pull-back distance and the spring stiffness to make the shot possible. The spring constant, K, is known but might vary for different tests. The displacement, x, is also known using the IR distance sensor. Both K and x will be used to determine the potential energy of the system.

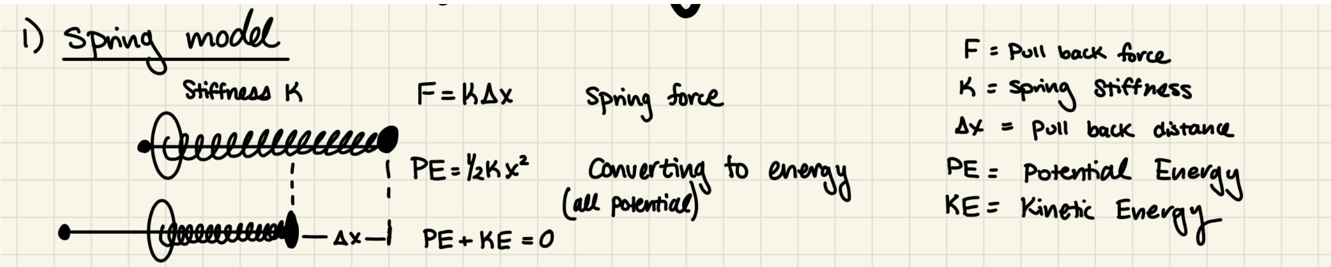
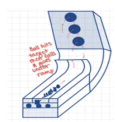
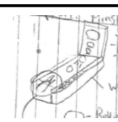
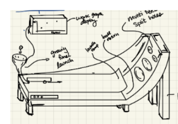
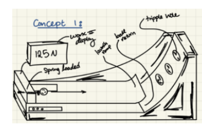


Figure 16: Spring Potential Energy Model Equations

Model 2 discusses the motion equations used to describe the height of the ball's maximum arc with the velocity coming off the ramp from the spring. All x distances, as well as starting velocity and launch angle to determine the height of the system at different distances and velocities. This will help determine where to place the targets.

Alternative Design Concepts		**Concept #1**		**Concept #2**		**Concept #3**		**Concept #4**	
									
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
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Easy to Use	11.18	4	0.45	3	0.34	4	0.45	3	0.34
Fun and competitive	24.10	4	0.96	5	1.21	2	0.48	4	0.96
Safe to use	19.28	3	0.58	3	0.58	4	0.77	4	0.77
	Total score	**1.542**		**1.783**		**1.253**		**1.735**	
	Rank	**3**		**1**		**4**		**2**	

Figure 17: Model 2: Projectile Motion Equations

Model 3 discusses the work put into the system as it relates to the force applied to the spring. The user puts work into our system by pulling back the spring-loaded piston. To determine the work put into our system, displacement data, δ can be collected with an IR distance sensor. Using δ as an input, along with a known spring constant k, Equation 1 will give us an estimate for the force, F, applied to the piston. Equation 2 will give us an estimate of the work put into the system based on that calculated force.

$$F = k\delta \tag{1}$$

$$W = F\delta = k\delta^2 \tag{2}$$

Model 4 discusses the force balance that can be used to estimate the spring constant of our spring-loaded piston. The process involves a known mass, m, and a method of measuring the displacement δ. In this method, the spring is held vertically in a vice with the only degree-of-freedom being the spring motion. The mass is placed in a manner that compresses the spring, causing a displacement that can be measured to obtain a δ value. Plugging these known values into Equation 3 will yield an estimate for the spring constant, k.

$$k = \frac{mg}{\delta} \tag{3}$$

5 Concept Embodiment

5.1 Initial Embodiment

Our prototype's performance goals are:

- Calculate and display mechanical work while pulling back the spring
- Device can hit balls into high/low target
- Return the ball in less than 8 seconds from any possible outcome

