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Project Report

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Abstract

The design process is fundamental in the practice of engineering . It is used for several reasons including designing simple and complicated mechanical parts. Although some mechanics might be simple, designing can be quite challenging especially when considering assemblies since the movements, the interaction of different materials and many more must be considered. The purpose of this project is to design a mechanism that can place balls in their corresponding bins. These balls are made out of different materials, have different weights but all have the same dimension. In order to best design the mechanical arm a few steps were taken. Firstly, a morphology chart was created in order to identify the subsystems. From there eight design sketches were made in order to have a better understanding and visualizing of how each part would interact with one another. Then, a weighted matrix was created in order to compare each design and see which ones were the best. A final sketch that incorporated parts of the best designs was created and calculations were made to be able to figure out the right dimensions as well as the forces being applied. Finally, the final design was generated in Solidworks, both 2D drawings and 3D CAD assemblies were made. Lastly, a simulation was made to demonstrate the interaction of the mechanism and the balls. Overall, all these steps were crucial to designing the mechanism. Although the design may not be perfect and may have its limitations, the design process provided valuable knowledge and can be applied in future projects or design processes.

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Introduction

The objective of this project is for engineering students to work as teams in order to create a design and then be able to convert it into a simulated prototype. In order to be able to create this mechanism a few steps must be followed. This includes the understanding of the problem, the variety of concepts that must be evaluated, building a prototype and finally testing that prototype with a simulation and engineering analysis. In this proposed project the students must design a mechanism to deliver Ø 3/4" Styrofoam, plastic or metal balls from a large container into small boxes (MEC322 Course Project Outline, 2021) . The mechanism must be able to fit over dowel pins with dimensions of Ø 0.250±0.001" and tolerance of 2.000±0.005", these are used to ensure stability of the mechanism while in use. All the balls are originally placed into a large container that is open for reach and must be moved into smaller boxes that have a whole on their front surface of 1".

Three different types of balls are used for this project and are different colours in order to differentiate them: metal (red), styrofoam (white) and plastic (blue). Each ball must be placed in their designated box. The metal balls must be placed into the red box, the styrofoam balls must be placed in the white boxes and the plastic balls must be placed into the blue boxes. Each box is placed at different dimensions from the designed mechanism, with the white boxes being the closest and the red the furthest (please refer to figure 1 for further understanding). It is important to note that although the balls will consist of different materials and weights, they all have the same dimensions.

A few constraints were given for the design and use of the mechanism. Firstly, a four bar linkage mechanism must be used, in order words a simple lever is not acceptable. As well, to operate the machine only two hands can be used, any assistance is not acceptable. Finally, while operating the machine, both hands are not allowed to pass the invisible barrier (the red line), so students must stay within the acceptable zone.

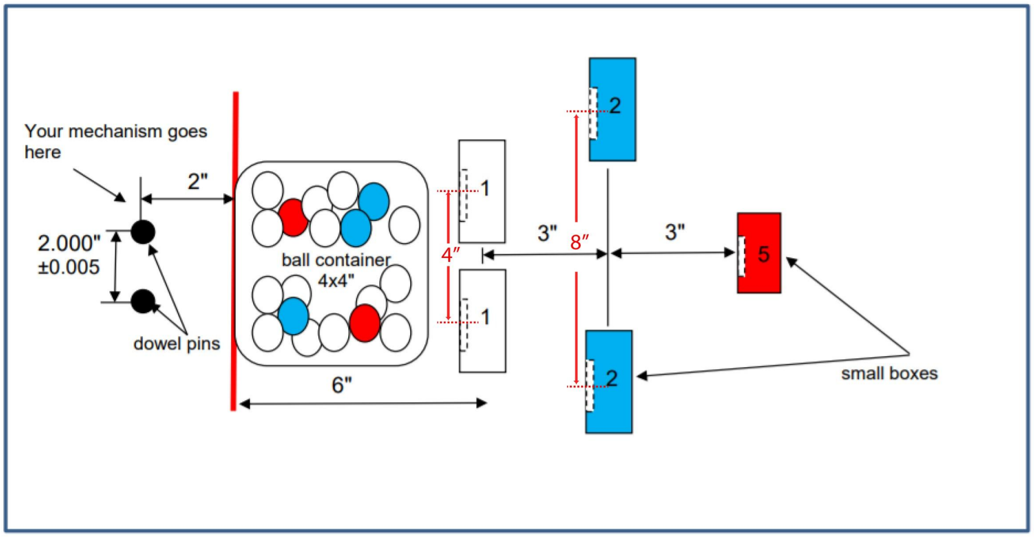


Figure 1: Diagram demonstrating the overview of the work station, provided in the project outline.

