ME2110 - Section A05 - Group 4

Final Report

Team 4 - Mamba's Madness

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Abstract

Throughout multiple design sprints for the Space Jam Final Project, many iterations were completed in order to improve upon the design and engineering requirements. For Sprint 1, a mousetrap and solenoid contraption was utilized for the Jumpshot/Pass System and a claw for the Dunk System. In Sprint 2, developments were made to the Jumpshot/Pass to include the ability to adjust the launch angle, allowing it to score more reliably. In addition, the claw was replaced with a tray and ram in the Dunk system, as this new Dunk mechanism required no power source and had the ability to score all three balls, Sprint 2 saw a score improvement leading to 51 points compared to 18 points from Sprint 1. Lastly, for the Final Competition, various enhancements were made such as redesigning the ram so that it moved the PVC tubes out of the way and the tray was placed higher up on the frame in order to score into the orange cups, which led to a final performance score of 93 total points across 3 trials.

Introduction

The theme for the Spring '21 ME2110 final competition is "Space Jam", based on the basketball movie. In *Figure 1*, the layout of the arena is shown, the three main tasks are the pass (3 points), the jumpshot (8 points), and the dunk (maximum of 30 points). The dunk challenge has variable points depending on which color cup the balls go into *Table 1*. The ultimate goal of the challenge is to obtain as many points in three rounds, capped at 22 points per round. The key design requirements of the robot are as follows: a maximum final assembly budget of $100, limited to the power sources (motors, solenoids, etc.) provided in the mechatronics kit, autonomously operates within less than a minute, initial size constraint of 20x20x18in, and requiring two team members for the competition set up time. These restrictions required teams to balance multiple systems within one robot while learning the importance of time management and teamwork.

Problem Understanding

To better understand customer and engineering design requirements, a House of Quality (HOQ) *(Tables 2.1-2.3)* was made that split customer needs into categories, such as maximizing points, ease of use, safety, cost, and the ability to operate autonomously and legally. These customer and engineering requirements often relate to each other. For example, the engineering requirements of being able to obtain exit velocity/launch angle and have consistent launching will also enhance the reliability of the robot. In contrast, the customer's budget requirement of $100 will lead to cheaper materials being bought, compromising the reliability and ease of repair of the robot. Furthermore, the Specification Sheet *(Table 3)* lists detailed engineering requirements derived from the HOQ. After Sprint 1, multiple specifications were changed such as aiming to score the jumpshot/pass 95% of the time and the dunk 85%. This change was especially challenging but ultimately helped the team choose methods that would achieve greater consistency.

Conceptual Design

There are four functions below the main function of scoring points: turn on/off, pass, jumpshot, and the dunk. These are listed graphically in the function tree in *Figure 2*.

Turn on/off: Per the engineering specifications in *Table 3*, the robot must have an activation mechanism and run autonomously, include a kill switch, and should stop operations after one minute. These requirements can be satisfied with code or physical power switches.

Pass: The robot must hold and deliver the ball to complete this function and it requires the least amount of design consideration of the three challenge functions. Delivering the ball can be done using: a catapult, a striking mechanism, a spinning wheel to launch the ball, or a ramp to roll the ball.

Jumpshot: The robot must hold and deliver the ball to complete this function. Because of how points are scored, this function has more points associated with it and is more important than the pass. With higher energy input the jumpshot can use the same mechanisms as the pass, in all design alternatives excluding the ramp.

Dunk: The five subfunctions of the dunk are to locate, collect, hold, move the robot, and deliver the balls. This is the hardest function to complete and is also the most important because of the large point values this function earns. A sensor-based system could detect the locations of the balls and collect them, such as grabbing claws that close when the ball is in reach. A sensorless system does not require the balls' locations to collect them, such as a tube collection system, collection tray, or scoop. The delivery is the most difficult sub-function to complete because higher accuracy is needed to distribute the balls into the small cups. Delivering the balls into the cups can be completed through dropping, launching, or using a suspended track. Lastly, moving the robot can be achieved with a motor and wheels, using a ramp and gravity, or using an extendable frame.