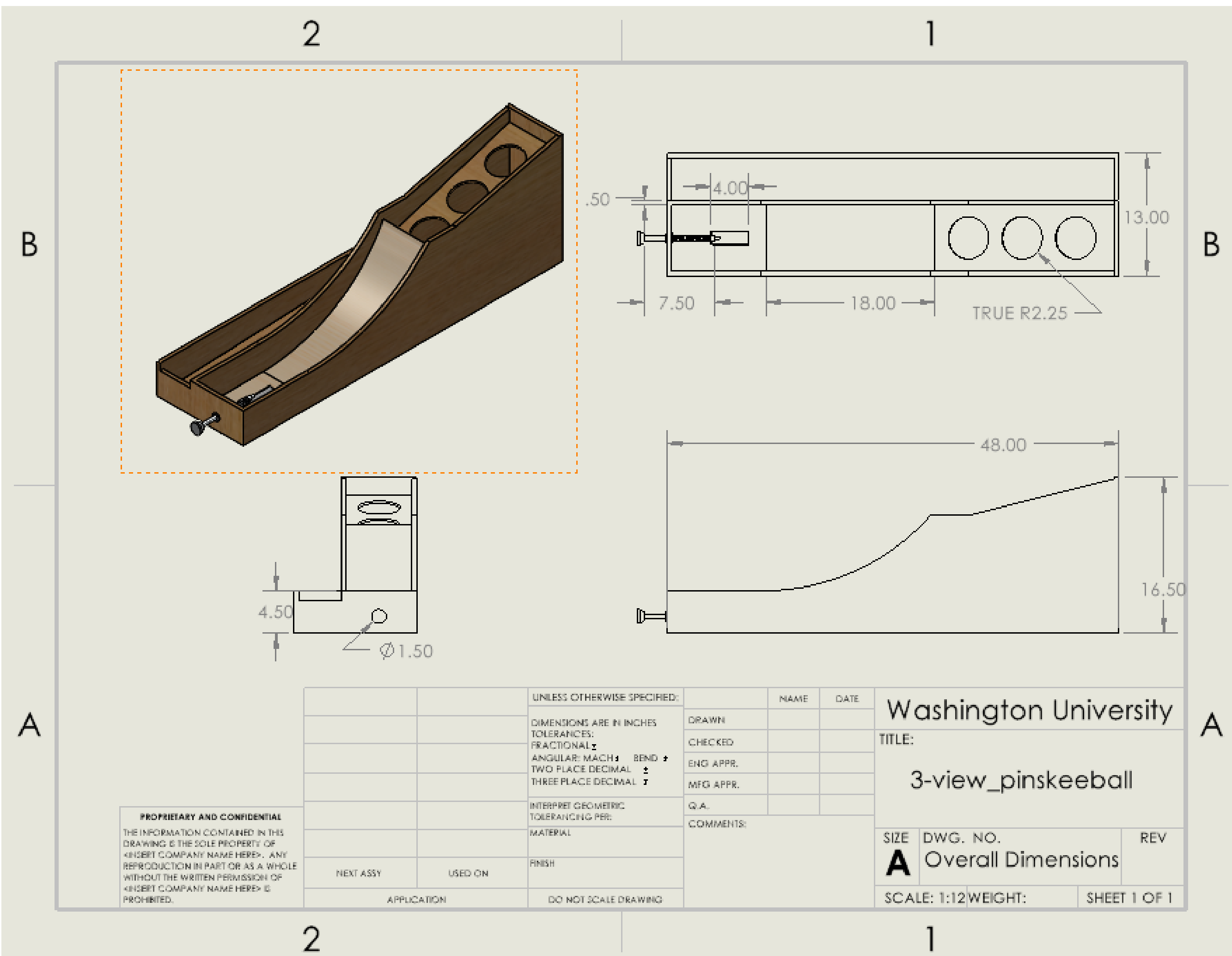

Figure 18: Assembled projected views with overall dimensions

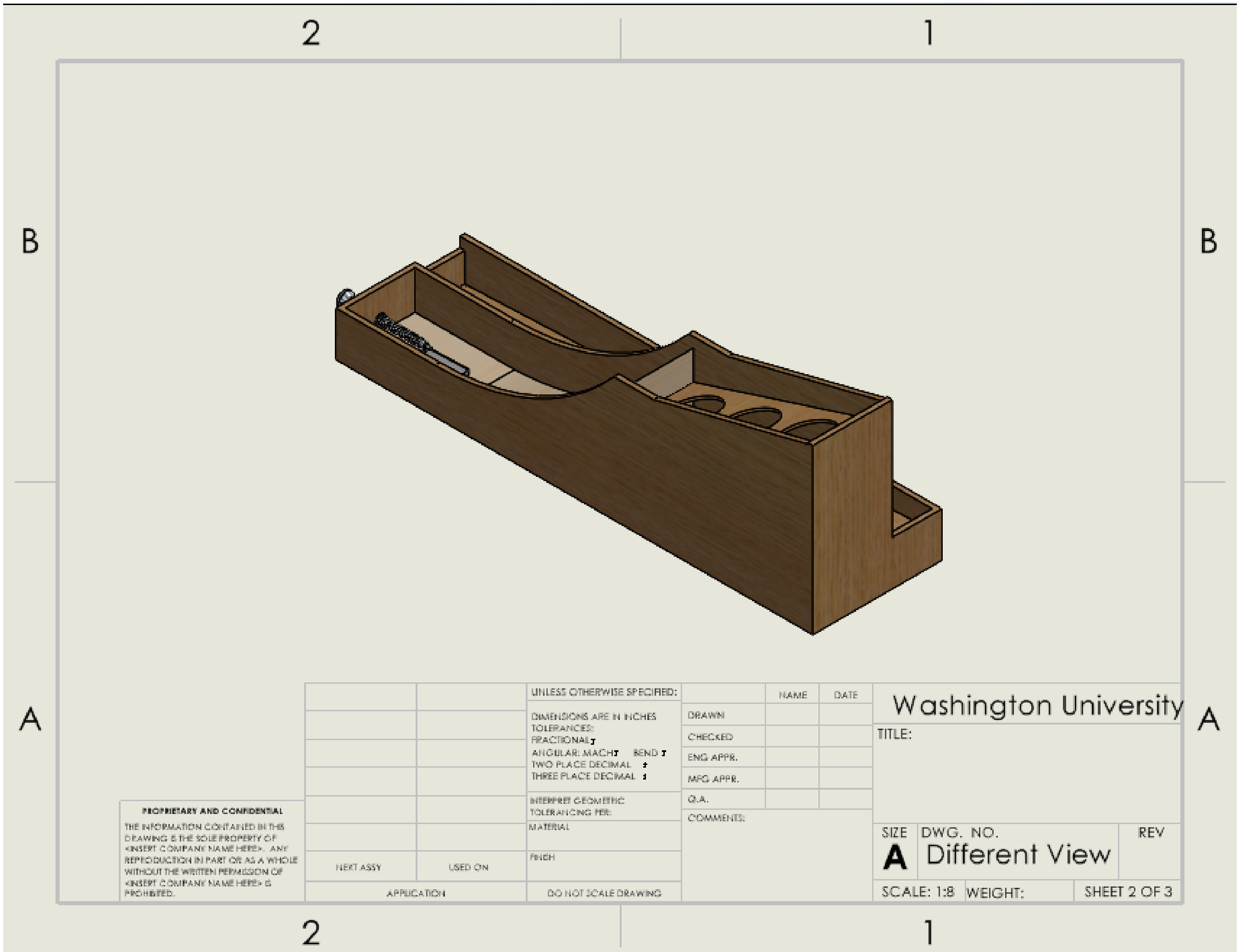

Figure 19: Assembled isometric view with bill of materials (BOM)