In order to be able to construct this mechanism a list of materials was provided as listed in the following table.

Table 1: List of materials provided in the project outline.

Material	Specifications
Acrylic Sheet	• Dimensions- 8" x 10" • Thickness- 1/8" (0.125") • Mass- 174 gm
Long Screws and Nuts	• Quantity- 12 of each • #4-40 x ½" • Thru holes for #4 screws Ø0.115" • Threaded holes Ø0.100" (For rotating joints)
Paper Clip	• Quantity- 1
Rubber Bands	• Quantity- 2 • Width- 0.25" • Thickness- 0.045" • Relaxed length- 2.5" • Maximum stretch- 10" • Spring constant- k = 0.8 N/m
String	• Length- 24"

Design Discussion

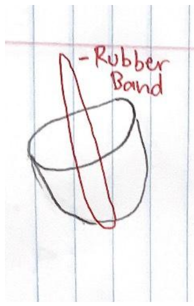
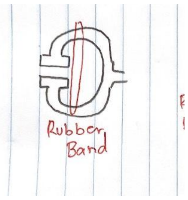
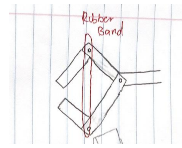
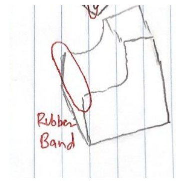
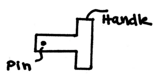
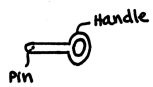
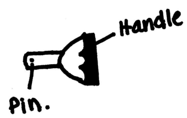
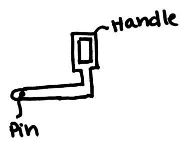
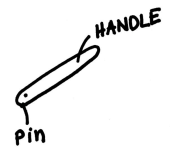
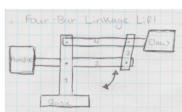
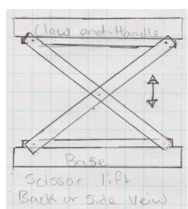
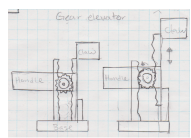
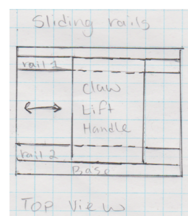
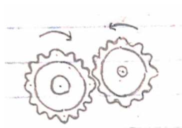
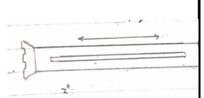
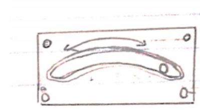
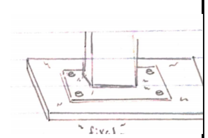
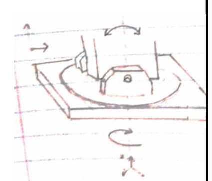
Design Plan and Competition Strategy

The design depends on two main factors: the challenge constraints and the team's game strategy. Challenge constraint was discussed in the introduction and the available materials are listed in table 1. The team's strategy is to deliver each type with simplicity and ease. Considering these factors and values the design process follows a brainstorming of systems, multiple concept designs via the morphological chart, subsystem selection & evaluation with weighted matrix, final design research and CAD visualization.

During brainstorming the team identified 4 subsystems, namely, the claw, handle, lift & movement, and the base. The claw subsystem functions as a ball-grabbing mechanism liable to pick up and drop off. The handle or user interface subsystem is responsible for controls and ergonomics. Finally, the other two subsystems share functionality of mobility, depending on mechanisms there overlap. The vertical elevation is the main task assigned to the lift system whereas the base system priority is lateral motion. In addition, the base provides support and the segment of the design attached to dowels.