Design Overview

The design for the final competition is as displayed in *Figure 3*. Learning from the mistakes of Sprint 1 and 2, the team honed in on the final design by following key design principles; simple, cheap, and reliable. With the total production cost of $38 and a manufacturing time of 19 minutes for the jumpshot, pass, and dunk mechanisms, it allowed for quick turnaround times between design iterations. In pursuit of the engineering requirement of being able to set up the robot in under 1 minute, the team simplified each of the mechanisms to reduce setup time. This allowed the robot to have the competitive advantage of being able to do a trial run before the first "official run" of the competition to check the systems' operation and still have time to set up again. The green box within the figure highlights the jumpshot and pass mechanism. The red box encircles the dunk system which incorporates a ram, a ball retrieval tray, and a drawer slide mechanism.

Figure 4 illustrates the design for the jumpshot and pass objective. The catapult-inspired mechanism uses a combination of a solenoid, quick release, and a mousetrap to launch the balls. The solenoid pulls back the lever to trigger the quick release which allows the mousetrap to unwind and launch the balls. The ball for the jumpshot and the pass are placed on the same catapult arm. However, the jumpshot ball is placed to have a longer moment arm in order to create enough launch velocity to get inside the target zone. The pass ball, with a smaller moment arm, is launched at a slower velocity with the intention of colliding with the target zone. The quick-release lever and hook subassembly, designed after Sprint 1, increased the consistency of triggering the launch system, which boosted the reliability of launch success to 95% of the time. The scoring consistency was also increased by the adjustable launch mechanism, a nut and bolt guide rail that stops the catapult arm at a user-specified launch angle. Circling back to our design principles, the design costs just $2.69 and takes approximately 15 minutes to manufacture.

The dunk system involves a drivetrain system, with a 4:1 gear ratio, to enable the robot to move towards the target dunk zone, as shown in *Figure 5.* The ram collides with the bottom part of the PVC tubes, causing them to fall backward. The chute knocks over the 8'' PVC in the middle of the track and picks up the regular ball. The tray system catches the Moneyballs while the drawer slides, pulled by a string coiled around a motor-driven axle and pulley system, extend the tray outward. As the tray extends, a sliding door mechanism, attached to a string, removes the cover plate and opens up a hole. The balls are then dropped into the chute which rolls the balls into the desired cup. After testing more than 20 laser-cut ram configurations, the team honed in on the optimum design of an arrow-headed ram shape. This ensures the PVC tubes consistently fall backward and are pushed aside to prevent jamming. In the end, the system achieved the engineering specification target to have all 3 balls fall inside the cups 85% of the time. This final design completes all the specification requirements for the dunk system as it fulfills the costs requirement by costing just $26 while taking only 15 minutes to laser cut.

Alternative Designs

Throughout the semester, the robot has seen several changes in every system with each iteration, improving upon the previous one. The first design iteration called for spinning rollers to fire the balls for the jumpshot and pass, and a system of claws to grab and release the dunk ball and money balls. For the spinning rollers to be effective, they would require new motors that were not provided to the team. Buying these new motors and using them would break the rules of the competition. This mechanism scored a 0 when it came to conforming to design constraints in the evaluation matrix *Table 4* so that design would need to be replaced. Similarly, three claws would also require too many motors, so the new design was downgraded to one claw.

The robot's second iteration included a cannon and a single claw. The cannon used a quick release powered by a solenoid to activate a mousetrap that hit both of the balls loaded into the barrel. The claw used a motor-driven gear mechanism to grab the middle ball and release it over the dunk cups after the robot had moved forward. These designs ended up being less effective than expected and the robot, again, needed a redesign. The cannon would often misfire and score 0 points for the jumpshot and pass. The claw couldn't score many points either as it could only place the stock ball in the red cup. These facts caused iteration 2 to receive 1's and 2's in the Jumpshot, Pass, and Dunk areas according to the Evaluation Matrix.

