ME2110 – Section A09

Final Project Report

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Abstract

The ME 2110 Minecraft challenge requires teams to ideate, design, fabricate, and assemble a robot that will score as many points as possible within a forty-second time frame by completing tasks on the competition track. Teams must complete the tasks while satisfying several competition parameters and limitations. Utilizing several design tools, 3 design solutions were developed. Team 5, “The Enderneers” prioritized having a multi-functional, rigid machine that could complete several tasks all at once from the designated Home Zone. A Computer Aided Design (CAD) based approach was taken, using the competition track CAD to ensure correct dimension and fit, as well as accurate fabrication and satisfying the 3D printing methodology, a methodology that provided rigidity through strong a PLA skeleton and attachments, and uniqueness via the inorganic shape fabrication that 3D printing allows. The “Transport Cube Design” was fabricated, which prioritizes multi-functionality and multi-task-ability, featuring a central housing that sits in the main chassis, carrying all subsystems, allowing for concurrent task completion. All requirements of the competition were satisfied, including a fabricated mechanism for every task. As outlined in the Performance Results, The Enderneers consistently scored 20 points in all runs of Sprint 1, 8 points across 3 runs in Sprint 2, and an advancement to the third round in the final competition along with a 54-point first round. The design approach was found to have limitations in speed compared to other mechanisms, however, the CAD & 3D printing based design strategy and multi-functionality of the machine characterizes a design with high potential for point scoring.

Report

The ME 2110 Minecraft challenge requires teams to design an autonomous robot that scores points by completing tasks on the competition track, *Figure 1*, including mining ore, defeating mobs, delivering the End Crystal, and taming the Wolf. Several planning tools were utilized, including a House of Quality (HOQ), Functions Tree, and Morphological Chart. An effective machine carries out functions outlined in the Functions Tree, *Figure 2*, such as pushing, pulling, lifting, and grabbing, while also avoiding disqualification by shutting off within forty seconds of round start. The morph chart, *Table 1*, lays out conceptual solutions that utilize sensors, pneumatics, and motors to maintain autonomy; telescoping pullies for lifting; spring-loaded arms for pushing and pulling, and claws for grabbing. Team 5, The Enderneers, prioritized having a multi-functional, rigid machine that can complete multiple tasks at once, with subsystems activated from a single assembly point. CAD was essential for accurate subsystem fabrication and fit within the competition track model. The Transport Cube design was chosen, featuring a central housing mounted within the main chassis, carrying all subsystems; critical subsystems for high-value tasks are mounted to the travelling cube such that concurrent task completion is possible, setting the Enderneers apart from the separate subsystems approach done by other teams. The Enderneers have a 3D Printing methodology, focusing on having a rigid, accurate, CAD based design with unique attachments at the cost of manufacturing and fabrication speed, allowing the team to integrate inorganic shapes into the design to attempt all tasks on the competition track without limitation on shape or function.

Satisfying the highest-level function of “Win the Minecraft Challenge” means the Enderneers must maximize points scored, the most important customer requirement in the HOQ, *Figure 3*, as all engineering specifications except one relate to this requirement. This means avoiding disqualification, or zero-point rounds, is paramount, which means satisfying limitations such as stopping the machine within 40 seconds of the round start, the rationale behind “Time Limit Satisfaction” being the next most heavily weighted requirement. To score more points than other teams, difficult but valuable tasks such as Taming the Wolf and Delivering the End Crystal must be completed, due to their value of 20 points each; these are the next most important requirements. Engineering requirements to satisfy these customer requirements are “Complete Multiple Tasks”, “Complete Tasks Quickly”, and “Eject Objects”. These requirements have a strong relationship to “Maximize Points” and satisfy customer requirements such as “Deliver the

End Crystal” and “Tame Wolf”, due to requiring an “Eject Objects” mechanism. The Enderneers interpret this competition as a challenge of designing a machine that is rigid, multi-functional, and multi-task-able, thus, the design strategy is based upon these factors, reflected in the engineering specifications laid out in the Specification Sheet, *Table* 2, giving the machine measurable data. A fabricated machine must maintain its original rigidity after test runs and last multiple weeks until the final competition, thus, the machine must perform 3+ test runs without maintenance while also avoiding noticeable deformations such as holes or cracks. Attachments, such as drawer slides, must be able to support a weight of at least 1 kg and withstand material degradation and fatigue throughout 10+ test runs. Lifting mechanisms must be able to apply forces of ≥10 Newtons, ensuring adequate lifting of competition pieces while supporting the weight of the mechanism itself. The fabricated machine’s chassis is specified to be ≤1” of required dimensions; these specifications give the Enderneers clearance for coding errors, heavier than anticipated loads, or measuring errors during fabrication.

Function requirements in the Functions Tree lay out the machine’s needs to satisfy customer and engineering requirements, with the backbone of all functions being “Score Points”, reliant on several sub-functions to complete tasks. Two high-value tasks, “Deliver Crystal” and “Tame Wolf,” each have their own functions: ejecting the Bone, reliant on a launch function, and delivering the end crystal, dependent on dislodging and lifting. To mine ore, the robot must pull ore into the home zone; however, a separate function to extend upwards or forwards is needed due to Iron Ore being halfway atop the spinning Obsidian Tower. Defeating mobs holds two sub-functions: *knock down* and *push* mobs into adjacent zones, deducting points from that team’s total. Disqualification nullifies effectiveness of any functions, therefore the “Comply with Rules” function exists, requiring the machine to stay within time boundaries, reliant on subfunctions of banana plugs and 120V power, serving as the robot kill switch and energy source. The morph chart illustrates solutions chosen to achieve functions, starting with a spring-loaded arm. Using the potential energy of 3.16 Joules stored in the Victor Mouse Trap Spring, a spring-loaded hinge connected to a retractable arm moves forward and backward, providing a force of 0.976 Newton-Meter / Radian to knock over objects such as mobs. Linear actuation achieves pushing and pulling motion, as the actuator is capable of both; this motion can be translated into rotational motion using crankshafts or gears, further assisting in pulling objects (ores) inward or knocking them over. End Crystal Delivery requires the ability to fasten around objects, thus, a solution is a rubber-band-loaded claw, which translates a #64 rubber band's force of 30-60 Newtons / Meter to a compressive force, fastening around the End Crystal with a clearance strength.

The final chosen design, *Figure 4*, is made up of two core extending sections that are held within a structurally sound main chassis: the Transport Cube, which carries 80 percent of the robot's mechanisms, and the Upper Bay, which extends further than the Transport Cube for rotating stage-related tasks. The Transport Cube is mounted to the main chassis via two 22-inch drawer slides at an optimal angle as determined by CAD and testing (6.5 degrees), *Figure 5*, while the Upper Bay is attached with a double stack of one 22-inch and one 14-inch drawer slide for a longer extension. Both sections are pneumatic piston-activated, being pushed out instantly at round start, with the Arduino triggering a pneumatic valve that supplies both pistons with pressure. The Upper Bay, *Figure 6*, consists of a 3D-printed iron ore deflector and a solenoid-enabled wolf bone payload compartment with a limit switch. The iron ore deflector has a 30-degree angle with a slightly cambered down face to reduce contact with ore, thereby decreasing friction, easily redirecting the iron ore pieces toward the robot, *Figure 7-8*. The wolf bone payload compartment is positioned right behind the deflector to reach as close as possible to the rotating stage and deliver the wolf bone. A limit switch is attached at the front of the payload compartment to be hit by the top-most knob on the rotating stage, such that based on the color assigned to the team, the Arduino times the release of the wolf bone and activates the solenoid attached to the payload compartment, *Figure 9*. The Transport Cube, *Figure 10*, is a part MDF, part PLA-based skeleton on drawer slides that can extend up to 2 inches from the end crystal, holding the majority of the robot's subsystems. It contains 5 main mechanisms: a 2:1 ratio torque-increasing gearbox connected to a set of foldable arms to sweep Diamond and Netherite ores, a pair of rack & pinion systems to deploy folded arms, a set of spring-loaded mob arms to knock over mobs, a telescoping arm with a rubber band tensioned claw, and a locking lever that holds the claw open. The gearbox, located at the back of the Transport Cube in *Figure 11*, contains four gears resting on a gear base. Two 48-tooth gears on the outside with cutouts to press fit bent sheet metal rods and two 24-tooth gears in the middle, one of which is attached to the motor shaft to be driven while the other reverses direction to ensure both left and right arms open out when the motor is run. The arms attached to this gearbox are made of multiple pieces that are connected with tiny door hinges, so they can be folded and tucked inside the Transport Cube, *Figure 12*. A rack & pinion mechanism is used as a deployment system for these folded arms that allows us to efficiently convert the Transport Cube's linear inertia into pushing force. Two rack gears are placed on opposite ends of the 1:2 ratio step pinion, and when the shorter rack is pulled back, it pushes the longer rack forward at twice the speed, *Figure 13*. The shorter rack is connected to the main chassis via strings such that it gets pulled back just when the Transport Cube is fully extended. This results in the longer rack being pushed out at twice the speed and shooting the folded arms out into their sweeping position. The Arduino times this deployment and runs the motor to sweep the Diamond and Netherite ores within milliseconds of the folded arm being deployed to snatch them from adjacent teams. Spring-loaded mob arms attached to the outer wall of the Transport Cube, *Figure 14*, are released at the beginning of the round while the Transport Cube is in motion. The spring inside the hinges of the arms forces them open while the main chassis walls keep them closed; the arms are sized so that when the Transport Cube slides out, they rapidly open at the perfect point to hit the mobs and push them outside our zone. The telescoping arm shown in *Figure 15* has a rubber band-tensioned claw attached to it that is used to complete the End Crystal task. The claw is made up of two fingers on each side with a 1:1 gear system in the middle to keep movement reliable and symmetrical. The fingers are tensioned by adding dowel pins to one of the holes and adding a rubber band around the pins. While the Transport Cube is inside the chassis or in movement, this claw is kept forced open by a locking lever mechanism, *Figure 16*, that uses the same string triggering method as the rack & pinion systems. Once the lever is pulled at the end of Transport Cube's extension, the claw is released at a perfect distance to close itself and capture the End Crystal, with this distance determined and dimensioned by computer-aided designs, *Figure 17*. The telescopic arm that the claw is attached to is mounted on the Transport Cube at a 63.5-degree angle to the ground, following the shortest path to the Obsidian tower based on the field CAD, carrying the captured End Crystal to the top of the tower. The system is made up of 3 stages of PVC pipes that are connected with strings in a cascade pulley system, such that when the motor-controlled winch, *Figure 18*, pulls the string attached to the first stage, all stages are simultaneously raised.

Two alternative designs were developed during the design process and compared using a concept evaluation matrix, *Figure 19*, with the first being the Wheel Design, *Figures 20-22*, a four-wheeled robot initially resting on a platform. It is launched into the arena by two pneumatic pistons attached to its starting platform, launching the vehicle to the end crystal knocking it out of the crafting table. Concurrently, two hinged arms connected to the starting platform are knocked onto the track from the impact of the robot; a roller switch at the front of the starting platform is clicked as the robot rolls over it, signaling motor rotation, pulling the arms inward via a string attached to the arm's ends, pulling in ore. The Wolf's Bone is placed at the edge of a hinged claw attachment, attached to a string, which is dropped once a color sensor detects the correct color. Once detected, a solenoid pin is pulled into its chamber, disconnecting from the string and allowing the bone to slide into the correct zone. This design's shortfall is instability and speed, as wheel designs can get caught under wires and are slower compared to other designs, as the robot must travel to the rotating centerpiece on wheels, which can take 5+ seconds. The second design was the Scissor Design, *Figure 23-25*, which uses solenoid-activated mousetraps placed behind the drawer slides to push the robot out. Two hinged T-shaped arms attached to the corners of the robot are shot out by pistons to mine ore, they are dimensioned to fall just past the 3 ores on the sides and have a string attaching them back to the pistons. A scissor mechanism with a suction cup suctions onto the top of the End Crystal and lifts it to the top of the tower using a telescoping arm. Shortfalls are present in the reliability of the design, as the suction cup must latch onto a smooth surface of the End Crystal to minimize the chances of vacuum loss, thus a design accounting for inconsistent grip force must be fabricated. This design pushes budget and time constraints, and fails the customer requirements of being reliable, stable, and portable, all of which are highlighted in the scoring of this design in the evaluation matrix.

Sprint 1's challenge was to mine all ores. The Enderneers achieved 20 points in all 3 runs for mining all 10 Iron ores, but were unable to mine any Diamond and Netherite ore. The Iron Ore Deflector worked flawlessly, mirroring the results seen in the 10 previous trial runs, *Figure 26*. Diamond and Netherite Ore mining was to be improved upon, which was done by increasing fabrication speed by decreasing infill in 3D printing fabrication, as fabrication time management was the root issue of Sprint 1, due to not having ore mining mechanism ready. The tradeoff of material strength for fabrication speed was valid, as this allowed for sooner testing, additonally the sweeping arm mechanism not requiring high material strength. Sprint 2's challenge was to complete all competition tasks. Although subsystems for each task were fabricated, *Figures 27-29*, Enderneers did not meet expectations, scoring 1 point, 0 points, and 7 points over the 3 runs, respectively. The root of all Spring 2 issues comes from a lack of testing. Code errors led to false activations, as the team was missing an initial delay before starting the main loop; mechanical issues, which were not noticed until the last minute, also contributed to false activation due to the front heavy weight of the Transport Cube being too much for its drawer slides to hold in the chassis. These issues went unnoticed due to not having an adequate amount of test runs beforehand and spending too much time in the design and fabrication phase to try and complete all tasks, rather than testing to identify existing issues early on. Before the Final Competition, the Enderneers were able to finish all fabrication for all tasks and do 5 test runs on the ME 2110 classroom track, where a working system was verified, and rotation issues with the telescoping arm were identified and fixed. In round one, the Enderneers earned 54 points, the highest score in the round, *Figure 30-32*. In the second round, the robot didn't activate due to banana plugs being plugged into the wrong input terminal. After advancing to the third round, the machine scored 14 points. Due to alignment issues, the claw missed the End Crystal; other teams were able to pull in Diamond and Netherite Ore faster than the Transport Cube's gear train could activate, and the Upper Bay got caught on its electrical wires, causing it not to extend all the way. The root cause of failure stems from a fundamental flaw in the design, which is a lack of speed. The Transport Cube takes ~1.5 seconds to enter the competition arena before the sweeping arms are activated to mine ores, compared to adjacent teams that immediately launch arms to position in ~0.8 seconds. Additionally, in round three, pneumatic piston-launched arms from an adjacent team completely blocked the sweep arms from obtaining ore, as their ore-mining arms extended quicker than the Transport Cube could travel to the arena.