As seen in figure 13, the final design features T-grip, Clamp, four-Bar linkage and horizontal track. The clamp utilizes a string to control behind from the line and rubber bands to close claws that can not be seen in the figure. However, the clamp shape will allow for the ball to be caught within its cavity when the strings are pulled on the rubber bands. Once at the designated box the string can be pulled to open the claw and release the ball. This is a practical design arrangement as one hand can operate the four-bar mechanism while the other hand controls the string. Further breakdown of the final selection process is available in the decision matrix.

Table 2: Morphological Chart

Sub-Systems	**Options #1**	**Options #2**	**Options #3**	**Option #4**	**Options #5**	**Option #6**
Claw	 Scoop	 Clamp	 Claw	 Bucket		
Handle	 T-Grip	 Circular grip	 D-grip	 L-shaped	 Simple handle	
Lift and Movement	 Four-Bar Linkage	 Scissor lift	 Gear elevator or lift	 Sliding rails		
Base	 two-gear system	 Horizontal track	 round motion	 single gear and screw	 fixed base	 rotational about the z with swivel

Given the 4 subsystems above there are 4x5x4x6 = 480 possible embodiments and none are considered inconsistent because they all function with each other.

Claw (grabbing mechanism)

- Scoop - spherical container manipulated from a rubber band. A similar mechanism to a net, the scoop will obtain balls from dragging.
- Clamp – Two pincer-like segments with a cavity for the ball, held together by rubber bands that are manipulated by strings.
- Claw - Another pincer-like structure that purely uses its shape and tensile strength in the rubber band to hold the ball.
- Bucket – Rectilinear container that can be tilted with strings to pickup and delivery.

Handle (user interface / ergonomics)

- T-Grip, Circular grip, D-grip, L-shaped, and simple handle used the same method for the functionality of extended user reach and grip. The main distinctions are their shapes that determine their ergonomics.

Lift and Movement

- Four-Bar Linkage – 4 bars linked with a (dorsal-ventral) pivot. Arranged similarly to a parallelogram. The lower arm will be connected to the handle and allow control. While the upper arm will be joined with the claw. This mechanism allows for motion in 2 axis and rotation about 1 axis. A side view is given in the morphological chart.
- Scissor lift – Two platforms linked together by bars crossed in an x-shaped with the pivot at the cross. The crossed bar is joined to tracks thus when the bars approach each other the platform is elevated. This mechanism allows for motion along 1 axis, would require multiple or a mix to move in all desired directions. A dorsal view is given in the morphological chart.
- Gear elevator or lift – A vertical tower controlled by that controlled by the handle and lifts the claw system. This mechanism allows for motion along 1 axis, would require multiple or a mix to move in all desired directions. A side view is given in the morphological chart.

- Sliding rails – Lateral channels that allow sliding along the axis, would be used in conjunction with a lift/ elevation system. A top view is given in the morphological chart.

Base (support / lateral motion)

- Two-gear system – A gear mechanism at the bottom of the system that allows subsystems on top of the base to rotate laterally. One gear controls another, thus speed and torque dependent on gear size, tooth leverage.
- Horizontal track – A straight track that allows the system sitting on top of the base to move in the lateral directions
- Round motion - A circular track that allows the system sitting on base for movement in the lateral directions along the arc
- Single gear and screw – A gear with a screw through its center allowing the gear to rotate in the z (vertical axis). The other subsystem will be on top of the gear and will rotate when the gear is turned.
- fixed base - Simple rectangular slab that fit on dowels, no motion.
- Rotational about the z with swivel – feature a swivel for rotation about z vertical axis and a pin joint for rotation about the ventral-dorsal

Sketch 1:

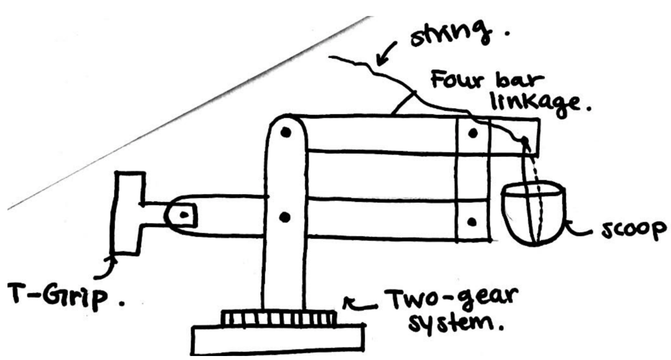


Figure 2: Concept sketch #1

This sketch consists of a T-grip handle, a four bar linkage, a scoop and a two-gear system that allows the system to rotate with a full range of 360 °.