In iteration 3, the cannon was replaced by a catapult with a more reliable quick release and an adjustable stop bar which would make the jumpshot and pass more controllable. The claw was replaced by a ramming-tray system that would ram into the PVC tubes and carry all 3 balls on a tray that would then dump them into the orange cups. This model gave much more reliable results, but it came with its own issues. With the catapult, the pass ball would occasionally bounce into the bucket, and thus did not count as a pass. The tray was also so close to the cups that it would sometimes get the balls stuck between it and the cups. These issues gave iteration 3 a score of 2 for the pass and dunk in the evaluation matrix, so they were addressed in the 4th and final iteration of the robot. The catapult was resized and reworked to be more accurate and the tray was raised up on the frame in order to allow for more space between the tray and the cups.

Performance Results

Sprint One:

As seen in *Table 5*, For trials one and two the solenoid failed to activate the quick release resulting in 0 points for this task. In trial 3, both balls hit the bucket and scored the full 6 points available. The Dunk system consistently collected and dropped the regular ball into the red cup for 3 points in every trial. All 3 trials combined to achieve 18 points out of a possible 30.

Sprint Two:

For trials, one and two, both the jumpshot and pass balls went into the bucket which counted only for the Jumpshot but did not count towards achieving the pass task resulting in 9 points in these two trials. For trial 3 both balls completed their respective task giving the team 11 points.

In the dunk task, for trial one, the team successfully gathered one regular ball and one Moneyball while only scoring the money ball since the regular ball got stuck between the tray and cups. For trial two, the tray only collected and dropped one Moneyball into the red cup. In trial 3, all balls were successfully recovered but none were scored due to stuck PVC tubes which prevented the extension mechanism from extending and dropping the balls into the cups. These inconsistent results achieved a total of 51 out of 66 points for sprint two *Table 6*. This was a 65% increase in points over Sprint 1.

Final Competition:

The jumpshot/pass worked successfully in every trial and the Dunk system was consistent in placing the regular ball into the red cups and the Moneyballs into the orange cups. This allowed for a total of 93 points out of the capped 66, *Table 7*. From *Figure 6*, we can see that the performance saw an average of a 28% increase from sprint to sprint, relative to the max points allowable. Compared with Sprint 2, the final robot design increased points by 45%.

Conclusion

In conclusion, the final design project allowed the team to experience the engineering design process from ideation to prototype. Design and planning tools helped to brainstorm and weigh decisions based on calculated customer needs, engineering requirements, and specifications. Throughout the stages of fabrication, students learned to use the bandsaw, laser cutter, and 3-D printer in addition to learning how to calculate tolerances, choose materials and practice lab safety skills. Lastly, the team engaged in iterative engineering processes which required the team to pivot and be agile, constantly redesigning and improving on the spot. Ultimately, all these lessons led to a Final Competition score of 93 points. This improvement in score showcases the team's growth in teamwork and problem-solving skills, all of which can be carried forth into future engineering projects.