The Minecraft Challenge stresses the importance of designing a machine with strengths in rigidity, multitasking, multi-functionality, *and* speed. These are parameters of a system that maximizes points, thus, The Enderneers followed a design process centered around these qualities, developing specifications that give the machine multi-functionality, multi-task-ability, and rigidity. However, speed was a limiting factor in the final design of the machine, evident by the slow sweep-arm extension in round three of the final competition, where 22 potential points were lost from ore. The Transport Cube's multi-functional design with the ability of task concurrency defines a design approach with potential for rigid and reliable high-scoring systems, shown to be effective by its subsystems working at a high level. With improvements in speed through different transport methods such as wood slides, or a low-density, lighter, non-MDF-based system, the concept developed by the Enderneers can extend to be successful in future design processes.

Appendix 1 – Figures and Tables

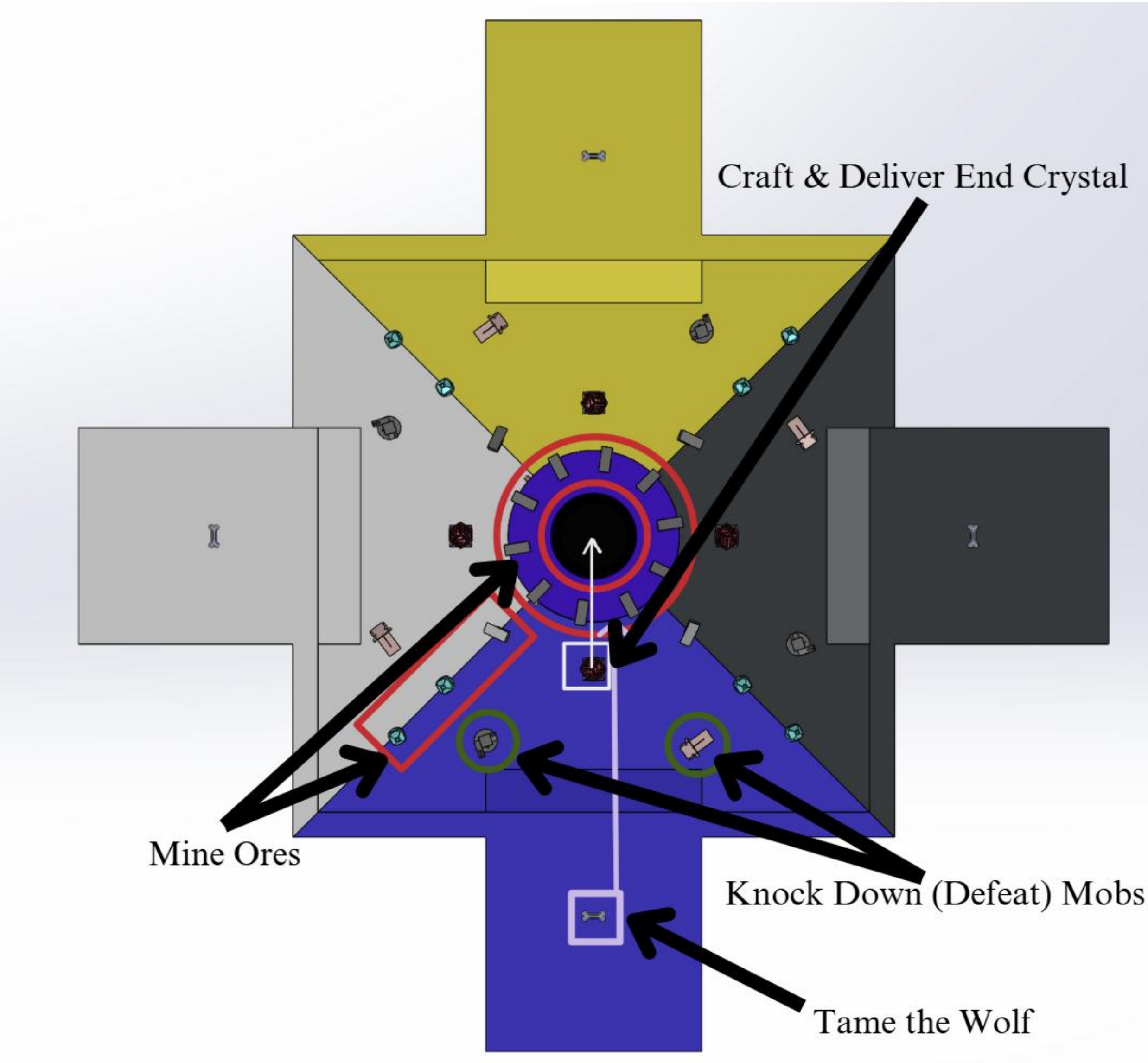


Figure 1: Competition Track

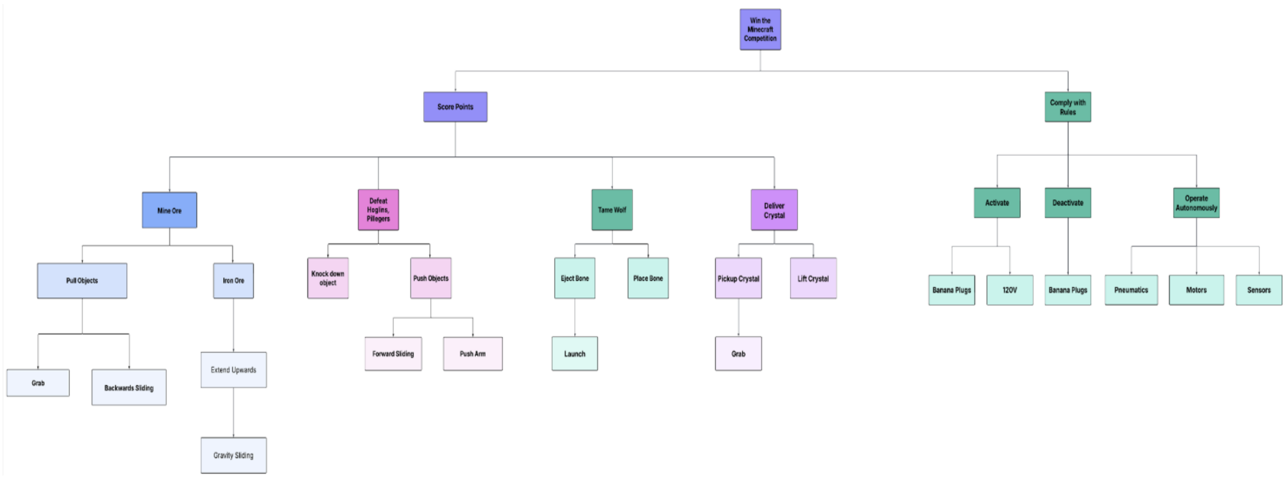


Figure 2: Functions Tree

Project:
Revision:
Date:

Correlations

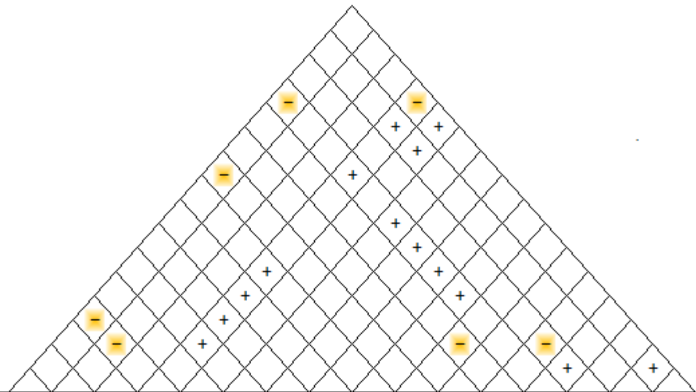
Positive +
Negative −
No Correlation

Relationships

Strong ●
Moderate ○
Weak ▽

Direction of Improvement

Maximize ▲
Target ◇
Minimize ▼



Category	Weight	Customer Requirements (Explicit and Implicit) \ Engineering Requirements	Costs ($)	Min & Max Dimensions (in)	Setup Time (sec)	Complete Multiple Tasks	Lower Run Time	Push Objects	Eject Objects	Pull Objects	Pick Up Objects	Weight	Extend Objects Upwards	No Track Damage	Chassis & Attachements Strength	Support Object Weight	Complete Multiple Tasks at Once	Complete Tasks Quickly
		Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Direction of Improvement	◇	◇	▼	▼	◇	▲	▲	▲	▲	◇	▲	▲	▲	▲	◇	▲
Objectives	9	Launch Machine		●		●												●
	9	Tame Wolf				●	▽	○	●		●		▽		▽	●		▽
	7	Mine Iron, Diamond, Netherite				●		●	▽	●	▽				▽		○	●
	9	Craft and Deliver End Crystal				●		▽	○		●		●		●	●		▽
	8	Defeat Hoglins and Pilligers				●		●			○							▽
	9	Keep Enemy Mobs outside Home Zone				○		○	●		○							●
	7	Force Mobs into Adjacent Zone(s)				○		●	●		○							●
Competiton Constraints	10	Time Limit(s) Satisfaction			●			○	○	○	○		○				○	●
	9	Operate Autonomously				●	▽											
	8	Affordable	●	▽								○						
	6	Fit within Bounding Box		●														
User Interaction	9	Consistent & Reliabile	▽		▽		●							○				▽
	7	Safe							▽			▽		●				
	7	Stablility	▽									○					●	
	10	Maximize Points	▽	●	●	●	●	●	●	●	○		○	●	○	○	●	●
	7	Portablility	▽		○							●						
Total Weight		Target	<= $120	11" x 23" x 17"	<= 2 minutes	>= 4	35-40 seconds	10 Newton	9.8 m/s^2	10 Newton	10 Newton	4.5 kg (~10 lbs)	>= 30 inches retraction distance	More than 5 runs with 0 damage	Perform w/o maintenance >= 3 trials	0.5 kg (~ 1 lb)	>= 2 tasks	<= 10 seconds per task
		Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
		Technical Importance Rating	105	233	210	597	189	381	386	183	301	115	150	180	127	192	204	503
		Relative Weight	3%	6%	5%	15%	5%	9%	10%	5%	7%	3%	4%	4%	3%	5%	5%	12%
		Weight Chart																
		Our Product																
		Competitor #1																

Figure 3: HOQ (House of Quality)