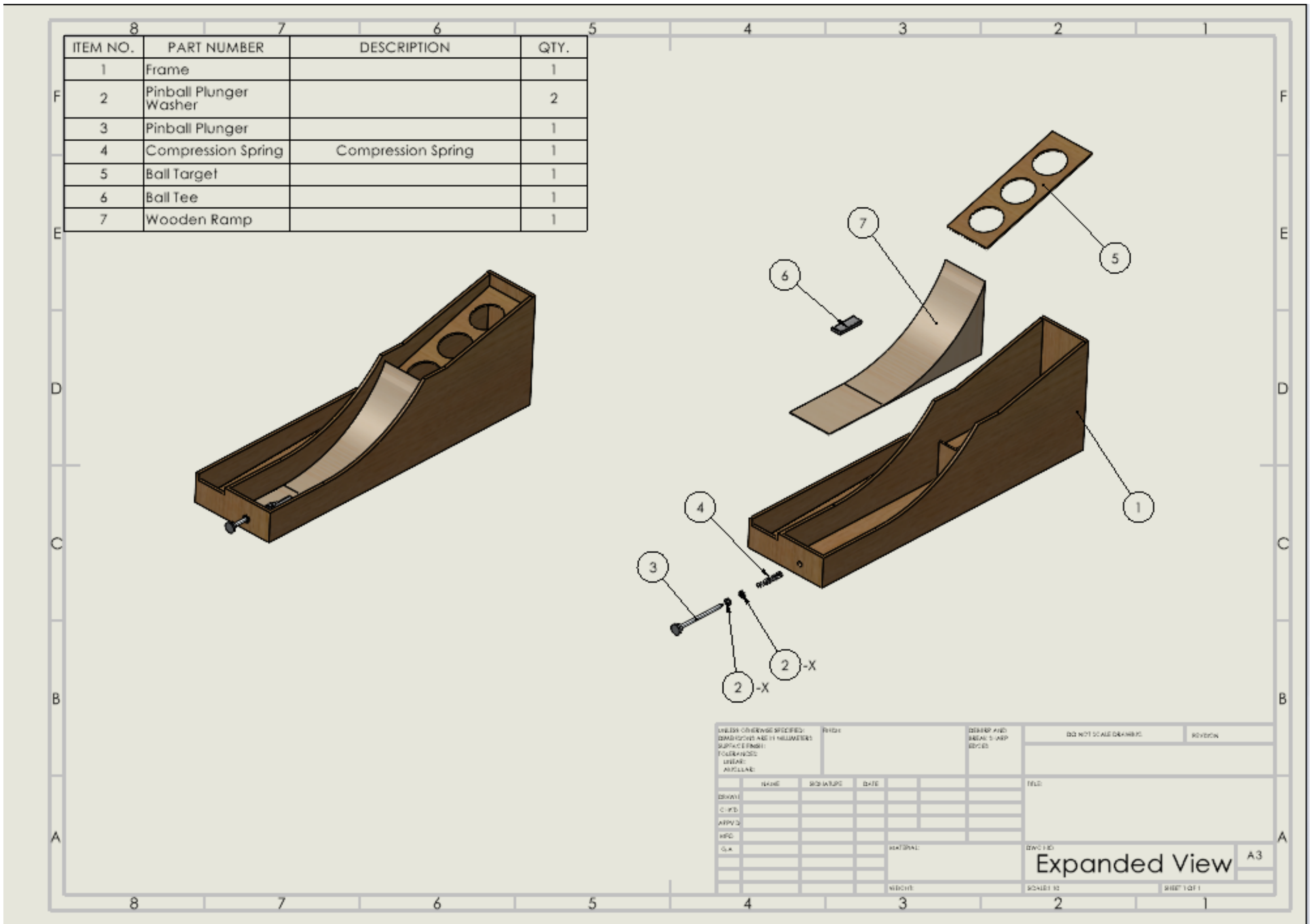

Figure 20: Exploded view with callout to BOM

5.2 Proofs-of-Concept

During Proof-of Concept testing the prototype evolved through multiple test stages. Starting with the cardboard prototype, there were many difficulties keeping the spring in place and ensuring the ball move linearly up the ramp. It was difficult to get consistent target placements with the ball as it was never hit at the same distance. With the current prototype, the base is built fully connected with a weight underneath the ramp which keeps the base from moving up when the spring is extended. The ramp was built with a flexible piece of wood which is much more sturdy than the cardboard ramp used in the initial prototype. The launch system is still in development but our goal is to create a tee that will hold the ball in a consistent placement and when the spring is pulled back the ball will fall back slightly with it and stop when it hits a small notch in the tee.