Appendix 1 - Figures and Tables

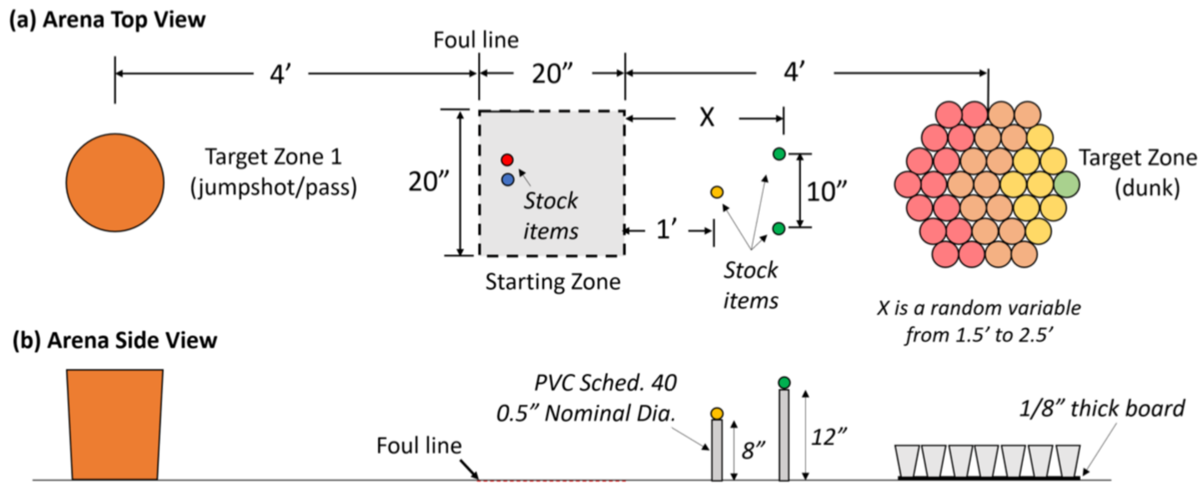


Figure 1. Layout of arena including top and side views. Red stock item is for the jumpshot task. Blue stock item is for the passing task. Yellow and green stock items are for the dunk task. Green stock items are moneyballs.

Figure 1: Arena Layout

Table 1: Point values

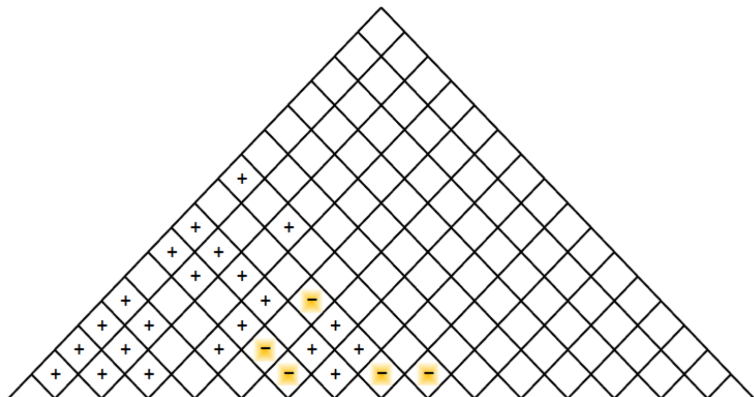
Task	**Competition Point Value**
Launch	1 (successful deployment)
Pass	3 points/item (hits target zone) 1 points/item (leaves starting zone)
Jumpshot	8 points/item (lands in target zone) 3 points/item (hit target zone but not in target zone) 1 points/item (leaves starting zone)
Dunk	6 points/item (green zone) 5 points/ item (yellow zone) 4 points/item (orange zone) 3 points/item (red zone) 1 points per item (not in a zone but off of PVC stand) *Money balls count 2x points per zone*

Table 2.1: House of Quality Overview

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Category	Importance Rating	Engineering Requirements / Customer Requirements (Explicit and Implicit)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Direction of Improvement	◇	◇	◇	▼	◇	▼	▲	▼	◇	◇						
			Perform procedures after turning on	Has a container for balls	Retrieves balls from a given height	Completes tasks within given time frame	Hit exit velocity for Jump Shot	Repairable under a time constraint	Consistent launching	Max Manufacturing Cost	Ensure projectiles cause no harm to surrounding individuals	Maximum Dimensions						
Operates Autonomously and Legally	10	Operates Autonomously	●		○	○				○	▽							
	8	Store Balls	○	●	▽	○			▽	○		○						
Maximise Points	8	Retrieve Y and G balls from PVC pipe	○	○	●	○			▽	●								
	5	Complete every task in 1 minute	▽	●	○	●				●								
	7	Make the jump shot	○	●		●	●		○			●						
	8	Deliver ball to a cup	○	○	○	●			○	○								
Ease of Use	9	Easily repairable						●	○	●	○	○						
	10	Reliable	▽				○	○	●		▽	○						
Safety	8	Doesn't hurt anyone near the surrounding field								▽	●	▽						
	7	Kill switch								○	●							
	7	Does not damage field						○			○							
Cost	9	Under a budget		▽	○	○	○	○	○	●	▽	○						
		Target	Performs as planned	2-3	8" & 12"	1 Minute	~= 13.6ft/s	3 Minutes	Launches at consistent distance for 4 times in a row	$100	Low risk level on PFMEA (8-40 SxOxD range)	20" x 20" x 18"						
		Max Relationship	9	9	9	9	9	9	9	9	9	9						
		Absolute Importance Rating	198	237	176	285	120	159	205	386	212	179	0	0	0	0	0	0
		Relative Importance Rating	9%	11%	8%	13%	6%	7%	10%	18%	10%	8%	0%	0%	0%	0%	0%	0%