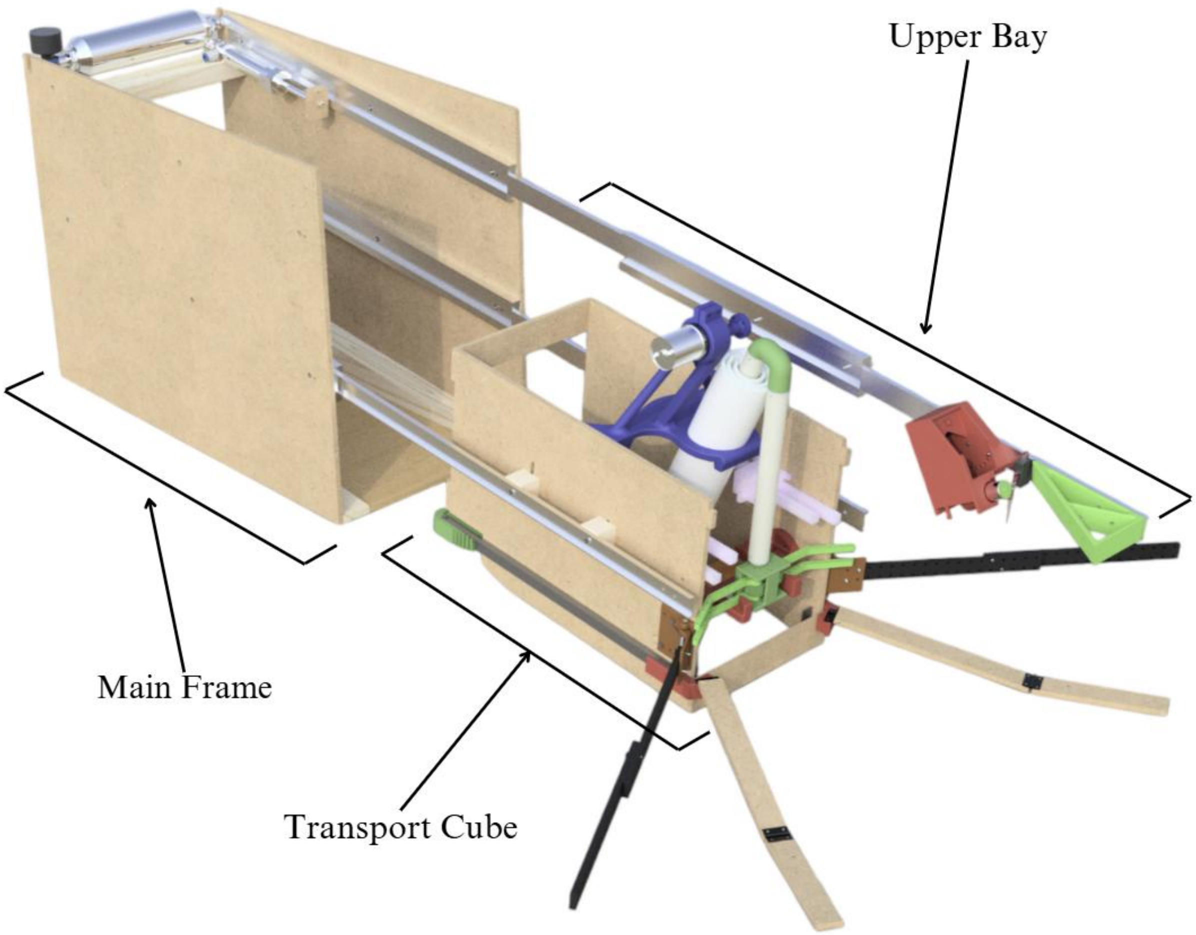


Figure 4: Final Chosen Design

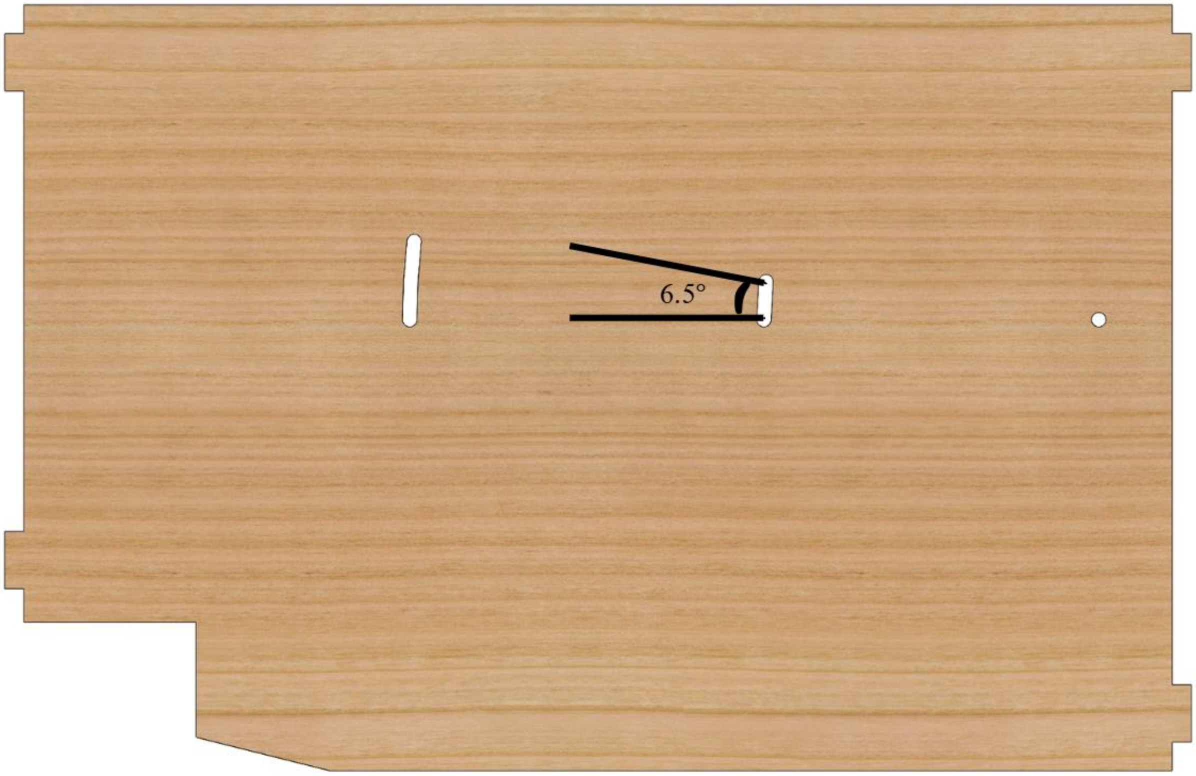


Figure 5: 6.5 ° mobility cutouts

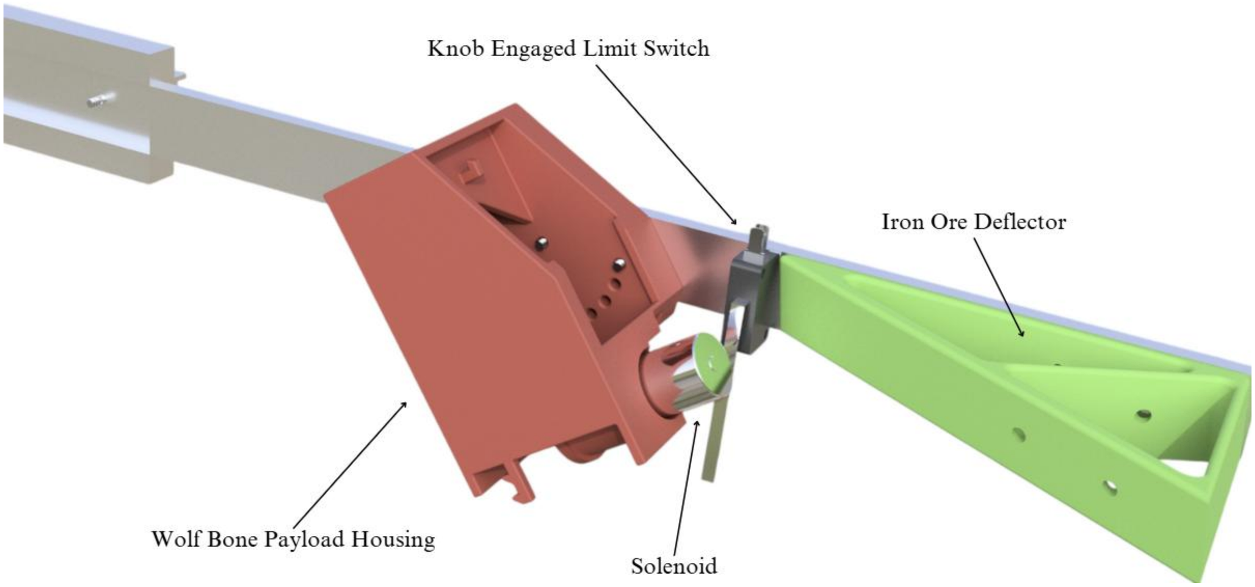


Figure 6: Upper Bay

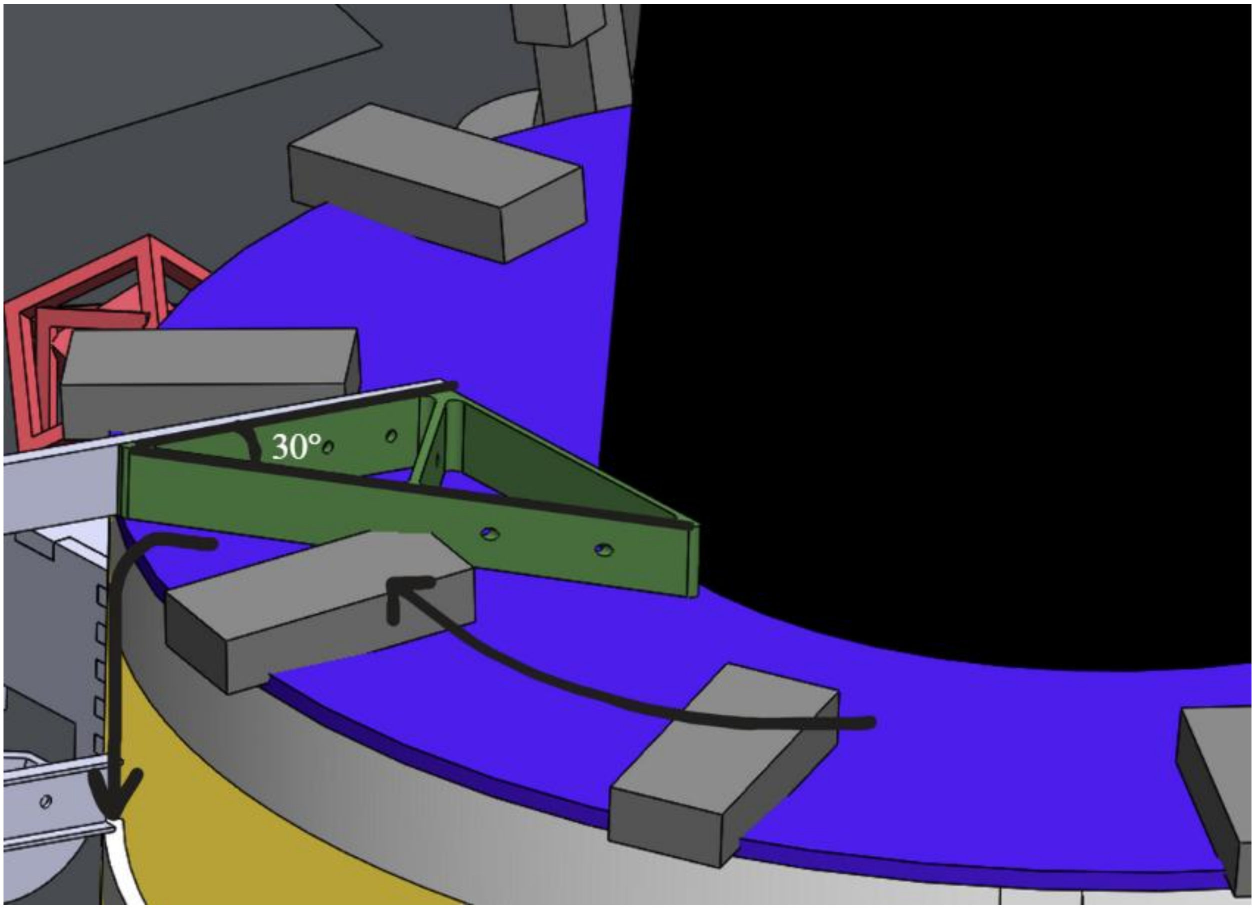


Figure 7: Iron Ore Deflector

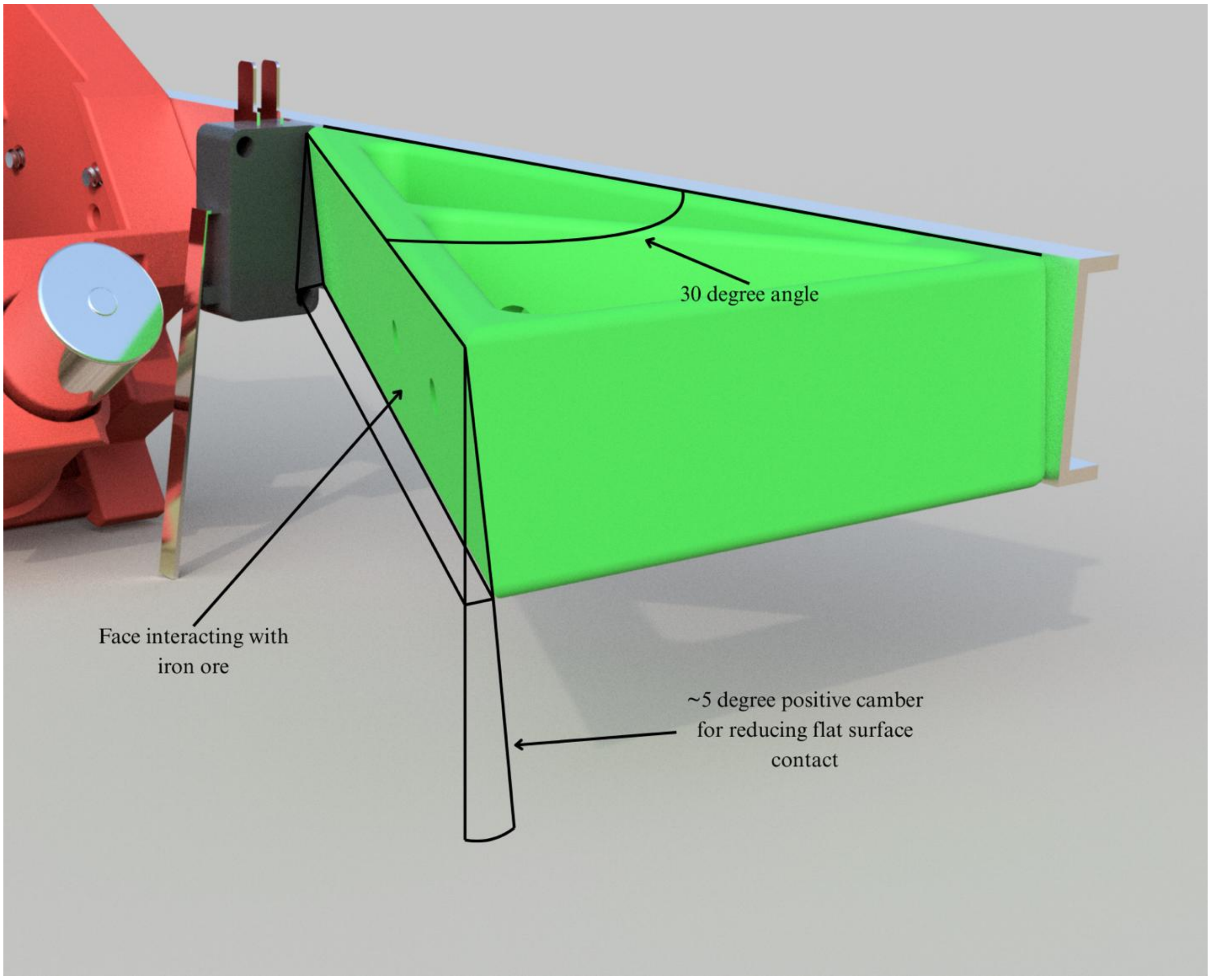


Figure 8: Iron Ore Deflector Camber

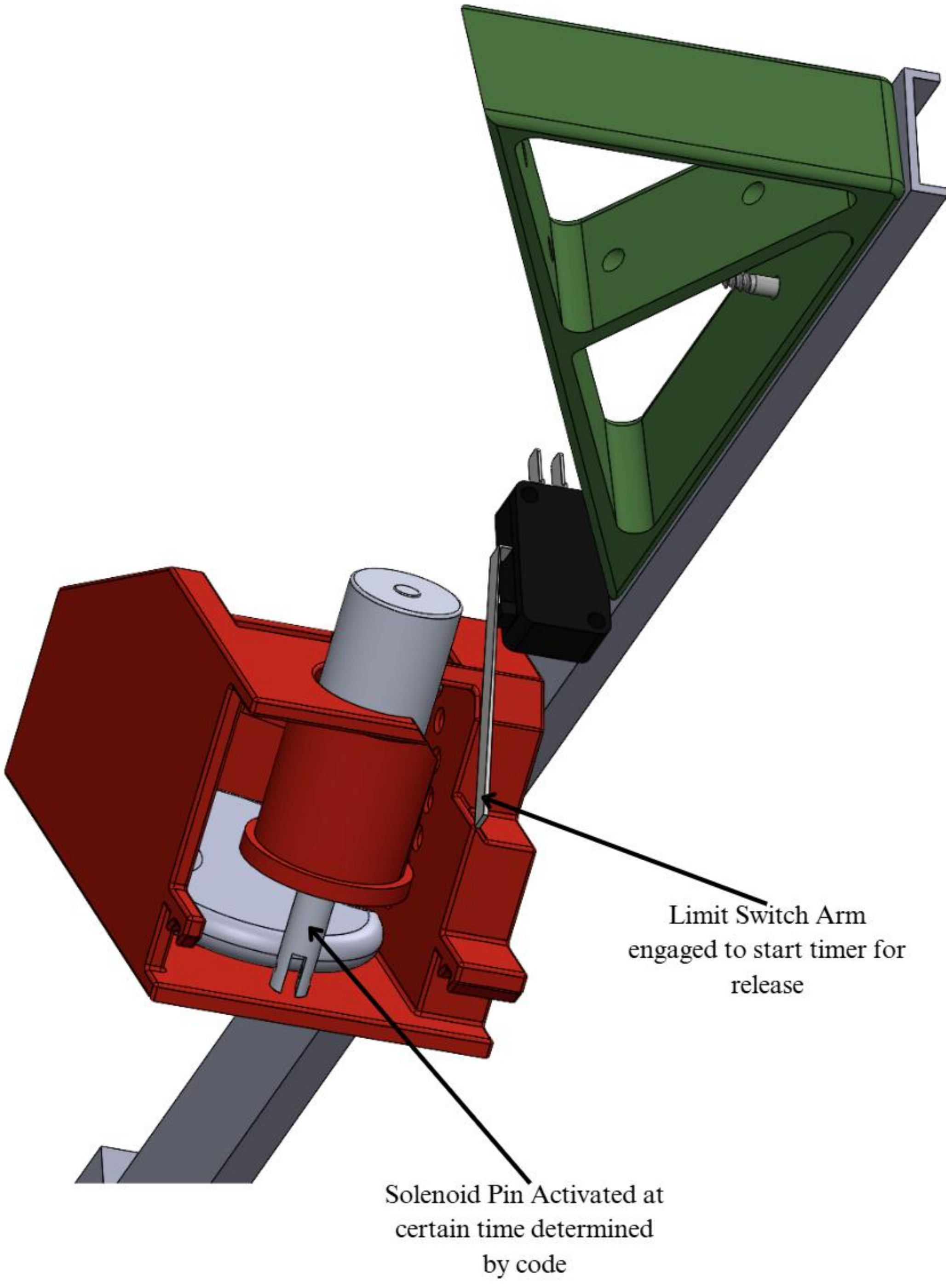