Sketch 2:

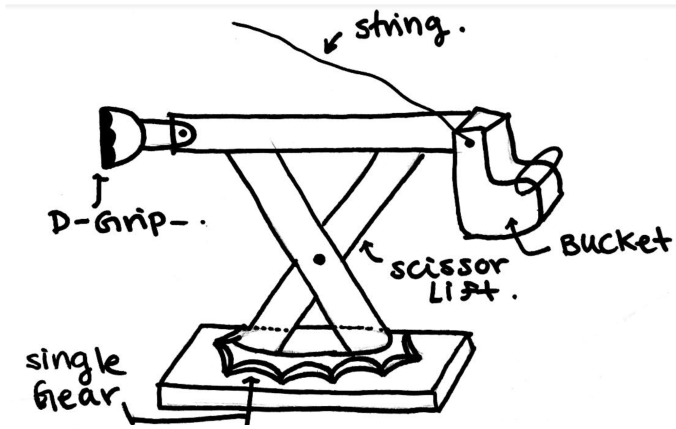


Figure 3: Concept sketch #2

This sketch consists of a D-Grip, a single gear, a scissor lift that allows the mechanism to move in the y axis, as well as a bucket controlled by a string.

Sketch 3:

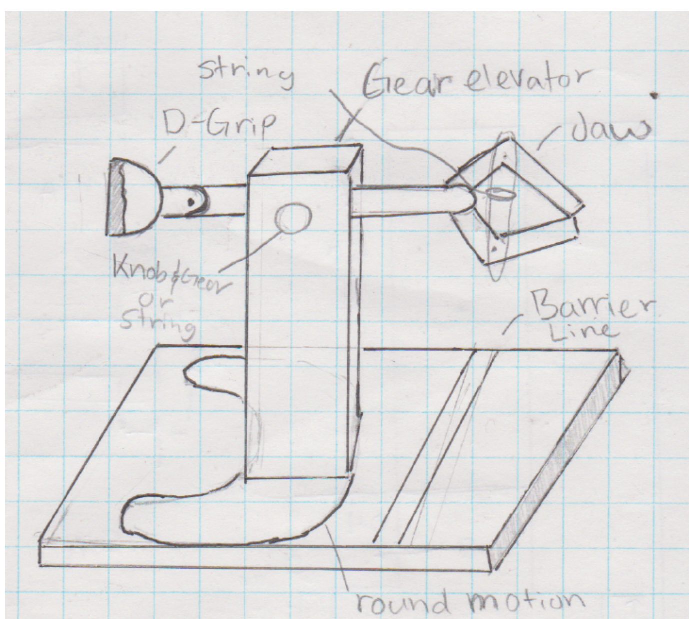


Figure 4 : Concept sketch #3

This sketch consists of a D-grip, circular track for radical movement on the plane parallel to ground. An elevator mechanism for vertical motion manipulated by the user's hand and a rotating jaw actuated from pulling strings.