5.3 Design Changes

Our selected concept has evolved from our initial prototype, Concept 2 in Section 4.4, while retaining the key functionality of our initial prototype. Our initial prototype represented the shape of a skee-ball machine, specifically with the ramp, the take-off, and the alignment of the targets. Our selected concept keeps the usage of a pinball plunger spring to launch a ball up a ramp into a series of targets to demonstrate work-energy transfer in a fun, competitive way. One key difference between our selected concept and our initial prototype is the shape of our ramp. In our selected concept, a ball is still ”shot” up the ramp, over a ”gap,” and into a series of targets or caught in a ball return if no target is hit; however, our initial prototype displayed a flat ramp with a small hump at the end of the ramp to ”launch” the ball into the targets. The ramp of our selected prototype is curved in shape rather than flat with a small ”hump” at the end of the ramp, as shown in our initial prototype. The ball is shot up a curved ramp to hit the targets, not across a flat ramp to a ”hump.” Another change from our initial prototype to our selected concept is the vertical angle of the targets. Our initial prototype modeled the targets as fairly upright and vertical. Through our design process and prototyping phase, we found that the ”verticality” of the initially prototyped targets proved difficult for the user to hit the targets. Therefore, we adjusted our selected concept to have more ”flat” (less vertically aligned) targets for the user to hit. This ensures that the user can see varying results of work-energy by pulling the pinball plunger back different distances and still hit or miss the targets with greater odds than in our initial prototype. One final way our selected concept varies from our initial prototype is our ball return. Our initial prototype modeled the ball return as a covered ball return resembling that of a skee-ball return. Our selected concept utilizes an open-air ball return to show the user the ball return. The ball return of our selected concept still accomplishes our prototyping goal of returning the ball to the user in less than 8 seconds, regardless of shot result.

6 Design Refinement

6.1 Model-Based Design Decisions

Using model 4 in section 4.4, we calculated the spring constant using a series of masses displacing the spring to a recordable distance. Assuming that the spring converts all potential energy from the pull back to kinetic energy the following equation can be written and then used to find the projectile path of the different balls being shot. Furthermore, multiple tests were performed with different masses as shown below to obtain an average spring constant. The potential was found by using the maximum spring travel of 3.3 inches.

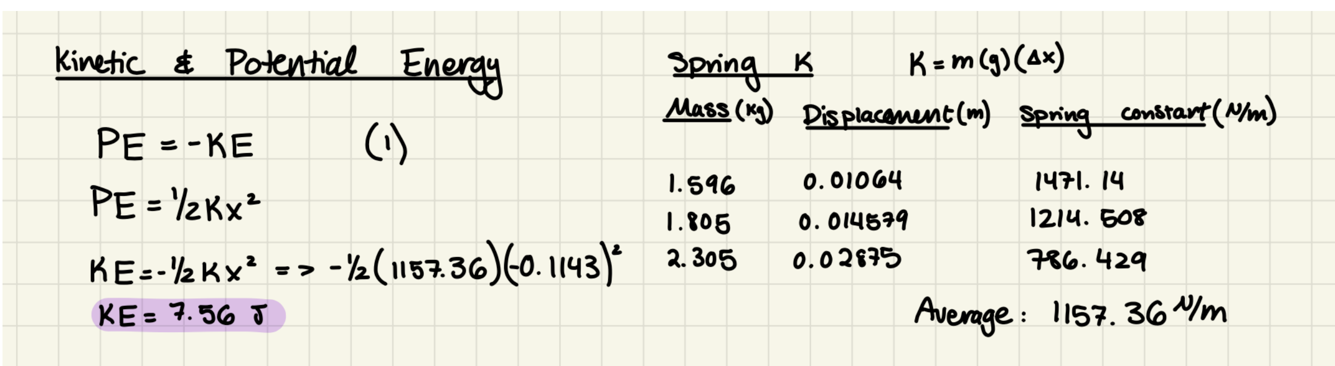

Figure 21: Kinetic Energy Calculations With Experimental Spring Constant

Therefore, with its maximum displacement, the spring system is capable of producing 7.56J of work.

The second model, seen in section 4.4, was used to calculate the angle of the ramp from the launch using set distances for each target (height and length). The following equations use the third target as an example with a distance of 42” away from the target and 12” above the launch. The following calculations assumed that the ball would travel through the hole at its maximum height, and no frictional losses would occur. Since aiming for the furthest hole, the maximum work quantity was used in the calculations. Using the following angle, the ramp's base of the curve was fabricated to match and further perfected experimentally. The following calculations show the angle used being evaluated.