Figure 9: Solenoid Timed Release

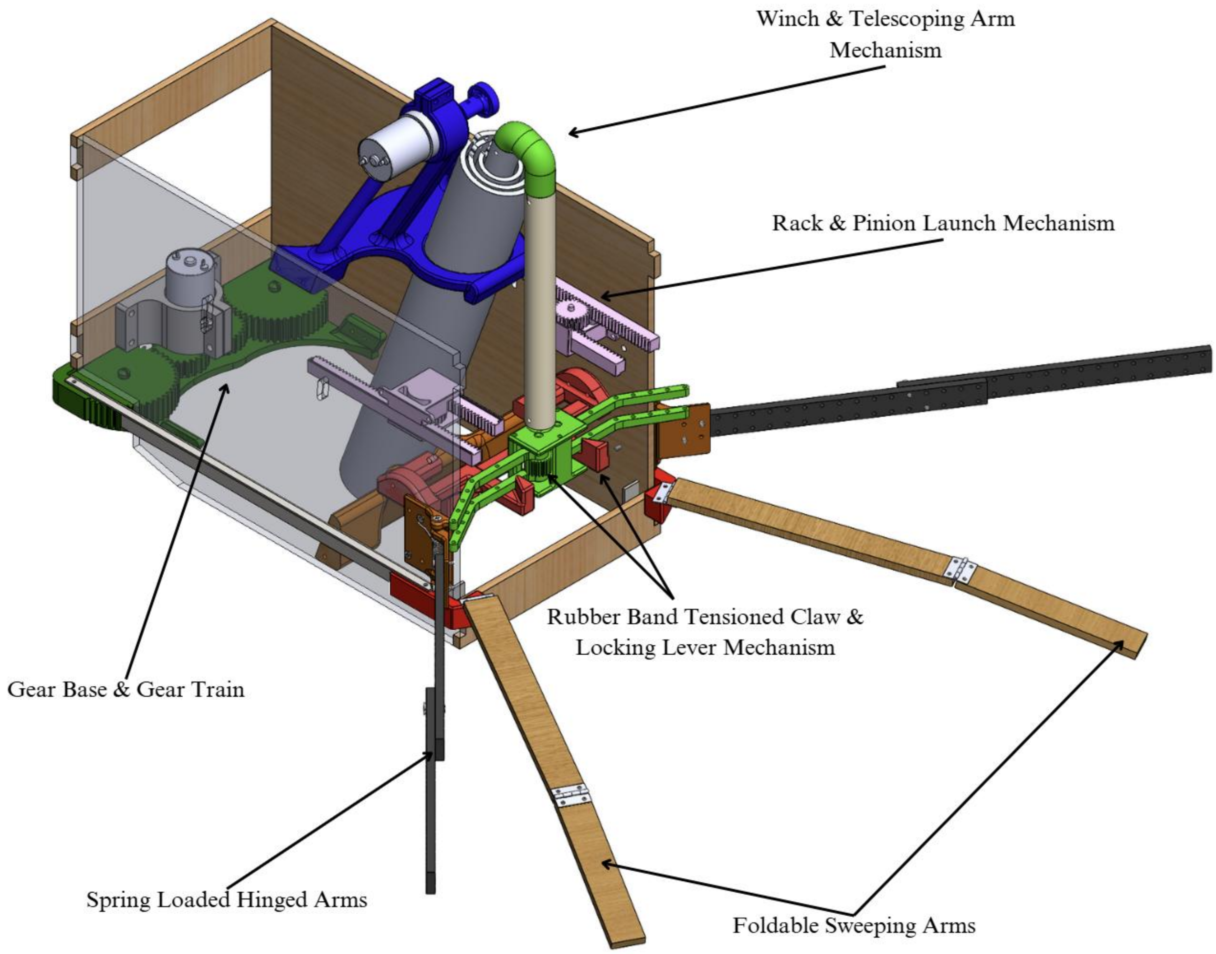


Figure 10: Transport Cube

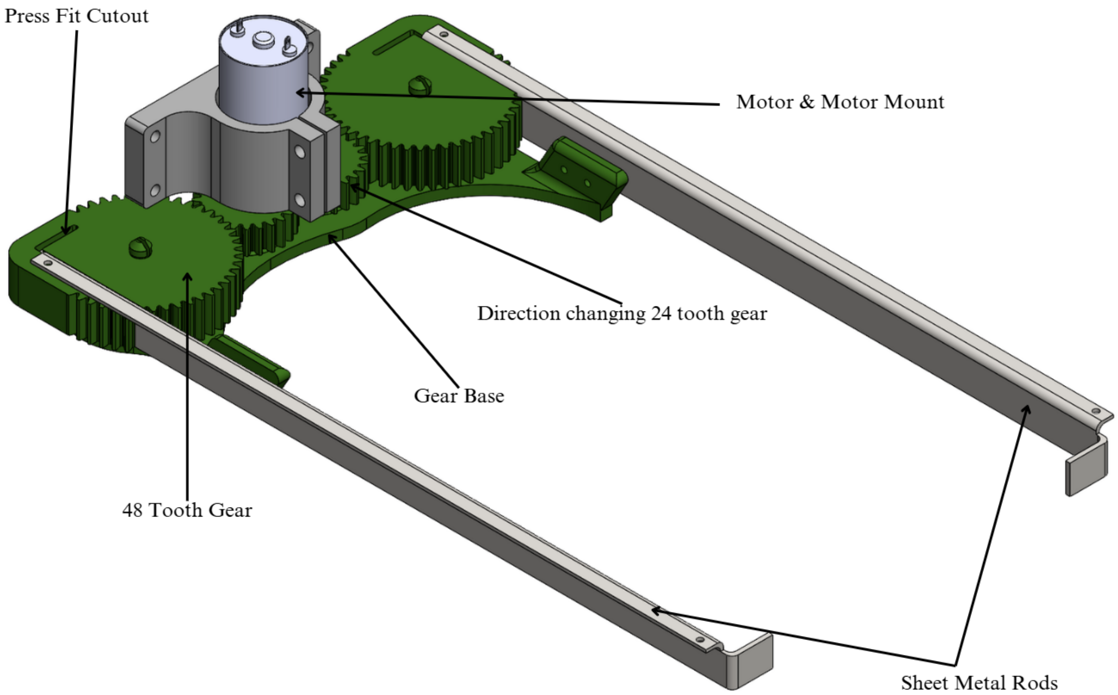


Figure 11: Gearbox

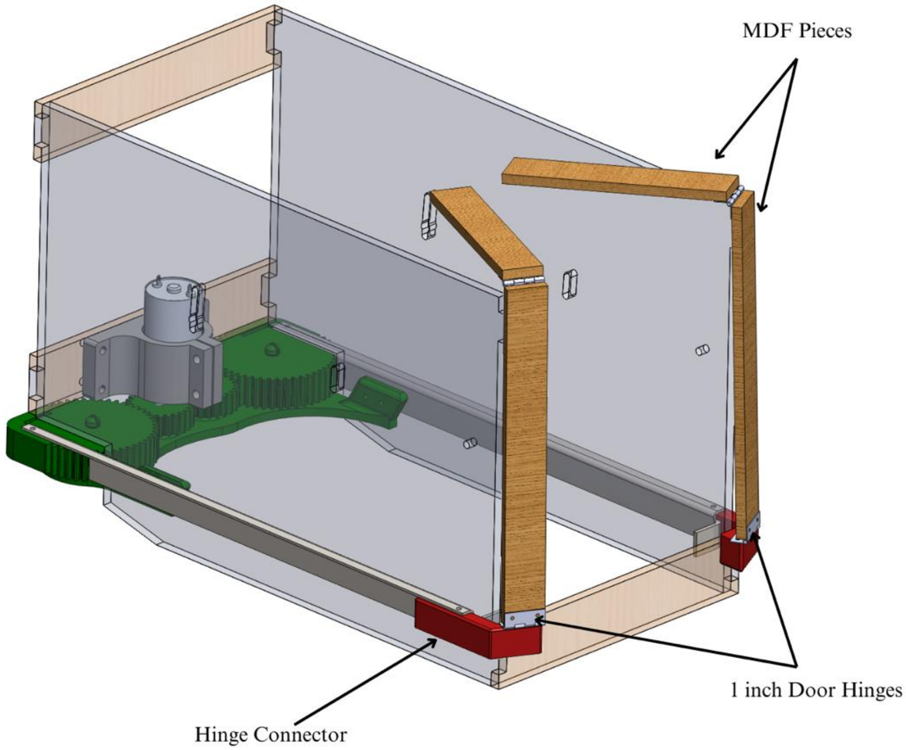


Figure 12: Sweeping Arms

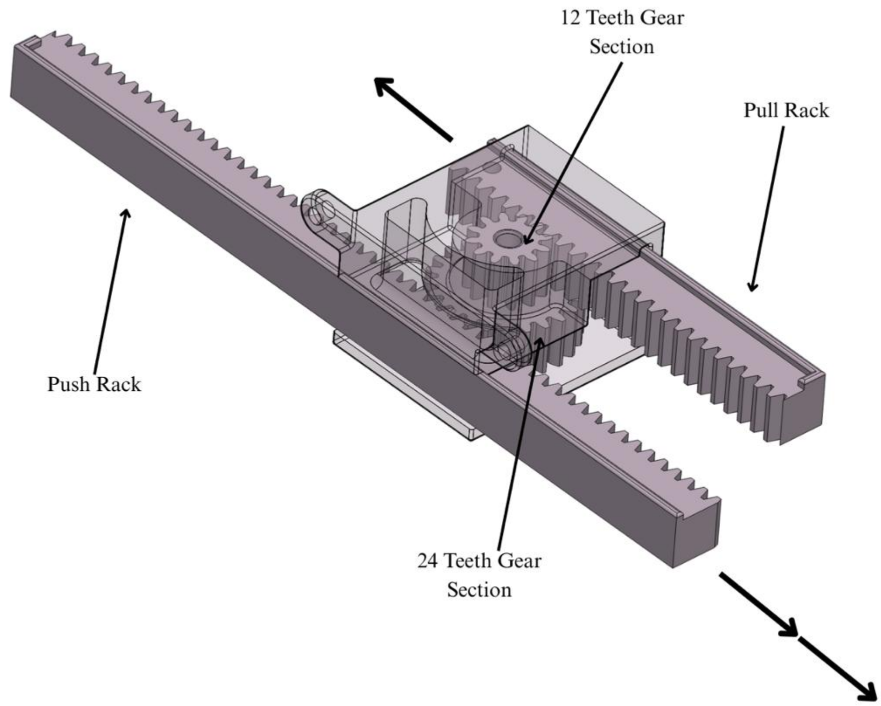


Figure 13: Rack & Pinion System

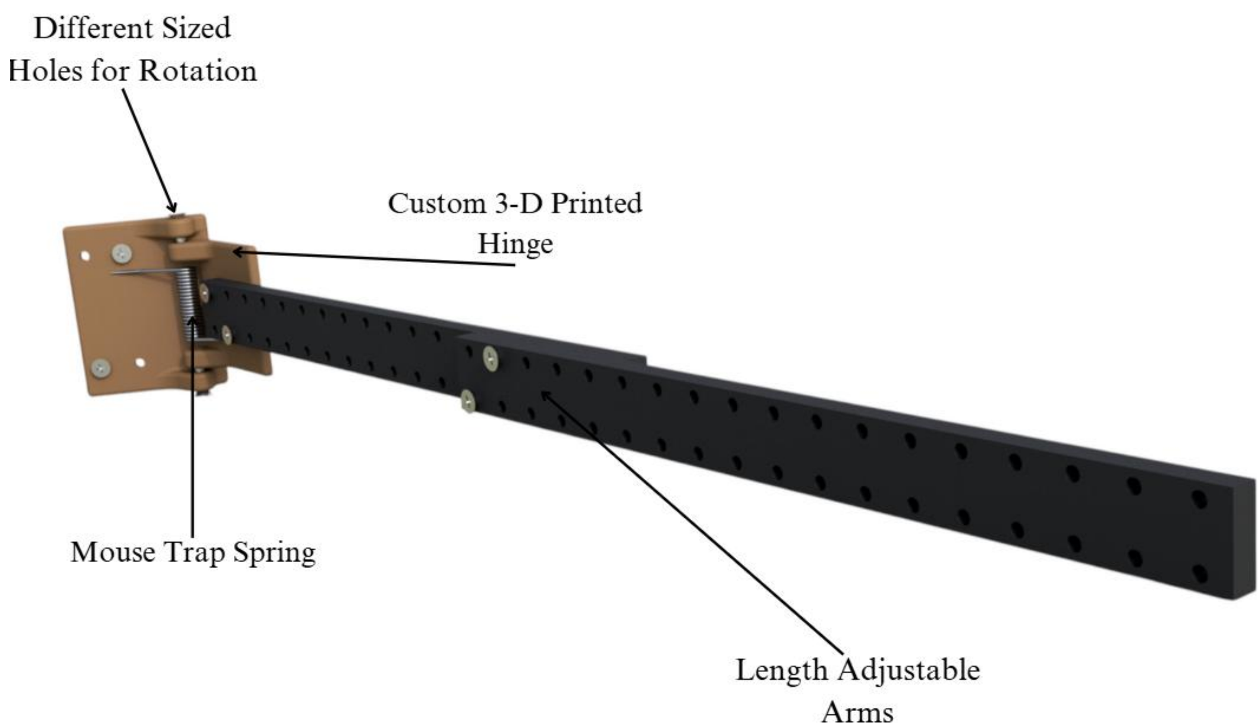


Figure 14: Spring Loaded Mob Arms