Sketch 4:

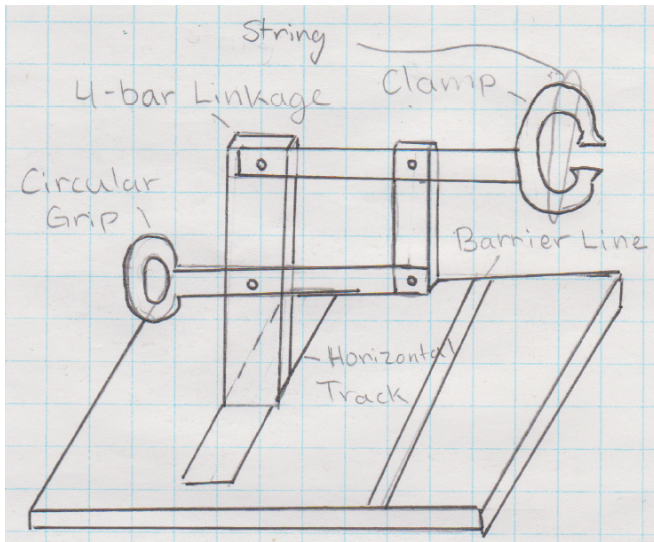


Figure 5 : Concept sketch #4

This sketch consists of a Circular-grip, horizontal track , a four bar linkage that provides forward & vertical capability. As well as a clamp that is manipulated by strings and will hold balls within the camp's concave cavity.

Sketch 5:

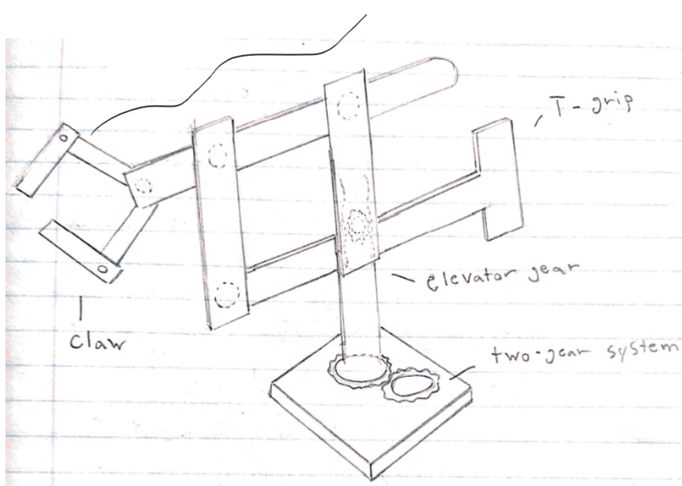


Figure 6 : Concept sketch #5

This sketch consist of an elevator gear, a two gear system allowing the mechanism to be able to rotate 360°, a claw and a T-grip to provide good grip for the user making it easier to control the design.

<u>Sketch 6:</u>

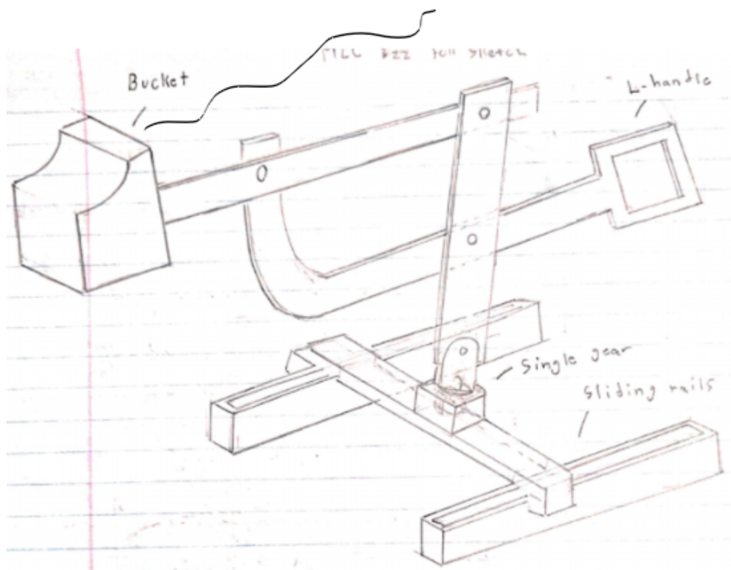


Figure 7 : Concept sketch #6

This sketch consists of a bucket that is used to scoop the balls and place them in their corresponding bins, a sliding rail allowing the system to move forwards and backwards and a single gear so the system can rotate.