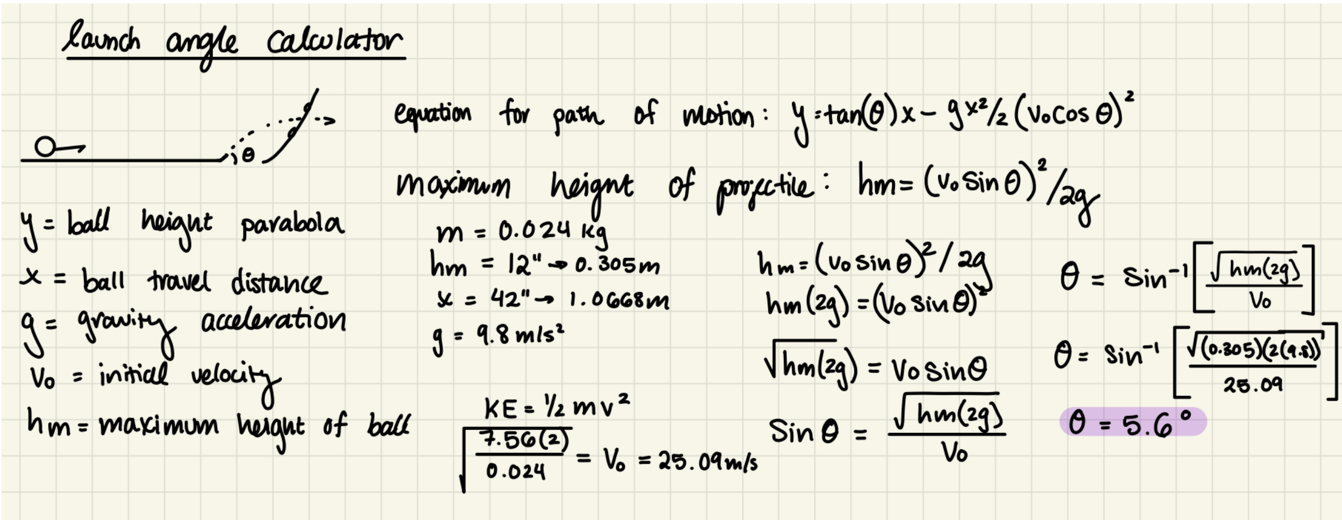

Figure 22: Ramp Angle Calculations

6.2 Design for Saftey

6.2.1 Risk #1: Ball becomes projectile

Description: If a user is in the way of the ball's trajectory, it could injure them if moving at a fast enough rate. If the ball hits the target and bounces off there is also risk for the ball to hit the user.

Severity: Marginal. The weight of the ball prevents damage from being too severe, but the ball could be moving fast enough to leave a mark.

Probability: Occasional. Getting hit by the ball at full speed would require that the body part of the user be between the launch and the target. This should not happen often, but since the game is competitive and for kids there could be instances of improper use that result in this.

Mitigating Steps: Ensure that users are not blocking the ball after its launch to decrease the probability of this event.

6.2.2 Risk #2: Spring pinching

Description: The spring is exposed and could pinch a user's fingers if they get in the way of it contracting.

Severity: Marginal. The spring is not strong enough to cause significant damage.

Probability: Likely. If the user touches the spring piston system on the inside of the device while it is deloading they are at risk of getting pinched.

Mitigating Steps: There is no reason for a user to need to touch the exposed spring. It should be ensured that users do not reach into the device except to place the ball initially. Additionally, the spring could be covered in a way that allows it to still function.

6.2.3 Risk #3: Wood failure

Description: The wood of the product could weaken over time to the point that it splits or splinters when put under stress.

Severity: Critical. Wood failure could lead to fragments of wood hitting users in the eyes.

Probability: Seldom. The device is made of strong, well-secured wood with supports, and we do not plan to use a ball heavy enough to break it.

Mitigating Steps: Check the wood for cracks consistently. The support for the target piece also helps to mitigate this risk

6.2.4 Risk #4: Electrical failure

Description: Our device has an electric component in the Arduino. If these components were to malfunction there is a risk of fire or electrocution.

Severity: Catastrophic. The entire device is wood, so a fire would not be good.

Probability: Unlikely. The Arduino is really small and will only be plugged in when the device is in use.

Mitigating Steps: Disconnect the device from power when not in use. Make sure the wires are well-secured

6.2.5 Risk #5: Spring Failure

Description: Our device has a spring that is put under cyclical stress for each game. If the spring fails under force it could fly off and hurt someone.

Severity: Critical. The injuries that could result from being hit by a flying spring could be severe. But the spring is small and not heavy enough to cause catastrophic damage.

Probability: Unlikely. The spring is not the highest quality so there is some possibility; however, it is not undergoing any extreme force.

Mitigating Steps: The spring could be covered by something so that it cannot fly off. A higher-quality spring would also mitigate this risk.

Severity of risk		Probability that something will go wrong				
	Category	**Frequent** Likely to occur immediately or in a short period of time; expected to occur frequently	**Likely** Quite likely to occur in time	**Occasional** May occur in time	**Seldom** Not likely to occur but possible	**Unlikely** Unlikely to occur
	Catastrophic				Wood Failure	
	Critical					Electrical Failure Spring Failure
	Marginal		Spring Pinching	Ball Becomes Projectile		
	Negligible hazard presents a minimal threat to safety, health, and well-being of participants; trivial					

Figure 23: Potential Risks

As illustrated in our heat map, wood failure is our highest priority risk. The ball is repetitively hitting the wood in various locations on the target and the wood encasing the targets. The wood has a higher likelihood to splinter or break and injure the user. Additionally, the force of our spring could rip or splinter the wood as our pinball plunger is embedded into the body of our device. This could injure the user on varying levels of magnitude. Next, our risk heat map illustrates we should prioritize spring pinching and the risk the ball becomes a projectile equally. The spring is exposed and could pinch the user. This could be painful, especially to our target audience of 6 - 10 year old kids. Additionally, if the ball takes an odd bounce or flies out of the physical confinements of our device, a rare occurrence, it could hit someone in the eye, forehead, mouth, or other parts of the face. Both of these risks seem to have a lower change of happening. Additionally, both our ball and spring do not have enough force to severely injure a person. Finally, our risk heat map illustrates we should prioritize both electrical and spring failure as low risks. This makes sense as our Arduino will be housed and secured. Additionally, the spring is unlikely to fully fail and provide any risk to the user if it should fail; it would simply misfire.