Table 2.2: House of Quality Customer Requirements

Operates Autonomously and Legally	10	Operates Autonomously
	8	Store Balls
Maximise Points	8	Retrieve Y and G balls from PVC pipe
	5	Complete every task in 1 minute
	7	Make the jump shot
	8	Deliver ball to a cup
Ease of Use	9	Easily repairable
	10	Reliable
Safety	8	Doesn't hurt anyone near the surrounding field
	7	Kill switch
	7	Does not damage field
Cost	9	Under a budget

Table 2.3: House of Quality Engineering Requirements

Target	Performs as planned	2-3	8" & 12"	1 Minute	~= 13.6ft/s	3 Minutes	Launches at consistent distance for 4 times in a row	$100	Low risk level on PFMEA (8-40 SxOxD range)	20" x 20" x 18"
Max Relationship	9	9	9	9	9	9	9	9	9	9
Absolute Importance Rating	198	237	176	285	120	159	205	386	212	179
Relative Importance Rating	9%	11%	8%	13%	6%	7%	10%	18%	10%	8%

Table 3: Specification Sheet

Changes	D/W	Requirement	Responsibility	Source
		Operates Autonomously and Legally		
2-17-21	D	Operates Autonomously	Overall Design Team	Competition Requirement
2-23-21	D	Volume limit of (20” x 20” x 18”)	Overall Design Team	Competition Requirement
2-23-21	D	Push button activation	Overall Design Team	Competition Requirement
2-23-21	D	Auto-off after 1 minute	Overall Design Team	Competition Requirement
		Maximize Points		
2-17-21	W	Launches ping pong distance of ~ 4’ and > 13” high	TBD	Calculation based on arena
2-17-21	W	Passes Ball within Target Zone 1 (within 4’)	TBD	Calculation based on arena
		Ease Of use		
2-23-21	D	Must be competition ready from an unloaded condition in under 3 minutes	Overall Design Team	Competition Requirement
4-10-21	W	Set up robot within 1 minute	Setup Team	Team Objective
2-23-21	D	Set Up by Two People	Overall Design Team	Competition Requirement

		Safety		
2-17-21	D	Does not damage field or harm nearby people	Overall Design Team	Competition Requirement
2-23-21	D	Fully static at start and end (Mechanical/Electrical) Potential	Overall Design Team	Competition Requirement
		Results Consistency		
2-17-21	W	Ensure each task can be repeated 4 times in a row	Overall Design Team	Statistical analysis calculation
4-10-21	W	Achieve Jumpshot Objective 95% of the time	Jumpshot Design Team	Team Objective
4-7-21	W	Achieve Pass Objectives 95% of the time	Pass Design Team	Team Objective
4-13-21	W	Collect all 3 balls for the Dunk 85% of the time	Dunk Design Team	Team Objective
		Mechanisms to Score		
2-17-21	D	Ball Storage: 2-3 40mm ping pong balls	Jumpshot Design Team	Competition ball size
2-17-21	W	Pick up items at 8" & 12" Height within "x" variable distance of 1.5' to 2.5'Lenght	Dunk Design Team	Competition ball position
2-23-21	W	Must produce an initial launch of 13.6 feet/second	Jumpshot Design Team	Velocity Calculation
		Production Costs		