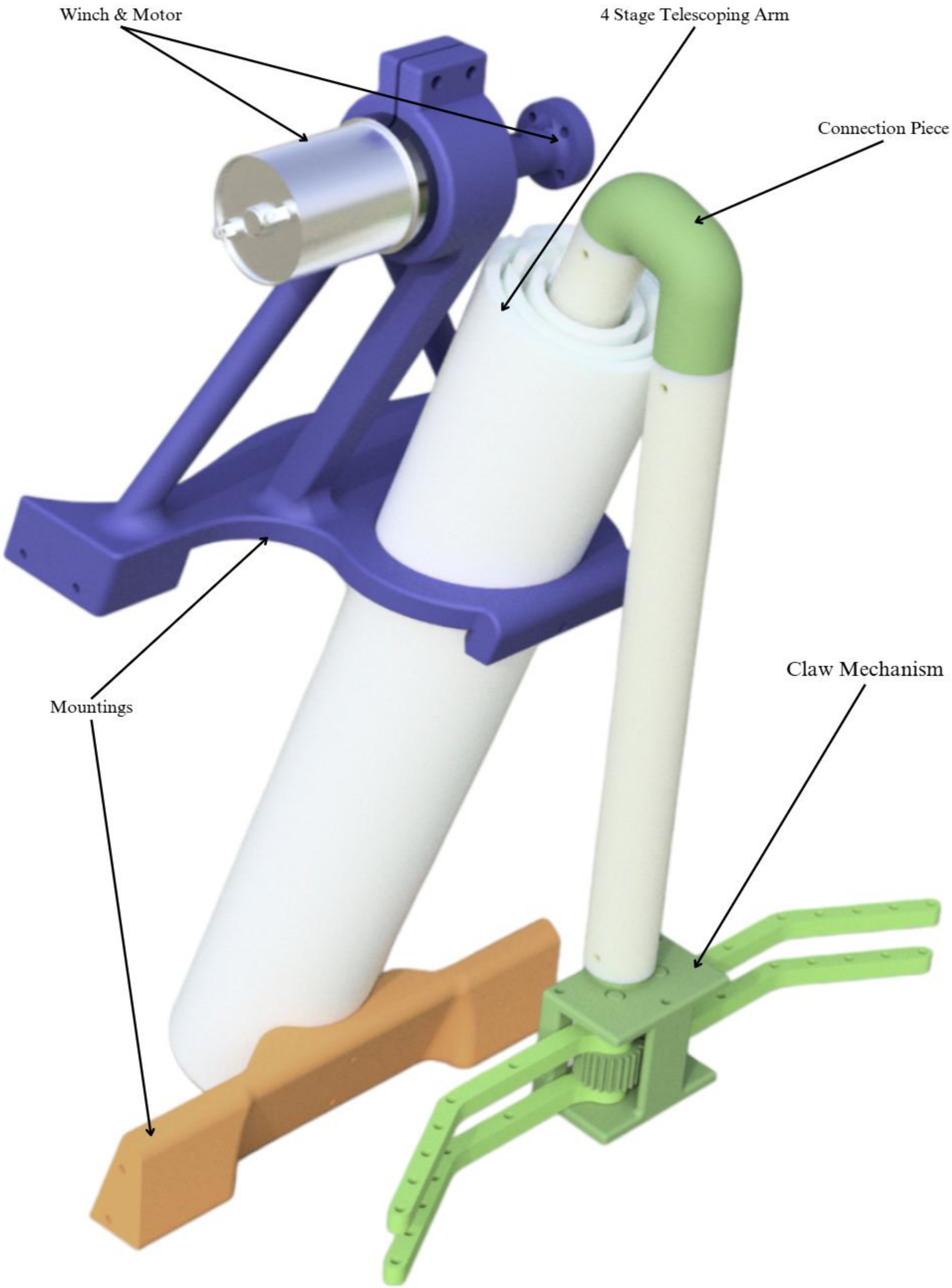


Figure 15: Telescoping Arm

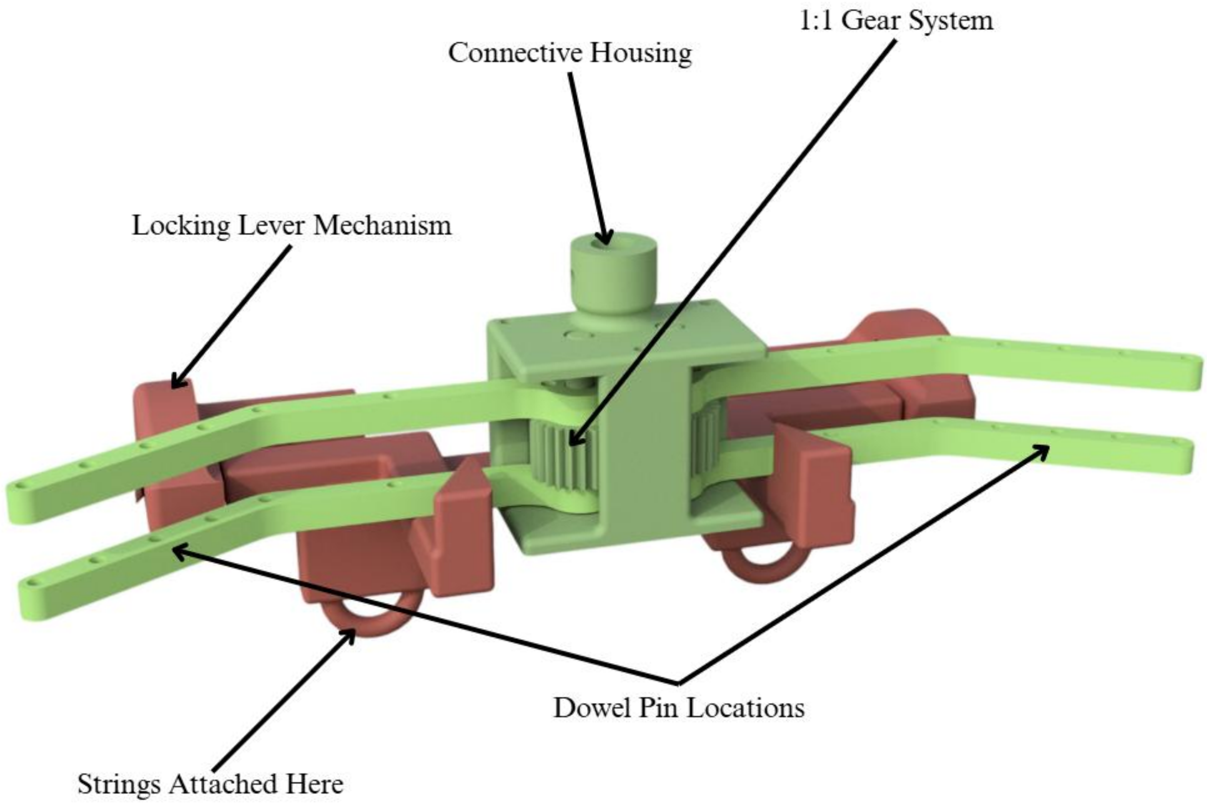


Figure 16: Claw Mechanism

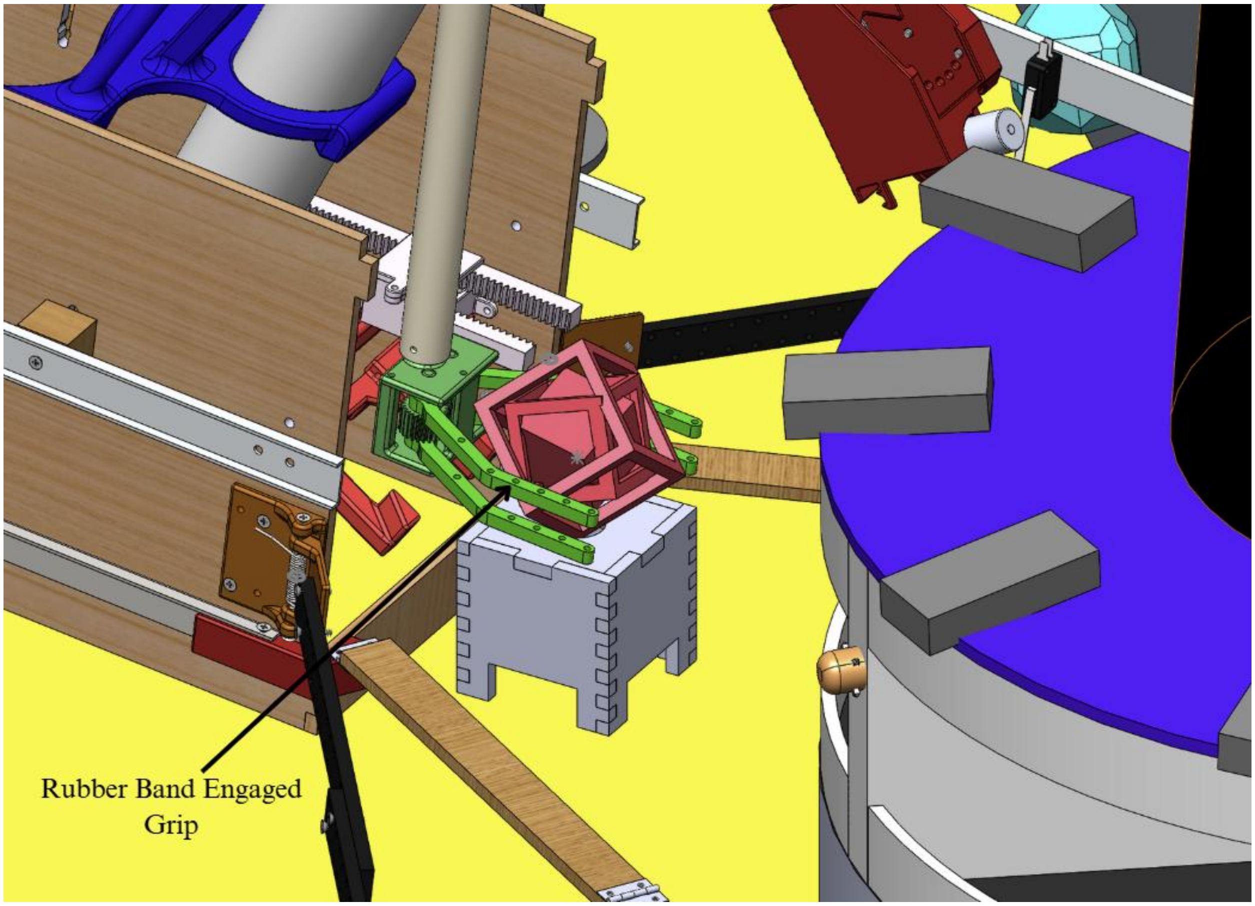


Figure 17: Released Claw Mechanism with Captured End Crystal

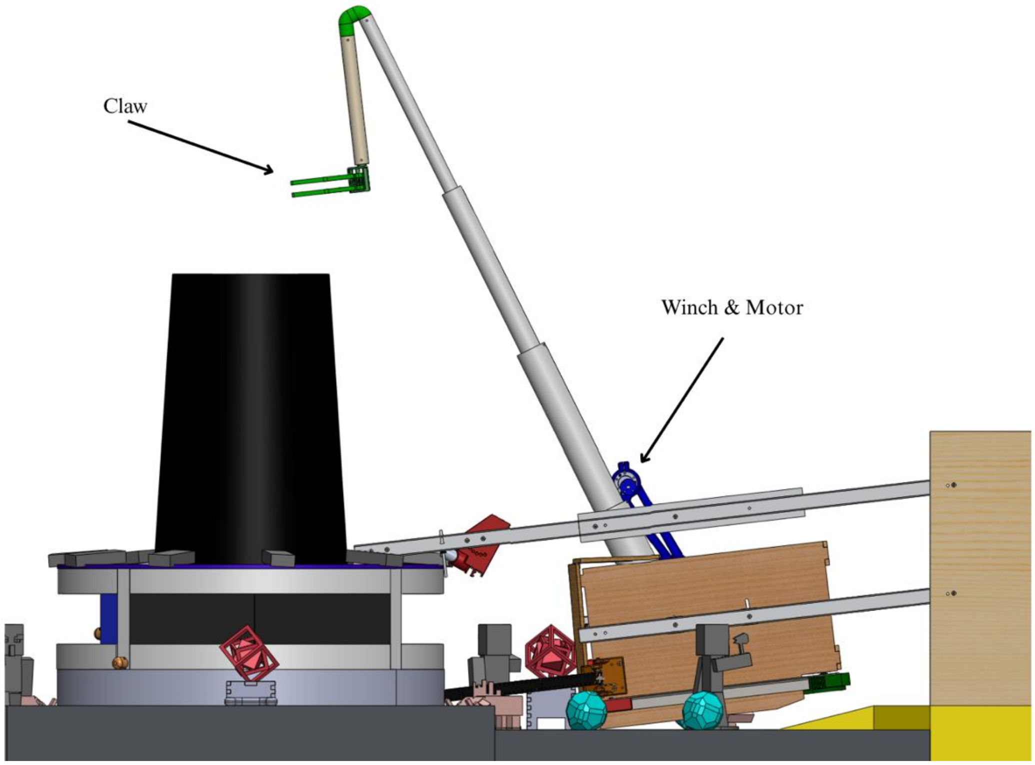
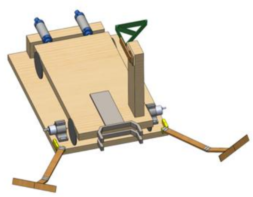
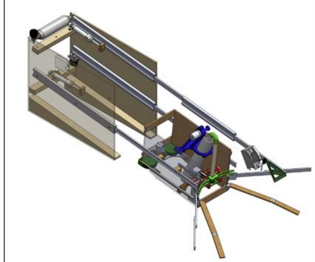
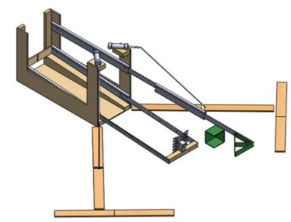