6.3 Design for Manufacturing

There are a total of 7 parts in our design including the frame, 2 pinball plunger washers, pinball plunger, compression spring, ball target, ball tee, and wooden ramp. No threaded fasteners were used in the design. However, many nails were used with a nail gun to connect all pieces together. The main TNC components of the device are all from the spring system. Within the spring system there is a shaft plunger, spring, and the mount flange. The shaft plunger is a necessary component as it holds the components together and keeps them in place. It allows each piece to move freely around it. The spring is objectively the most important part of the device. It helps exert pressure and increase the work put into the ball. The mount flange allows players to pull back the spring system and hit the ball.

6.4 Design for Usability

There are a couple parts of our project that might include color. The display showing work might change colors to show the best range of values to hit each target. Changing font or boldness might help those who are color blind. A vision impairment could also make it difficult to see the ball and targets. There is little aim needed to hit each target but having an impairment could still make it difficult to use the device.

A hearing impairment may cause harm to players from a safety standpoint. If you can't hear when the ball hits the target or hear it rolling down the ramp, you can't prepare for it either rolling back to you for another turn or the slight chance of it hitting something and coming back and hitting the player. Hopefully being able to see the ball is a a safety factor in itself. I am not sure how else to change the design to help with this impairment.

The main user interaction with this device is pulling back a spring. For people that have a physical impairment, this could cause difficulty. Depending on the spring used and associated spring constant, it might be slightly difficult to pull back the spring if it is stiff. Having arthritis (for example) will make it harder for a player to pull the spring back all the way and enjoy all aspects of the device. Using a less stiff spring will help with a physical impairment.

If a player has a control impairment, they might not understand the usage of the sensor/display system. The idea is that the sensor data will be used to calculate the work in the spring at different distances and using that value the user will decide when to release the spring. A control impairment may cause difficulties in a player's ability to do so. Explaining the instructions very clearly before will help people fully understand what is happening.

6.5 Design Considerations

Table 3: Factors considered for design solution

Design Factor	**Applicable**	**Not Applicable**
Public Health		X
Safety	X	
Welfare	X	
Global		X
Cultural		X
Societal	X	
Environmental		X
Economic	X	

Table 4: Contexts considered for ethical judgments

Situation	Applicable	Not Applicable
Global context		X
Economic context	X	
Environmental context		X
Societal context	X	

7 Final Prototype

7.1 Overview

The final prototype is shown below in figures 24-27. The prototype successfully achieved all of its performance goals. The first goal was to calculate and display the mechanical work done while pulling the spring back. This was achieved by using a distance sensor attached to an Arduino. A red piece of paper was used as an object for the sensor to track to seen in figure 28. As the spring is pulled back, the distance is measured and analyzed in the arduino code A. The distance sensor tracks the front of the spring pulled back so to determine the length pulled back by the user, the distance the sensor reads is subtracted from the maximum distance the spring can be pulled back. When the spring is at its zero position, the sensor will read the full spring distance meaning the spring has been pulled back 0cm. The calculated distance is then used to calculate the work done in the spring and printed on the screen. The next goal was to hit three different targets. This goal was the hardest to achieve consistently at first. A lot of the error most likely comes down to the variability in the spring system. However, the performance goal was ultimately achieved and each target was hit at a different Work magnitudes. The final performance goal was to always return the ball in less than 8 seconds which was easily achieved by including a ball return with a slanted ramp for the ball to run back on.