Sketch 7:

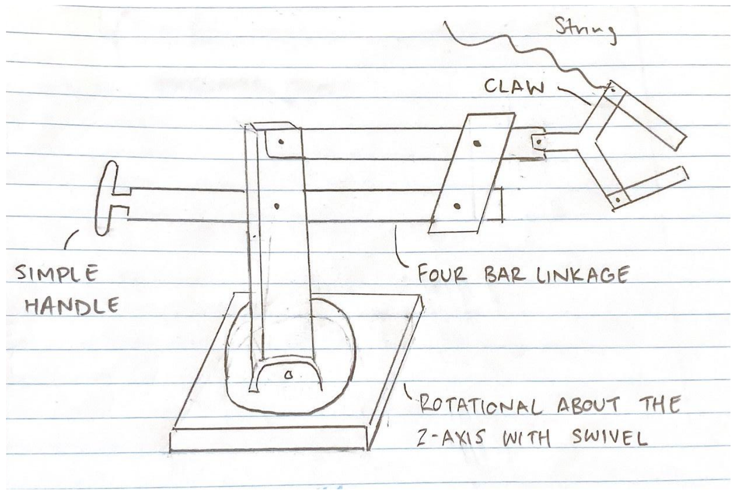


Figure 8: Concept sketch #7

This sketch consists of a simple handle, a claw to be able to pick up the balls, a four bar linkage that allows the mechanism to move forward to reach the balls and finally a rotational about the z-axis with swivel.

Sketch 8:

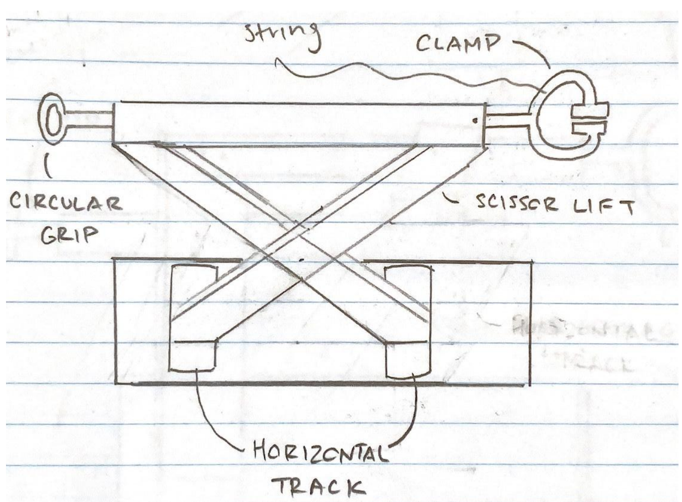


Figure 9: Concept sketch #8

This sketch consists of a circular grip to control the mechanism, a scissor lift that allows the system to move in the y direction, a clamp controlled by a string and a horizontal track allowing the mechanism to move from side to side.

<u>Four Bar Linkage Research</u>

The final design incorporates a 4-bar linkage, a fundamental mechanism used in a variety of applications. The characteristic of a 4-bar linkage is defined by Franz Grashof's inequality 0 $S + L \leq p + q$. S (shortest length), L (longest), p, q (other links). Grashof's condition states if the arms lengths stratify $S + L \leq p + q$ there will be full rotation. The types of motion a 4 bar can perform depends on the lengths of arms, and inversion (arrangement) of the linkages. There are three possible arrangement double-crank, crank-rocker, double-rocker (Rocker – oscillates

Crank – Full revolution). As well as the special case parallelogram linkage were $S + L = p + q$, all configurations can be seen in figure # below. If the links become collinear then the motion will be unpredictable and the model unstable without constraints. Thus, to limit complexity collinear linkages will be prevented and not considered.