Figure 18: Extended Telescopic Arm with Claw within Obsidian Tower Dome

	Concept	Prototype 1		Prototype 2		Prototype 3	
							
Criteria	Importance	The Wheel Design		The Carriage Design		The Suction Cup - Scissor Design	
Launch Machine	9	2	18	4	36	2	18
Tame Wolf	9	3	27	3	27	4	36
Mine Iron, Diamond, and Netherite	7	2	14	4	28	4	28
Craft and Deliver End Crystal	9	2	18	3	27	3	27
Defeat Hoglins and Pilligers	8	3	24	3	24	1	8
Keep Enemy Mobs outside Home Zone	9	0	0	3	27	1	9
Force Mobs into Adjacent Zones	7	1	7	3	21	1	7
Time Limit Satisfaction	10	4	40	4	40	3	30
Operate Autonomously	9	4	36	4	36	3	27
Affordable	8	4	32	4	32	2	16
Fit within Bounding Box	6	4	24	4	24	4	24
Consistent & Reliable	9	2	18	4	36	2	18
Safe	7	3	21	4	28	2	14
Stability	7	2	14	4	28	2	14
Maximize Points	10	2	20	4	40	3	30
Portability	7	2	14	3	21	3	21
	Total		**327**		**475**		**327**
	Relative Total		**0.290**		**0.421**		**0.290**