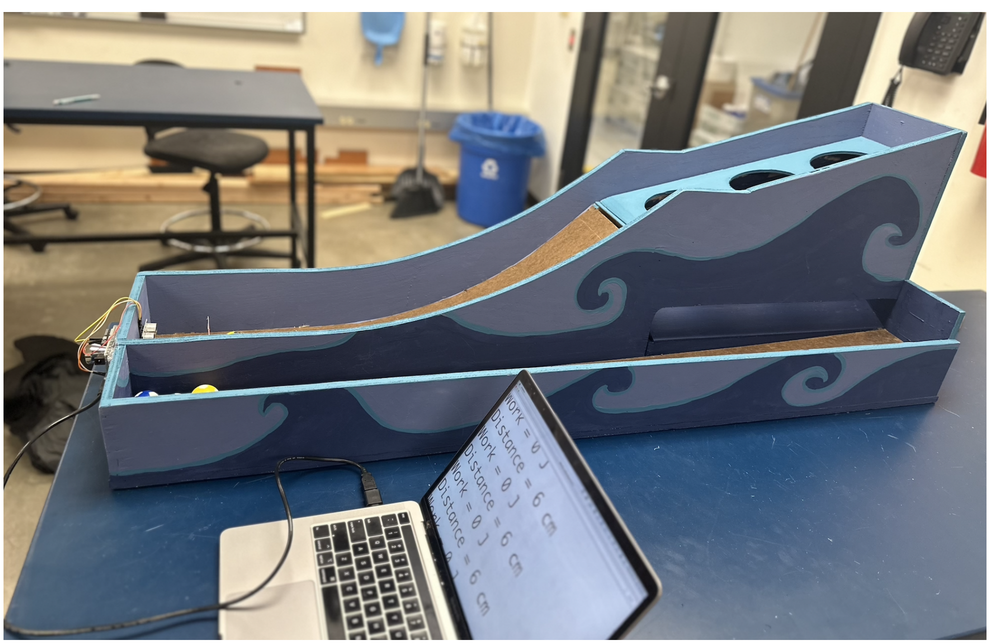

Figure 24: Right Side View

Figure 25: Left Side View

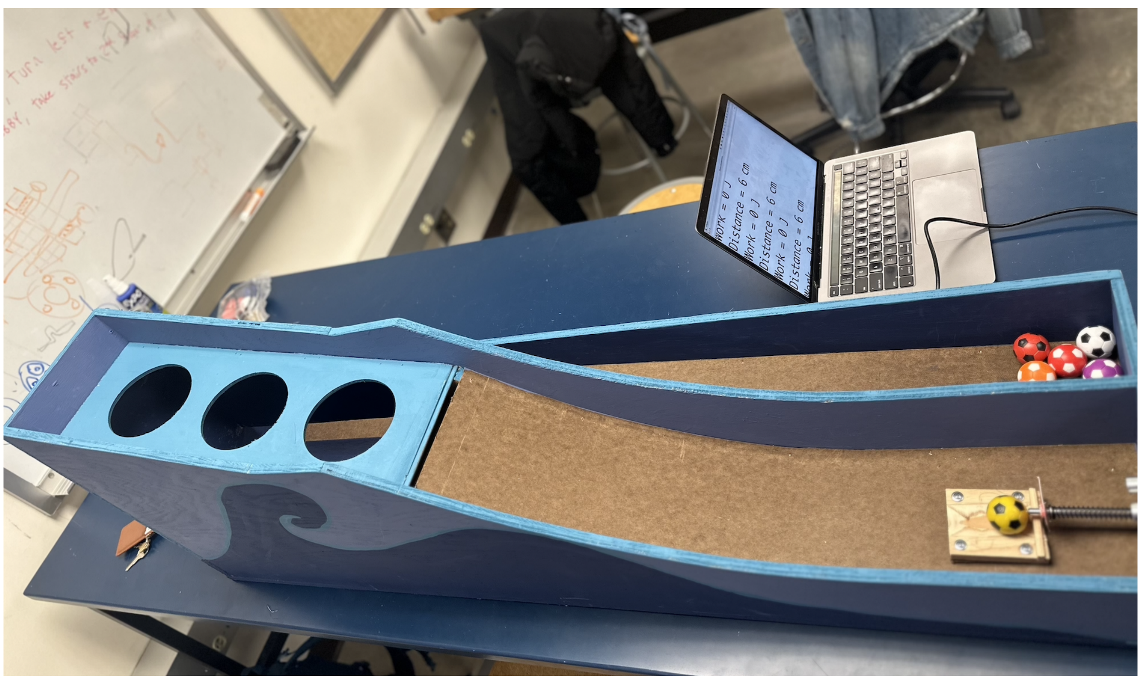

Figure 26: Top View

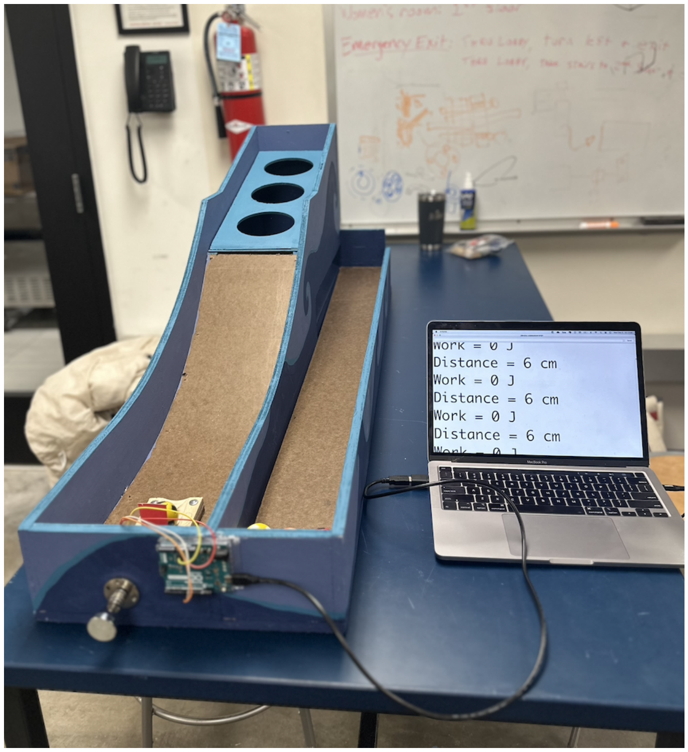

Figure 27: Front View

Figure 28: Spring System

7.2 Documentation

Directions:

The Pinkskee ball machine is relatively easy to use! First, connect the Arduino Leonardo to a computer with the Arduino-C IDE installed. You may optionally display the Arduino-C IDE from the computer to a larger monitor via a HDMI or USB-C connection. Ensure the red flag that comes with the device is mounted to the pinball plunger. If it is not, you can replace it by pushing a small, rectangular piece of cardstock onto the end of the pinball plunger that hits the ball, slide it on until it touches the end of the spring. Once the sensor is displaying a distance of 6 cm and work of 0 J, the device is setup!