2-17-21	D	Bill of Materials must be under 100$	Overall Design Team	Competition Requirement

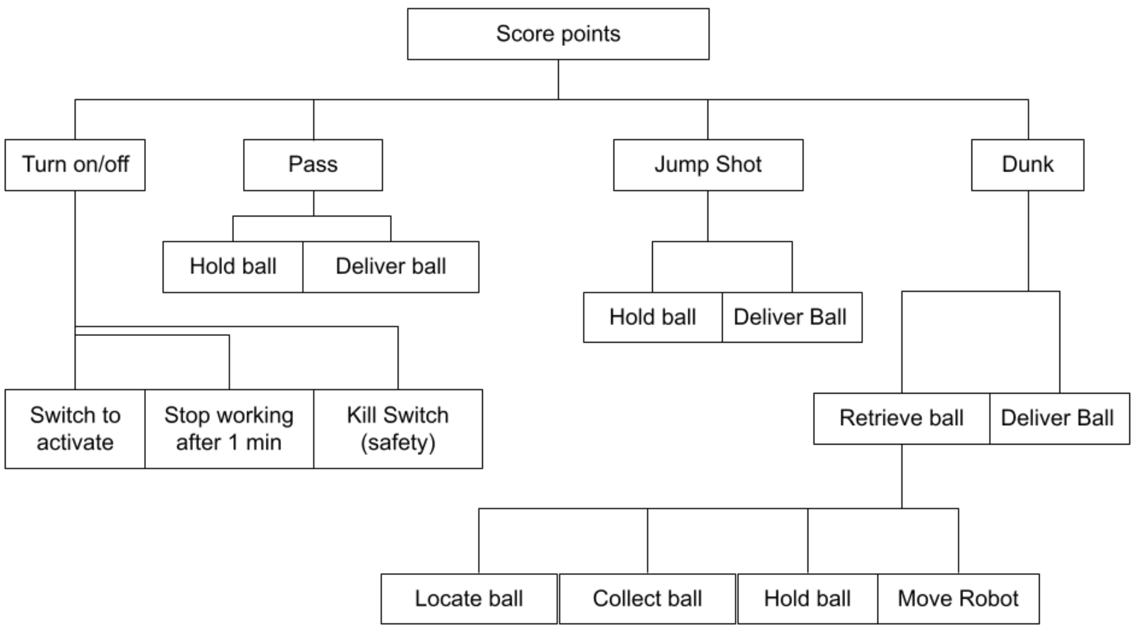


Figure 2: Function Chart

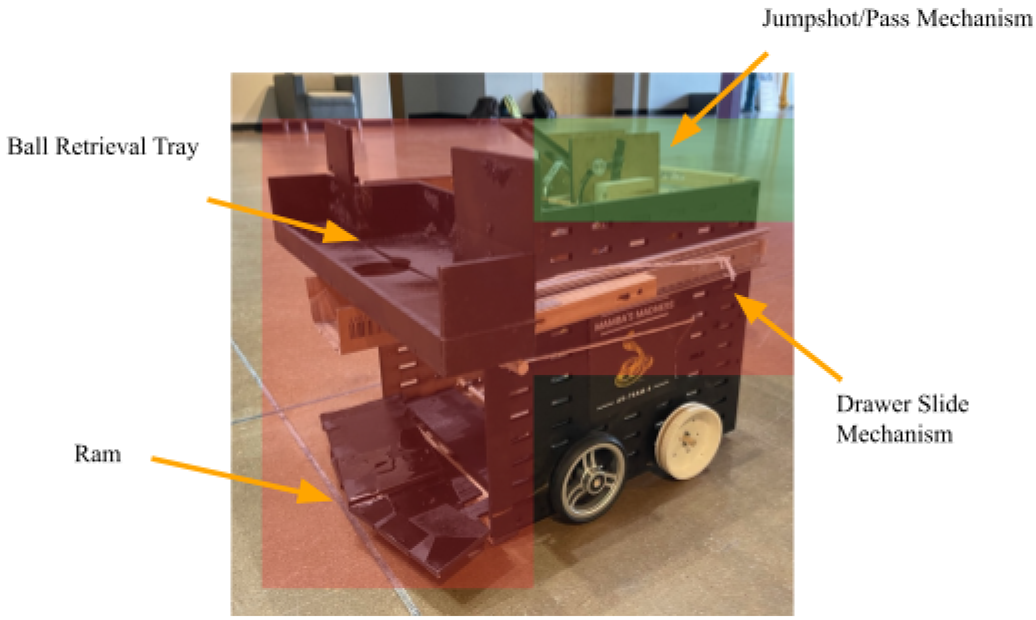


Figure 3: Design Overview

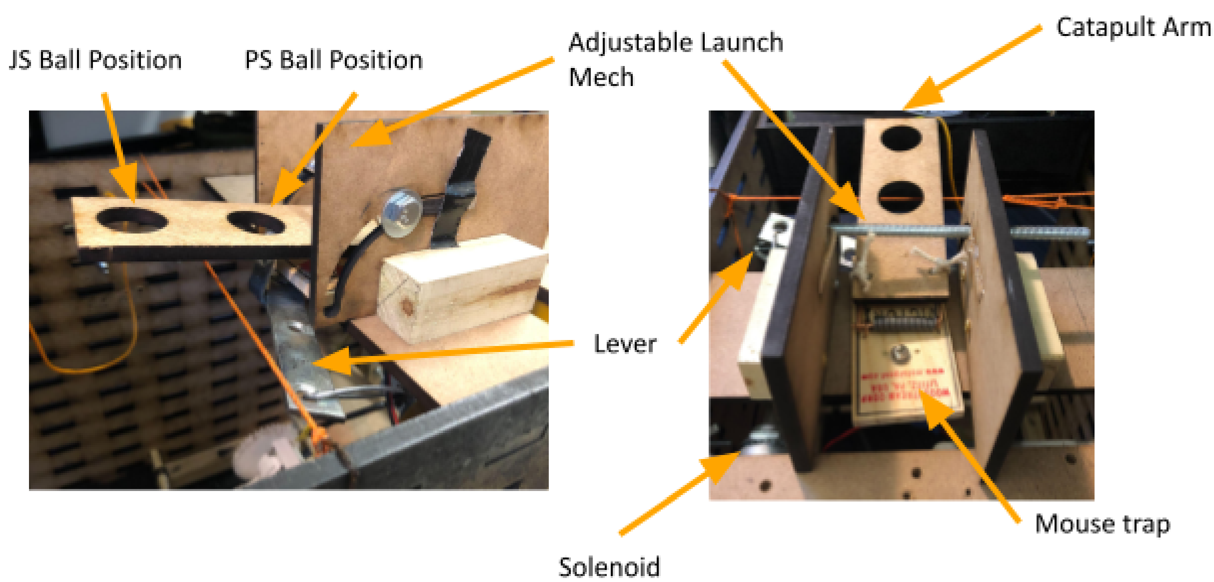


Figure 4: Jumpshot/Pass Mechanism

Figure 5: Dunking Mechanism

Table 4: Evaluation Matrix

Criteria	Importance	Iteration 1 Rating	Iteration 1 Weighted Total	Iteration 2 Rating	Iteration 2 Weighted Total	Iteration 3 Rating	Iteration 3 Weighted Total	Iteration 4 (final design) Rating	Iteration 4 (final design) Weighted Total
Makes Jump Shot	8	1	8	2	16	3	24	4	32
Make Pass	4	3	12	1	4	2	8	4	16
Retrive all three balls	5	1	5	1	5	3	15	4	20
Complete dunk challenge	9	1	9	1	9	2	18	4	36
Easily reparable	7	2	14	3	21	3	21	4	28
Inexpensive	5	2	10	4	20	3	15	3	15
Conforms to design constraints	10	0	0	4	40	4	40	4	40
Fabrication time	7	1	7	4	28	3	21	3	21
Total	55	10	65	12	143	16	162	23	208
Relative Total	220		0.295		0.650		0.736		0.945
Rank			4		3		2		1