4 - very good, 3 - good, 2 - satisfactory, 1 - unacceptable, 0 - not aplicable

Figure 19: Concept Evaluation Matrix

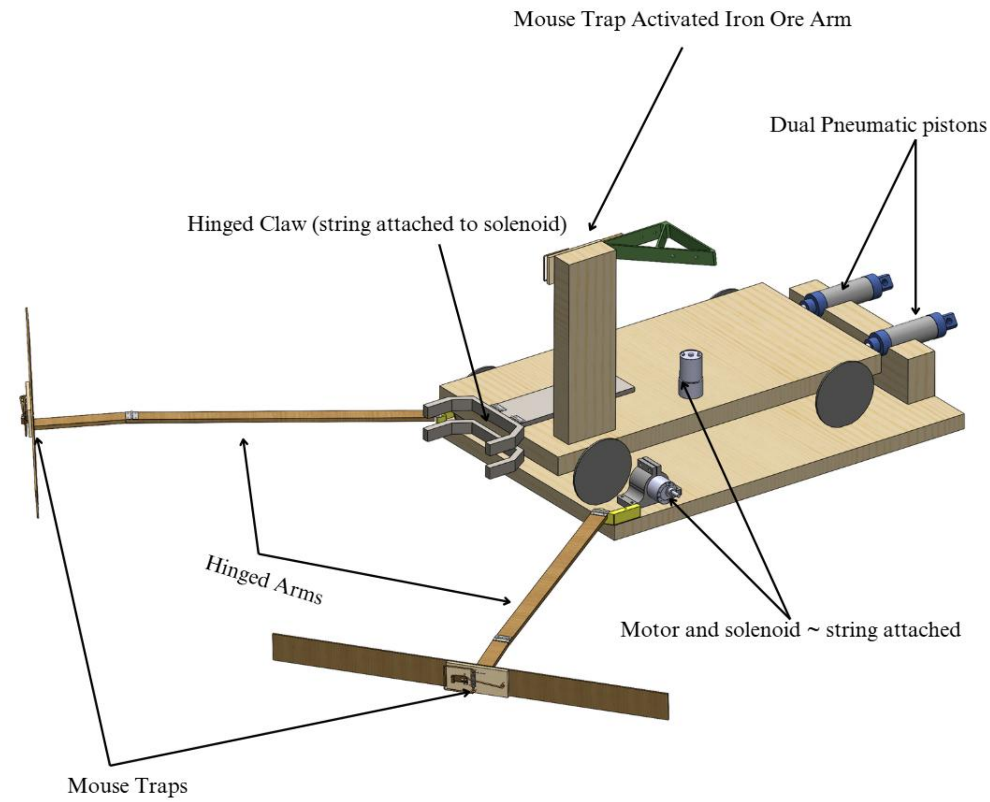


Figure 20: The Wheel Design Orthographic View

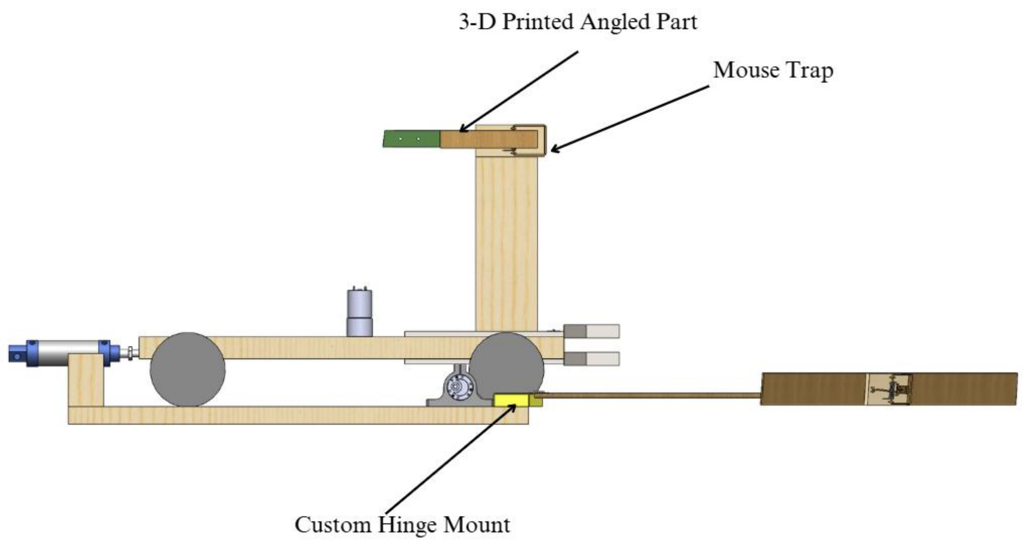


Figure 21: The Wheel Design Side View

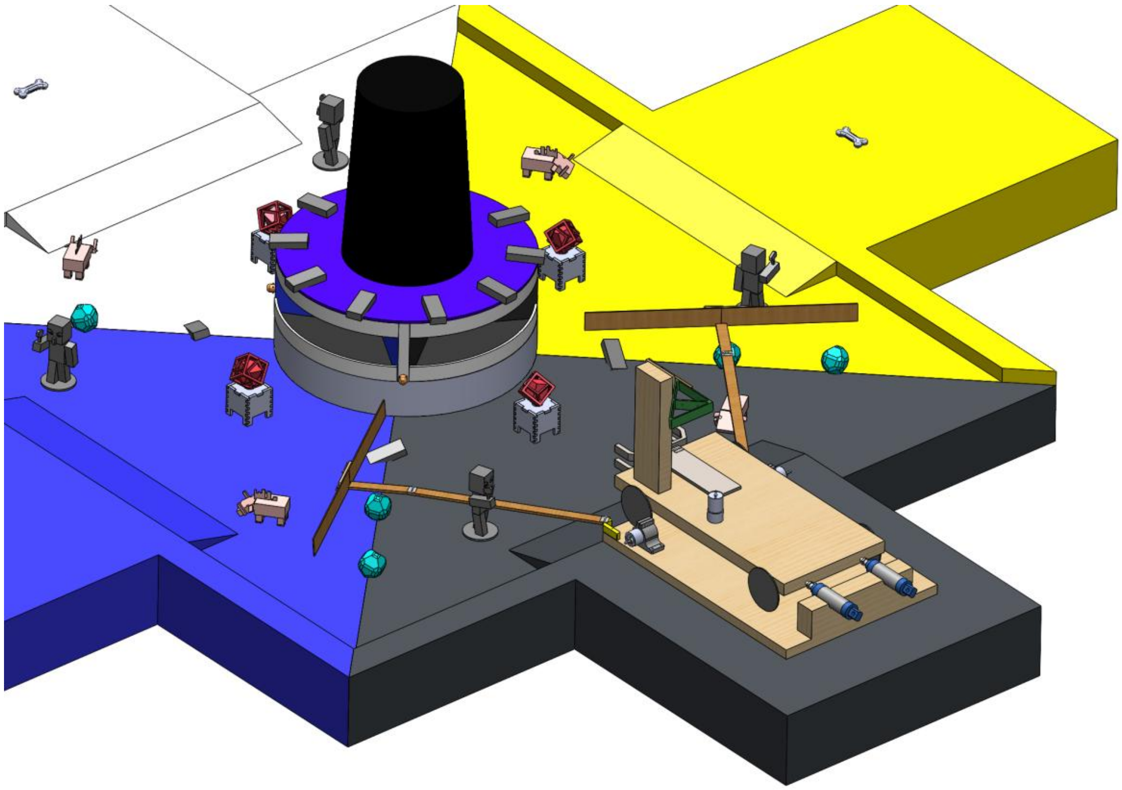


Figure 22: The Wheel Design Track View

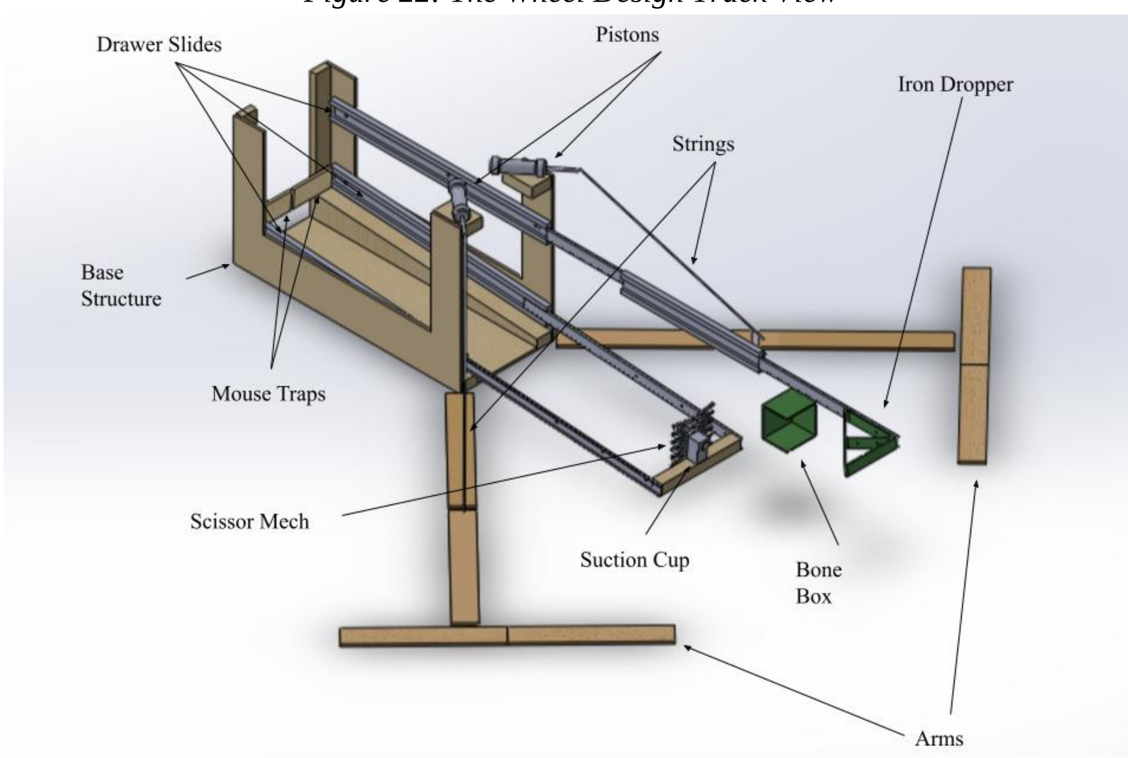


Figure 23: The Scissor Design Orthographic View

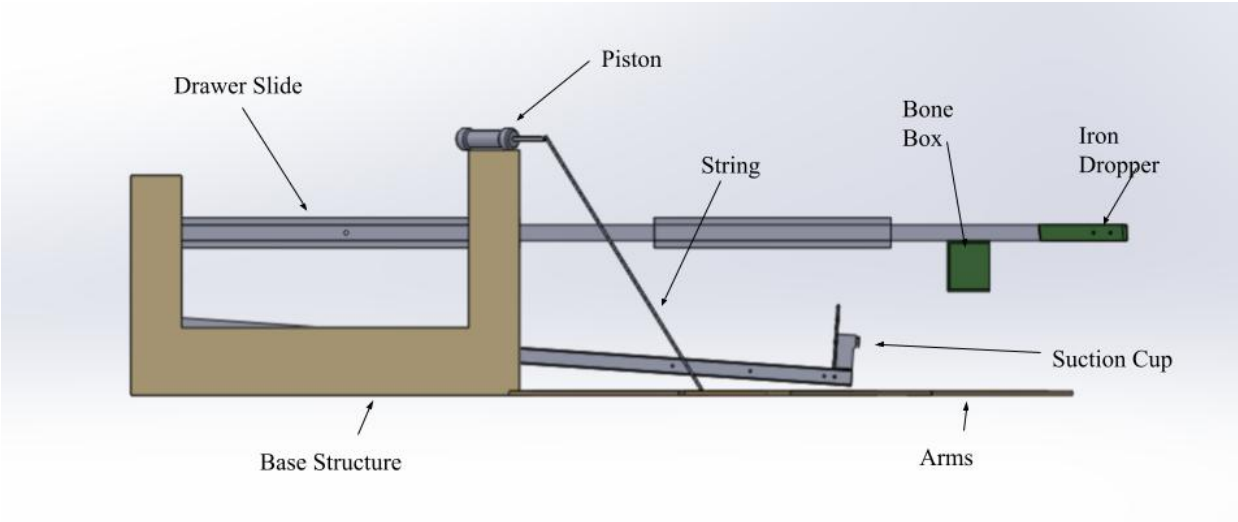


Figure 24: The Scissor Design Side View

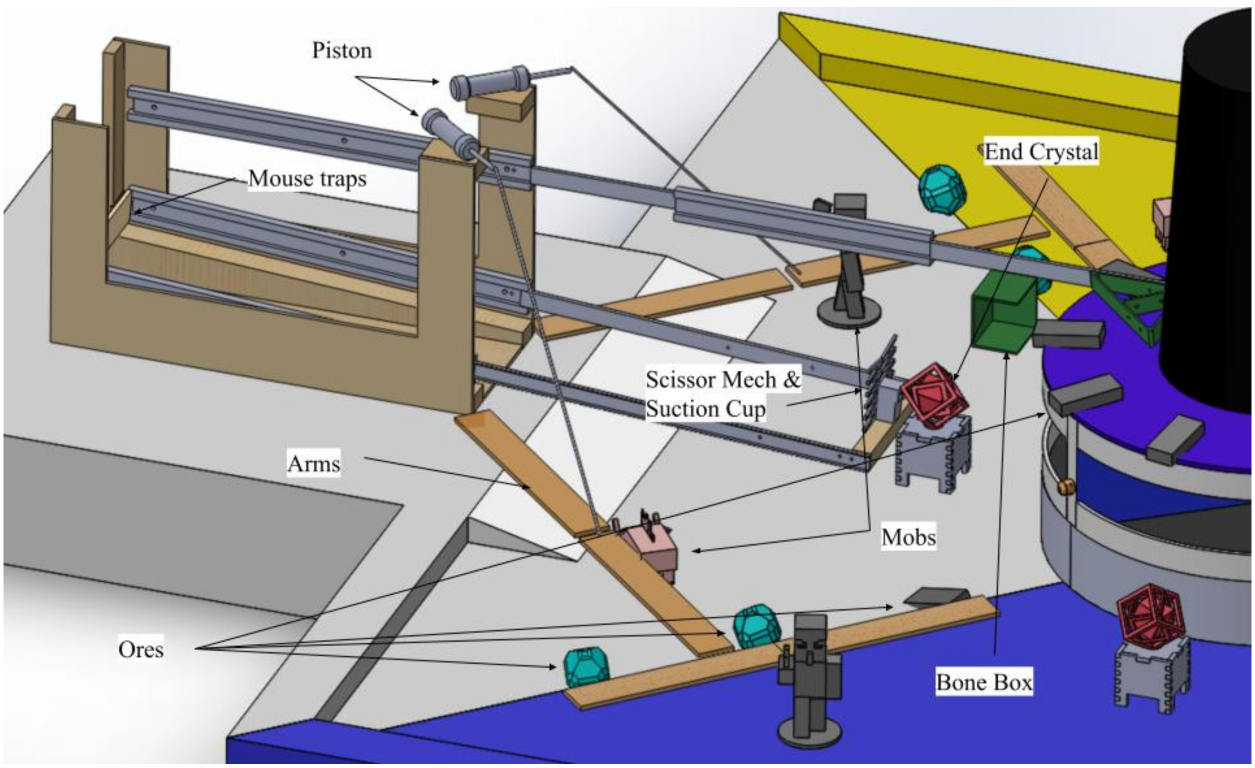


Figure 25: The Scissor Design Track View

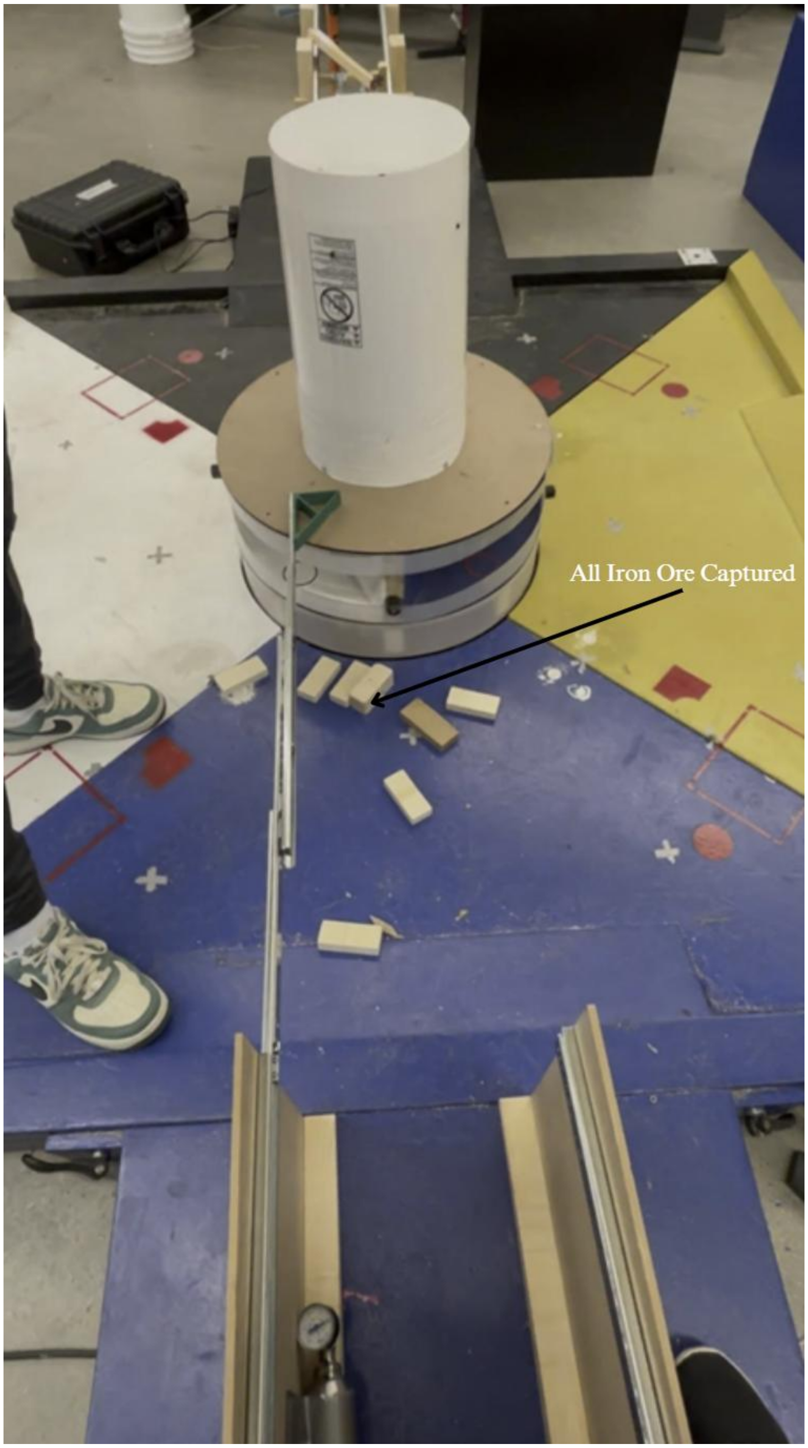


Figure 26: Pre Spring 1 Testing

Figure 27: Pre-Sprint 2 Telescoping Arm Testing

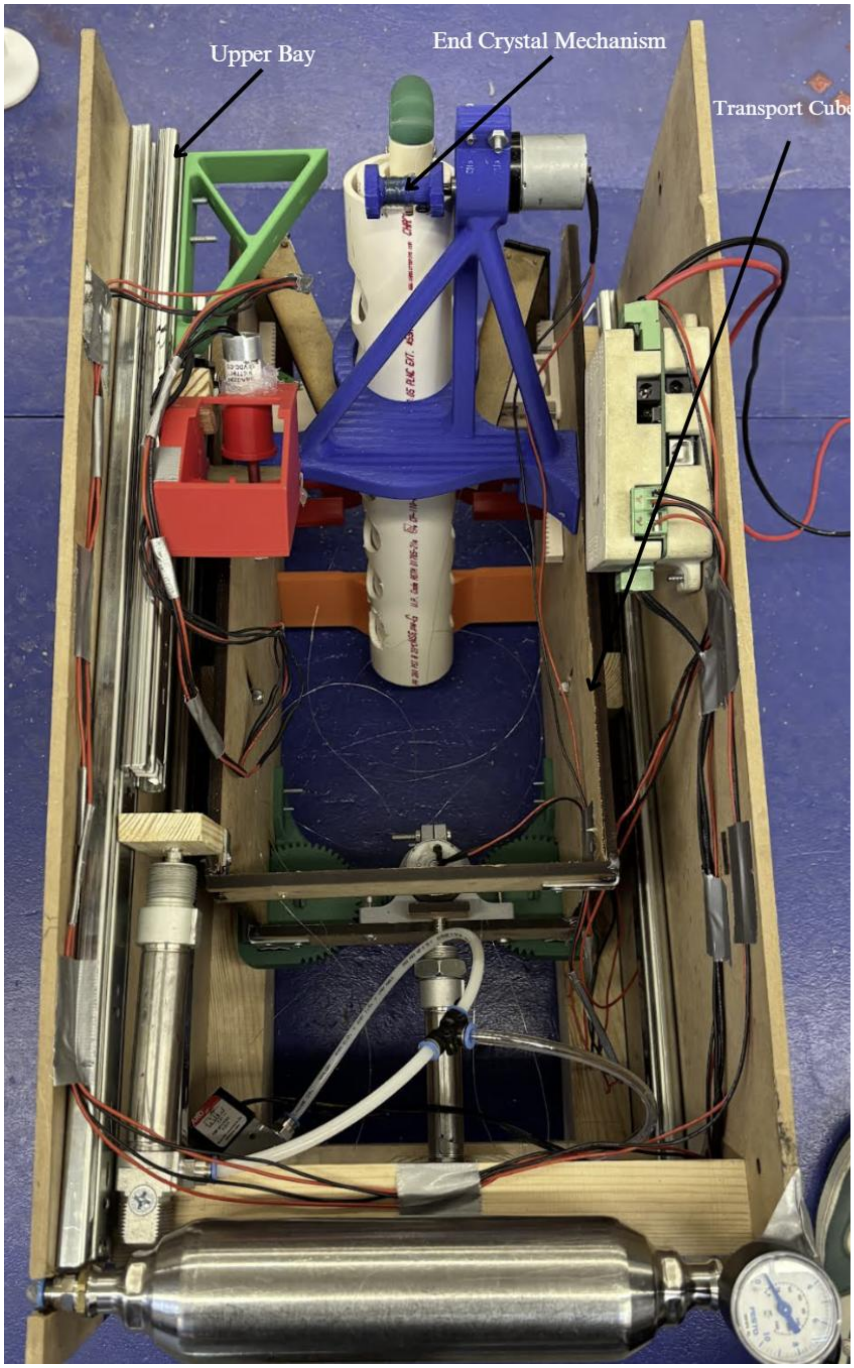


Figure 28: Pre-Sprint 2 Machine

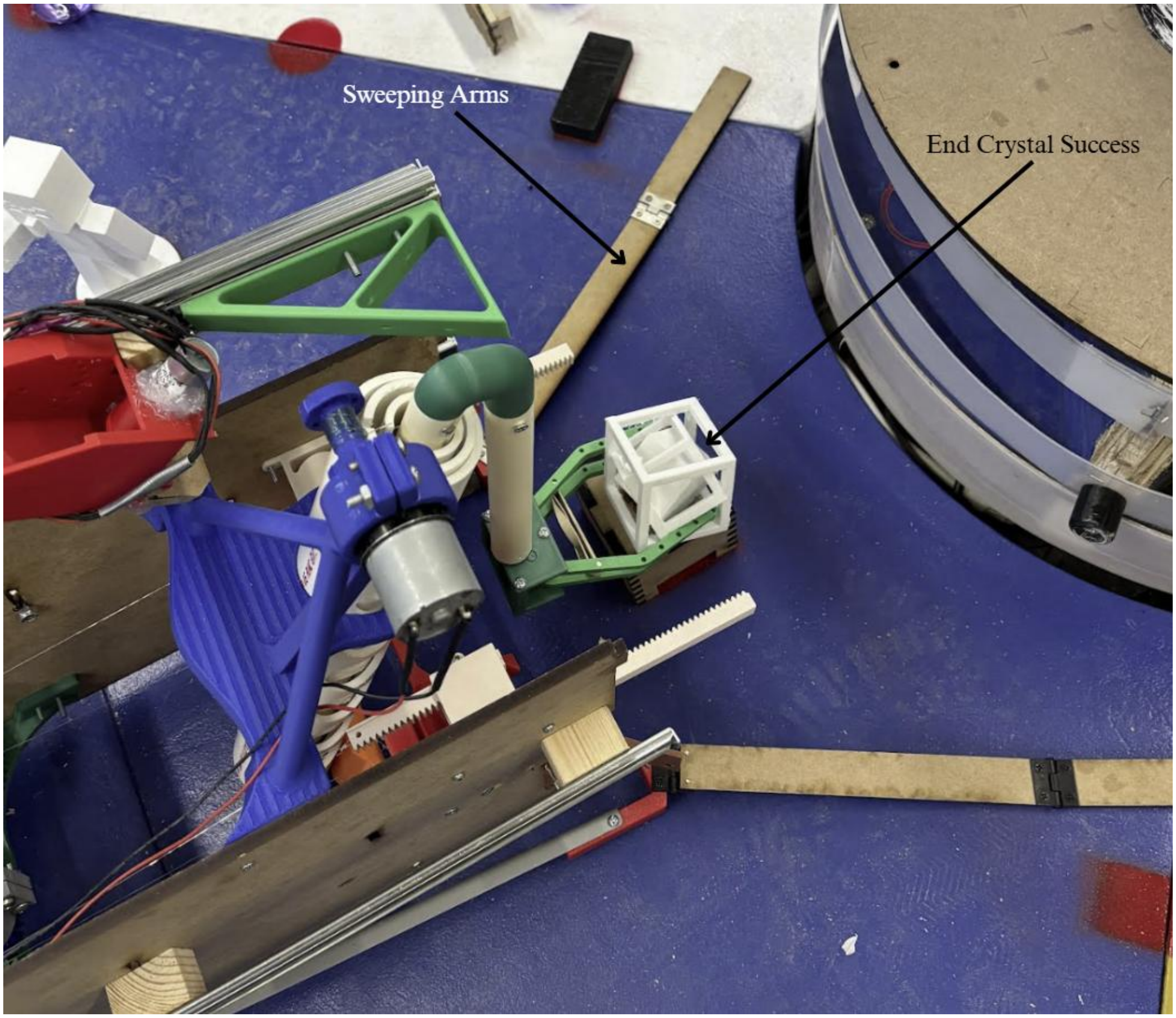


Figure 29: Pre-Sprint 2 Testing

Figure 30: Upper Bay Fabrication Post-Sprint 2

Figure 31: Pre-Round Final Competition

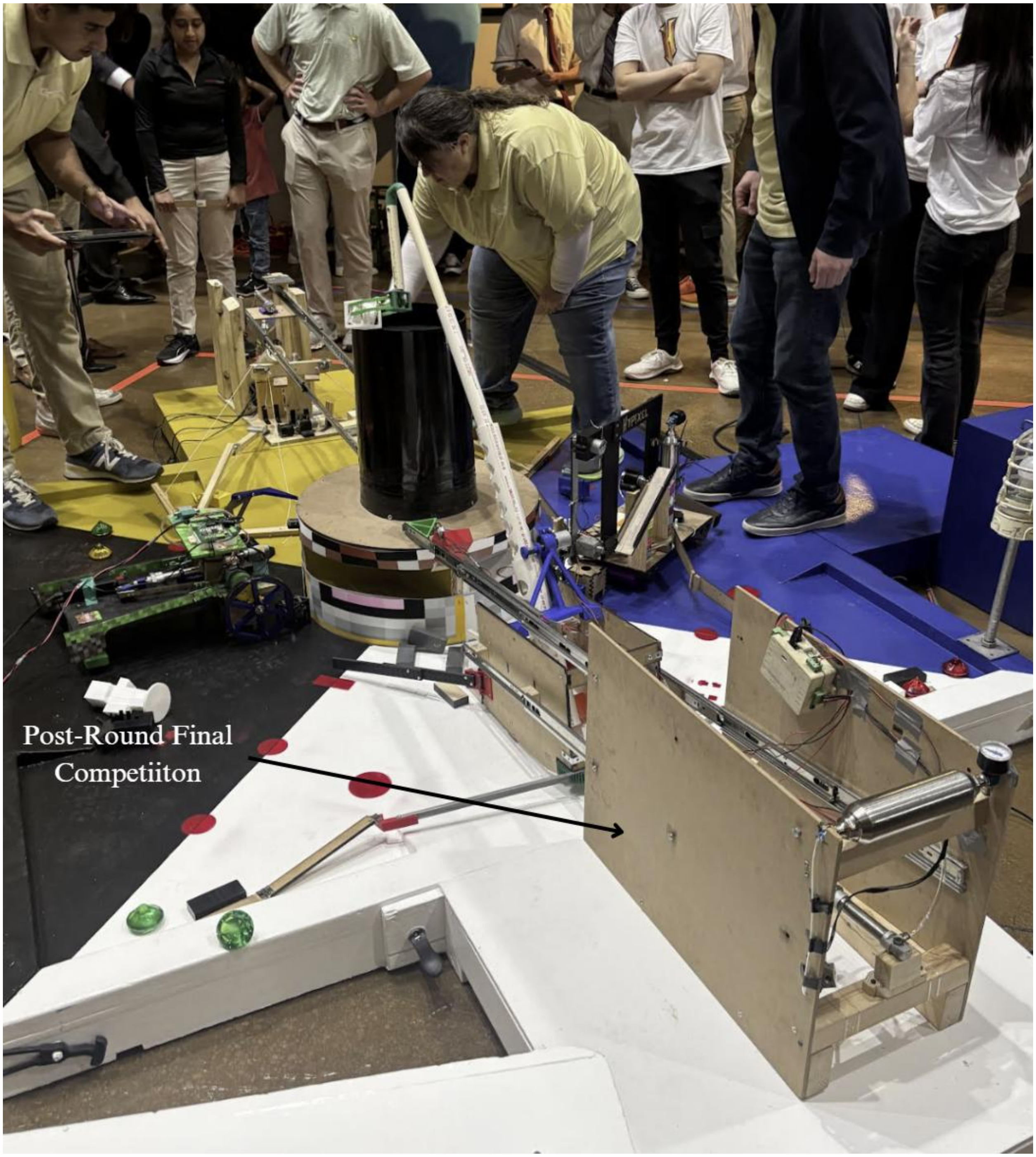


Figure 32: Post-Round Final Competition

Table 1: Morphological Chart

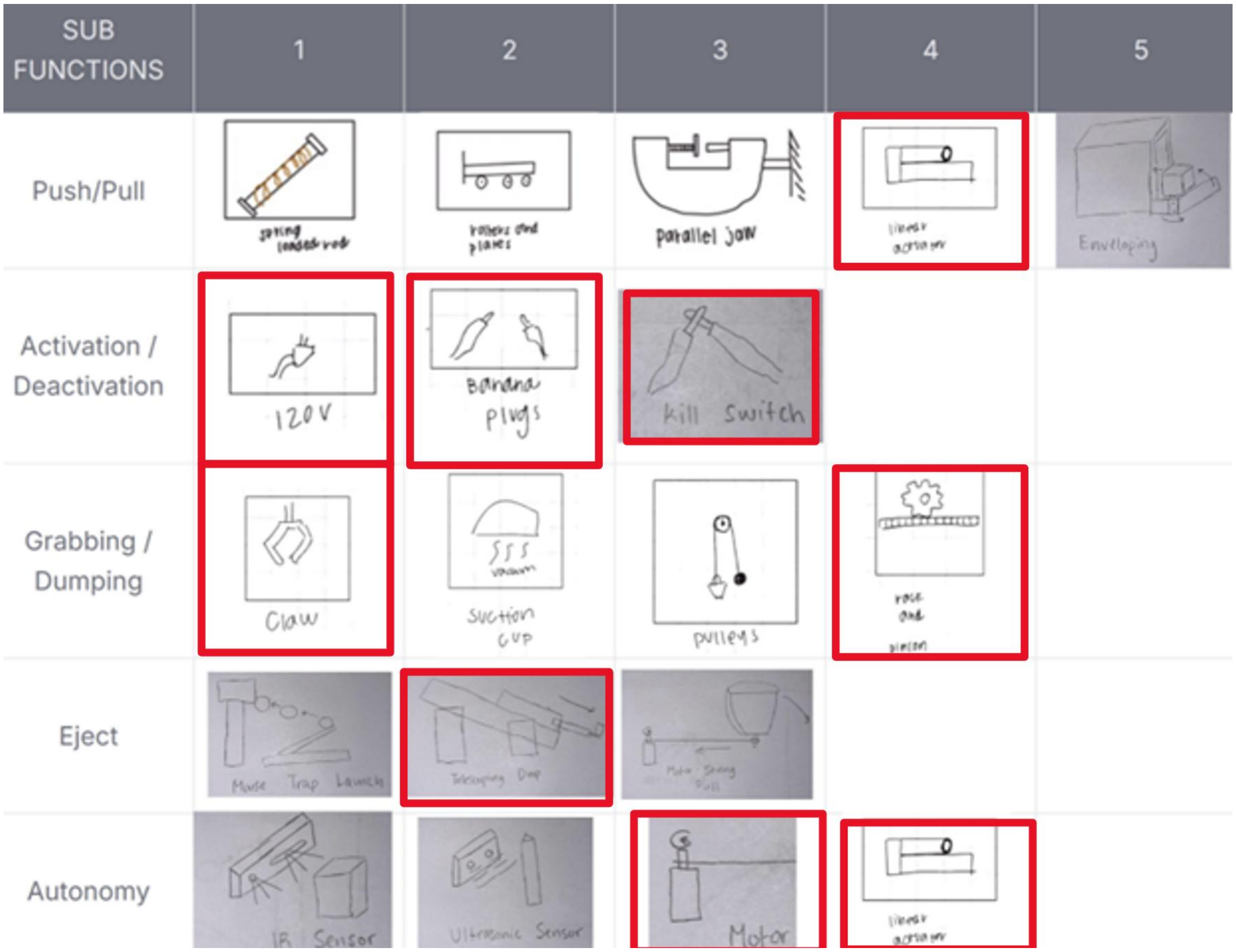


Table 2: Specification Sheet

		Specification		Issued:
		For: ME 2110 Robot		
Changes	**D/W**	**Requirement**	**Responsibility**	**Source**
2/13/2025	D	Win Mincraft Challenge	Design Team	Overall Customer Demand
2/13/2025	D	Complete Tasks in Minecraft Competition	Design Team	Final Design Project Guidelines
2/13/2025	D	Avoid Disqualification	Design Team	Final Design Project Guidelines
		Dimensions		
2/13/2025	D	Length: 11" ± 1"	Design Team	Final Design Project Guidelines
2/13/2025	D	Width: 23" ± 1"	Design Team	Final Design Project Guidelines
2/13/2025	D	Height: 17" ± 1"	Design Team	Final Design Project Guidelines
		Budget Limitations		
2/13/2025	D	<= $120	Design Team	Final Design Project Guidelines
2/13/2025	W	<=$100	Design Team	Final Design Project Guidelines
		Setup Time		
2/13/2025	W	Complete pre-round machine setup in < 2 minutes	Design Team	House of Quality
2/13/2025	D	Complete pre-round machine setup in <3 minutes and 45 seconds		Final Design Project Guidelines
		Tasks Completion		
2/13/2025	D	Machine capable of completing at least 4 total tasks	Design Team	House of Quality
2/13/2025		Machine capable of completing multiple tasks at once	Design Team	House of Quality
		Timing		
2/13/2025	W	Complete all desired tasks in under 40 seconds	Design Team	Final Design Project Guidelines
2/13/2025	D	Machine shut down after 39 ± 1 seconds of round start	Design Team	Final Design Project Guidelines
2/13/2025	W	Each individual task takes no more than 10 seconds		
		Push Objects		
2/13/2025	D	Apply 10 Newtons of force to pushed objects	Design Team	House of Quality
2/13/2025	W	Push 1 Hoglin and 1 Pilliger into adjacent zones	Design Team	House of Quality
2/13/2025	W	Knockdown 1 Hoglin and 1 Pilliger within Home Zone	Design Team	House of Quality
2/13/2025	W	Extend forward 24"	Design Team	House of Quality
		Eject Objects		
2/13/2025	W	Eject objects through dropping, acceleration at 9.8 m/s^2	Design Team	House of Quality
2/13/2025	D	Eject the bone into a wolf's mouth	Design Team	House of Quality
2/13/2025	W	Eject the bone into "home zone" wolf's mouth	Design Team	House of Quality