Inversions:

1. Double crank - Shortest link (s) is fixed (ground)
2. Crank-rocker - link adjacent to s is fixed.
3. Shortest link opposite longest link double rocker

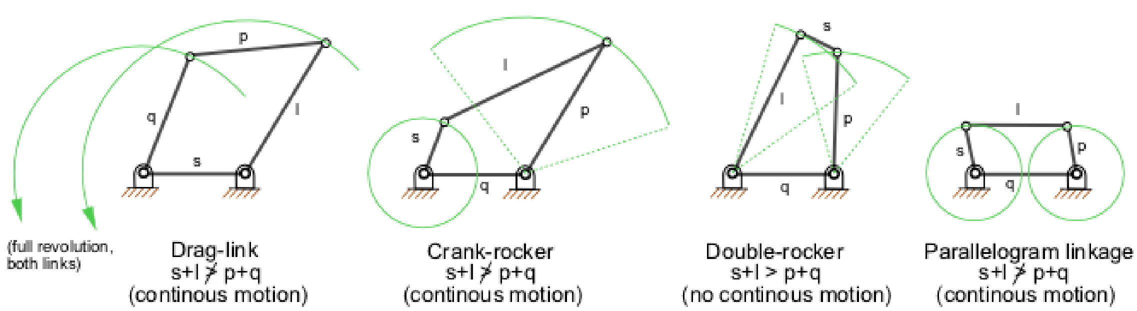


Figure 10: Four bar linkage inversions

[3] Fixed link is *ground* |Actuator i*nput link* ie, human input |*Coupler* – connect input and output links

To better visualize the desired motion path an online simulator was utilized. This led to the selection of a limited double rocker. A double rocker was selected because (1) the point path points straight ahead when stretched outward – needed for the boxes (2) the point tilts downwards when close – needed for the balls. A screenshot of the simulation seen is below.

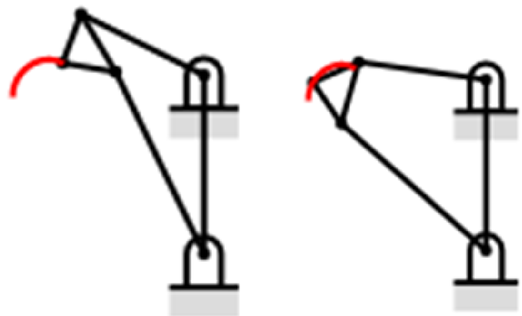


Figure 11: Screenshot of four bar linkage pathways

Design Evaluation Matrix (Weighted Matrix)

As shown above a total of 8 concept sketches were made in order to be able to have a better visualization of the system and how each subsystem would work together. These design sketches have been put into a weighted matrix to be able to determine the best and worst options. In order to determine that a five scale system rating system was used: -2, -1, 0, 1 ,2. With -2 and -1 being the worst ranking and 1, 2 being the best, while 0 being neutral so not much effect on the system. In order to rank each concept drawing and find the best alternative, each concept was evaluated on 5 components : Functionality, usability, producibility, maintainability and sustainability. Not all criterias have the same weight, each has a specific weight according to which one is the most crucial to the mechanism. For example: Functionality weighs more than the other requirements due to its importance (it has a weight of 20% while others are 10%). Here are the detailed explanation of each component:

1. Functionality
    a. Withstand the weight of the balls
    b. Resist bending - structurally sound
    c. Able to move in x, y and z direction.
    d. Able to pick up differently sized balls (adjustable/rotational claw system)
2. Usability

   a. Simple to operate
   b. Manually useable
   c. Allow ease of motion in desired direction
   d. Lightweight
3. Producibility
   a. Assure the device is easy to CAD
   b. Be within the required material specifications (dimensions)
   c. Must adhere to the list of materials given
4. Maintainability
   a. Does not need to be maintained
   b. Easy to assemble/simulate
5. Sustainability
   a. Minimal use of material (acrylic)
   b. Easily decomposed

After analysis each concept sketch with the five requirements here are the results of the weighted matrix:

	(A) Decision to evaluate:	[Describe the decision you're considering]							
	Score (auto-calculated):	0.7	0	-0.4	0.5	0.2	0.2	0.4	0.4
	(D) Options:	Sketch 1	Sketch 2	Sketch 3	Sketch 4	Sketch 5	Sketch 6	Sketch 7	Sketch 8
(B) Factors of this decision	(C) Rank of Factors (0-3)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2 - 2)	(E) Meets need? (-2-2)
Fuctionality	20.00%	1	-1	0	1	1	2	1	1
Maintainability	10.00%	2	0	-1	1	0	-2	2	1
Producibility	10.00%	1	1	-2	1	0	-1	-1	0
Usability	10.00%	1	1	-1	1	1	2	1	1
Sustainability	10.00%	1	0	0	0	-1	-1	0	0