To use the device, follow the following instructions:

- Select your favorite colored Foosball Ball. You can compete with your friends by only using your favorite colored Foosball ball. If you and a friend have the same favorite color, play rock-paper-scissors for the ball.
- Place the Foosball ball on the tee. The tee ensures the ball starts from the same position before each shot.
- Pull back the pinball plunger! You'll notice the distance and the work update approximately every two seconds. Hold the pinball plunger until both the distance and work values constantly display the same values. Each work values corresponds to a different target:
  - *Distance*: 3cm
Work: 1.34 J
Target: Lowest Target
  - *Distance*: 2cm
Work: 2.24 J
Target: Middle Target
  - *Distance*: 2cm
Work: 3.37 J
Target: Top Target
- Continue shooting until you've hit each target at least once! Out of all of your friends, who can hit each target in the least amount of tries?
- Once your are finished with the device, unplug the Arduino Leonardo to preserve it's longevity until the next day!

Troubleshooting:

We've compiled some potential issues you may run into while using the Pinskee ball machine in your display with our recommended solutions.

- *The plunger is sticking or not firing. What do I do?*
This means there's too much friction between the shaft of the plunger and its bearing. We'd recommend applying WD-40 in the small, circular area between the two components. This will allow the shaft to glide freely, but not become loose.

- *The ball fractured. How do I replace it?*
  The ball included with our Pinskee ball machine is a standard Foosball ball. They may be ordered on Amazon.com or bought in-person at Target, Walmart, or any stores that sale tabletop game gear.

- *My Arduino is not working. How do I get it on?*
  First, ensure that all of the Arduino wires are connected and secured. If all the wires are connected and secured, ensure the device lights up when it is plugged into your computer as this ensures it is receiving power. If it is not, we would recommend buying a replacement Arduino Leonardo and rewiring it to the same pins. If the white power light illuminates, ensure each pin is assigned to the correct pin in the code. If so, ensure your Arduino Leonardo is found and selected as a port option (this can be found in *Tools/Ports¡COM3/4/5.* If so, try a new cable. Any USB cable is compatible with an Arduino Leonardo. If all of the above work, we'd recommend purchasing a new Arduino Leonardo and rewiring it. Any Arduino device is compatible with our code. If the wires are identically rewired in the new device, you should be use the same code previously used. For any additional Arduino-related issues, we'd recommend contacting Arduino Customer Support.

- *My Foosball Tee is loose. What do I do?*
  We'd recommend cutting a similar block piece of wood with a small indent to hold the ball. As long as the new tee is the same height and width of the old tee, the performance of the spring launch system should not be affected. The new tee will be able to be secured in place with the same screws previously used by the old tee and provides the same ball height for the plunger to "shoot" the ball.

Additionally, we want to note that the device struggles to display a distance difference between the Middle and Top Targets. As noted, the distance between the spring and the ball is approximately 2 centimeters for both targets; however, the work is largely different. This is due to the Arduino Code. Because of the small change in distance between the two targets, the Serial Plotter does not display a difference between the two values. However, the overall work does change and this is to be noted.

A HC-SR04 Ultrasonic Sensor Software Code - Arduino C

```

// Define Trig and Echo pin:
#define trigPin 9
#define echoPin 10

// Define variables:
long duration;
int distance;
float work;
float dx;
float max_dist = 7.4;
float k = 1157.4; // N/m

void setup() {
  // Define inputs and outputs:
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);

  //Begin Serial communication at a baudrate of 9600:
  Serial.begin(9600);
}

void loop() {
  // Clear the trigPin by setting it LOW:
  digitalWrite(trigPin, LOW);
  delayMicroseconds(5);

  // Trigger the sensor by setting the trigPin high for 10 microseconds:
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  // Read the echoPin, pulseIn() returns the duration (length of the pulse) in ...
      microseconds:
  duration = pulseIn(echoPin, HIGH);
  // Calculate the distance:
  distance = duration * 0.034 / 2;
  dx = (max_dist - distance)/100;
  work = k* dx *dx;

  // Print the distance on the Serial Monitor (Ctrl+Shift+M):
  Serial.print("Distance = ");
  Serial.print(distance);
  Serial.println(" cm");
  Serial.print("Work = ");
  Serial.print(work);
  Serial.println(" J");
  delay(50);
}
```

B Parts List

	Part	Source / Link	Supplier Part Number	Color, TPI, Other ID	Unit Price	Tax	Shipping	Quantity	Total Price
1	Loaded Spring Rod,Ball Shooter for Arcade Pinball Machine	Amazon	B07DCQYJTJ	6.06 x 6.06 x 2.01 inches	$21.99	$1.98	$0.00	1	$23.97
2	Foosball Table Balls 1.42 Inch Table Soccer Balls	Amazon	B0C2Z2BDNS	7 Color	$7.99	$1.35	$0.00	1	$9.34
3	Leonardo with Headers for Arduino	Amazon	B00R237VGO	Revision R3 Atmega32u4	$14.99	$1.35	$0.00	1	$16.34
4	EPLZON HC-SR04 Ultrasonic Module Distance Sensor	Amazon	B09PG4HTT1	Package of 5	$9.99	$0.90	$0.00	1	$10.89
5	1/8 - 2'x4' Hardboard	Menards	129119	Masonite	$5.59	$0.55	$0.00	1	$6.14
6	1/2" - 2'x4' Oak Plywood	Menards	1254486	Plywood	$36.99	$3.69	$0.00	2	$81.36
7	Interior Paint Flatt	Home Depot	678885050917	29oz	$13.98	$1.40	$0.00	3	$46.13
8	1-1/4" 18GABrad Nails	Home Depot	1000532390	1000 per Box	$8.98	$0.90	$0.00	1	$9.88
								TOTAL	$204.05