Table 5: Sprint 1 Performance

Sprint 1 - Total obtainable points: 30					
Trial	Launch Point	Jumpshot Points	Pass Points	Dunk Points	Total Points
#1	1	0	0	3	4
#2	1	0	0	3	4
#3	1	3	3	3	10
Average	**1**	**1**	**1**	**3**	**6**

Table 6: Sprint 2 Performance

Sprint 2 - Total obtainable points: 66					
Trial	Launch Point	Jumpshot Points	Pass Points	Dunk Points	Total Points
#1	1	8	1	8	18
#2	1	8	1	6	18
#3	1	8	3	3	15
Average	**1**	**8**	**1.67**	**5.67**	**17**

Table 7: Final Performance

Final Competition - Total obtainable points: 126					
Trial	Launch Point	Jumpshot Points	Pass Points	Dunk Points	Total Points
#1	1	8	3	19	31
#2	1	8	3	19	31
#3	1	8	3	19	31
Average	**1**	**8**	**3**	**19**	**31**

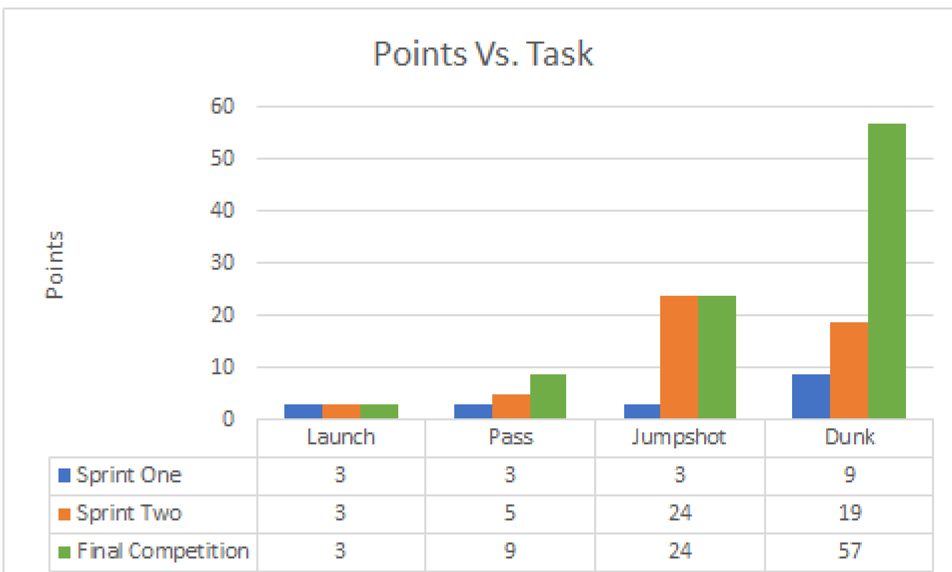


Figure 6: Comparison Plot of Points in Sprint One, Two, and Final Competition

Appendix 2 - Contributions

-Justin Chow: Wrote the design overview section, updated the specification requirements, and created *Table 4* detailing the scores in all 3 competitions. Edited and offered feedback on all sections of the paper.

-Luc Livio: Wrote the Alternative Design section and created and entered Table 4 in the appendix. Participated in the group read-through of the paper and provided constructive feedback.

-David Salazar: Wrote the performance section and entered *Figure 7* in the appendix. Critiqued all sections and participated in group read-throughs of paper.

-Truc Vu: Wrote the abstract, problem understanding, and conclusion and entered in their adjoining appendix figures/tables into the appendix. Edited and offered feedback to sections of the report.

-Robert Weinmann: Wrote the introduction and conceptual design sections and entered in their adjoining appendix figures/tables. Critiqued all sections and participated in group read-throughs of paper.