		Materials		
2/13/2025	W	Maximum weight (summation) of all materials: <= 4.5kg (~10lb)	Design Team	House of Quality
2/13/2025	W	No material damage after 5+ runs	Design Team	House of Quality
2/13/2025	D	Non-Poisonous	Design Team	House of Quality
		Pull Objects		
2/13/2025	W	Mine 3-4 Diamond and 2 Netherite ore from the zone boundary	Design Team	House of Quality
2/13/2025	W	Apply >= 10 Newtons of force to pulled objects	Design Team	House of Quality
		Pick Up Objects		
2/13/2025	D	Attachments support >= 10 Newtons of weight (mass of object x acceleration of	Design Team	House of Quality
2/13/2025	W	Apply >= 10 newtons of upward force to lift objects	Design Team	House of Quality
2/13/2025	W	Lift End Crystal out of specificed zone	Design Team	House of Quality
		Extend Objects Upward		
2/13/2025	W	Extend at a 45° angle	Design Team	House of Quality
2/13/2025	W	Extend 24" at specified angle	Design Team	House of Quality
		Chassis And Attachments Strength		
2/13/2025	W	Preform tasks without maintenance for >= 3 trials	Design Team	House of Quality
2/13/2025	W	99% stiffness after more than 3 trials	Design Team	House of Quality
		Support Object Weight		
2/13/2025	W	All attachments support weight of 0.5 kg	Design Team	House of Quality
2/13/2025	W	Initial loading area for bone supports 0.5 kg	Design Team	House of Quality
		Complete Multiple Tasks at Once		
2/13/2025	D	>= 2 tasks at once	Design Team	House of Quality
2/13/2025	W	2 DC Motors operating at once	Design Team	House of Quality
2/13/2025	W	2 Pnuematic Actuators operating at once	Design Team	House of Quality
		Complete Tasks Quickly		
2/13/2025	D	Complete desired task at or under 10 seconds	Design Team	House of Quality
2/13/2025	D	Push attachment velocity at 0.5 m/s	Design Team	House of Quality
2/13/2025	D	Angled extendable arm (upwards) velocity at 0.5m/s	Design Team	House of Quality
		Autonomous Operation		
2/13/2025	W	5 mouse traps (Victor Brand, M154 or equivalent)	Design Team	Design Constraints
2/13/2025	W	2 DC Motors	Design Team	Mechatronics Kit Components
2/13/2025	W	2 Pnuematic Actuators	Design Team	Mechatronics Kit Components
2/13/2025	D	Energy for launch from 120 V Outlet	Design Team	Final Design Project Guidelines
2/13/2025	W	100 PSI Air Tank	Design Team	Design Constraints
2/13/2025	W	1 Ultrasonic, 1 Infared Sensor	Design Team	Mechatronics Kit Components
2/13/2025	W	2 Solenoids	Design Team	Mechatronics Kit Components

Appendix 2 – Contributions Statement

1. Sean Breton – Wrote the introduction, problem understanding, conceptual design, performance results, and conclusion and helped with alternative designs sections and design overview sections. Developed several figures.
2. Uchechi Onukwue – Wrote the Alternative Design section, helped with several other sections, assisted with proofreading and editing. Developed several figures.
3. Shrey Patel – Wrote the design overview section and helped with the introduction, problem understanding, conceptual design, performance results, and conclusion. Developed several figures and renderings.
4. Dev Shah –
5. Srijan Grover – Helped with editing, proofreading, and figure development. Helped with performance results section.