Figure 12: Weighted Matrix

From the weighted matrix we can analyze that sketch 2 and 3 were the worst while sketches 1 and 4 were the best. In order to pick the best final alternative some components from both those two best sketches have been chosen resulting in the following final sketch:

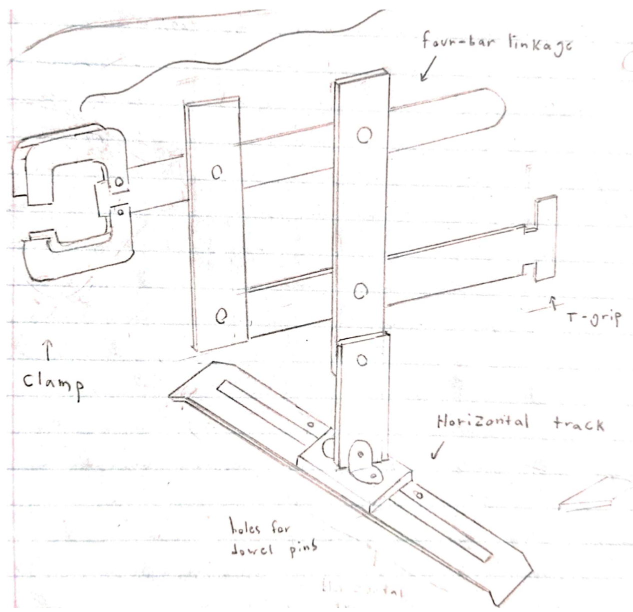


Figure 13: Final Design Sketch

As shown in figure 11 the final sketch consists of a clamp, a four bar linkage, a horizontal track and a T-grip handle. The clamp is used in order to be able to pick up and place the balls in their corresponding bins. In the clamp there is a semi circle built in it (please refer to the CAD drawing, figure 14) slightly bigger than the dimensions of the balls to ensure that the balls can fit without rolling out. As well, the clamp is easy to use with the string and unlike other claws like the bucket or the scoop (from table 2) it can easily pick up the balls. When it came to the lift and movement the four bar linkage was chosen since it can reach far destination and has the freedom to move in both the x and y axis. Some other subsystems had limitations, for instance, the scissor lift would not be able to move in the x direction which would limit the distance of how far the mechanism can reach. As well, the gear elevator is too complex and might be harder to operate especially since we can only use two hands. Overall, the four bar linkage was the best pick. When it came to the base the horizontal track was chosen, this will allow the whole mechanism to freely move left and right making it easier to have better placement when picking up the balls. Finally, for the handle the T-grip was chosen since it provides an easy grip for all users. Other handles had some limitations like the simple handle (from table 2) can be hard to use for some users since it does not provide a good grip which can be slippery. All in all, these 4 pieces fit all of our requirements (functionality, usability, maintainability, producibility and sustainability) and are able to place all balls in their designated bins located at different distances.

Table 3: Advantages and originality for each subsystem.

Subsystem	Advantages	Originality
Clamp (claw subsystem)	Natural cavity for ball ● shared force liability between rubber band and gravity. ● Precise for one ball String and rubber band ● Few control - Require one hand to pull ● Simple controls – pulling ● Quick pick up and drop off	Basic mechanisms customized to fit competition – limited control to opening with automatic closing
4 bars linkage with pivot (lift subsystem)	● Does not require complex parts shapes -Simple assembly, usage, predictable ● Provide motion along 2 axes ● Slim body does not obstruct the field ● Easy controls – Require one hand to control	Based on the four-bar linkage research and applicability in the Solidworks environment
T grip (handle subsystem)	● Provide brace for resting hand and grip for active ● Form as a solid addition to four bar linkage	Incorporated within four-bar mechanism
Horizontal track (base subsystem)	● Simple predictable motion ● Provide lateral motion ● Gear track provides increments and makes movement repeatable	Utilizing gears for horizontal motion specifically for increments

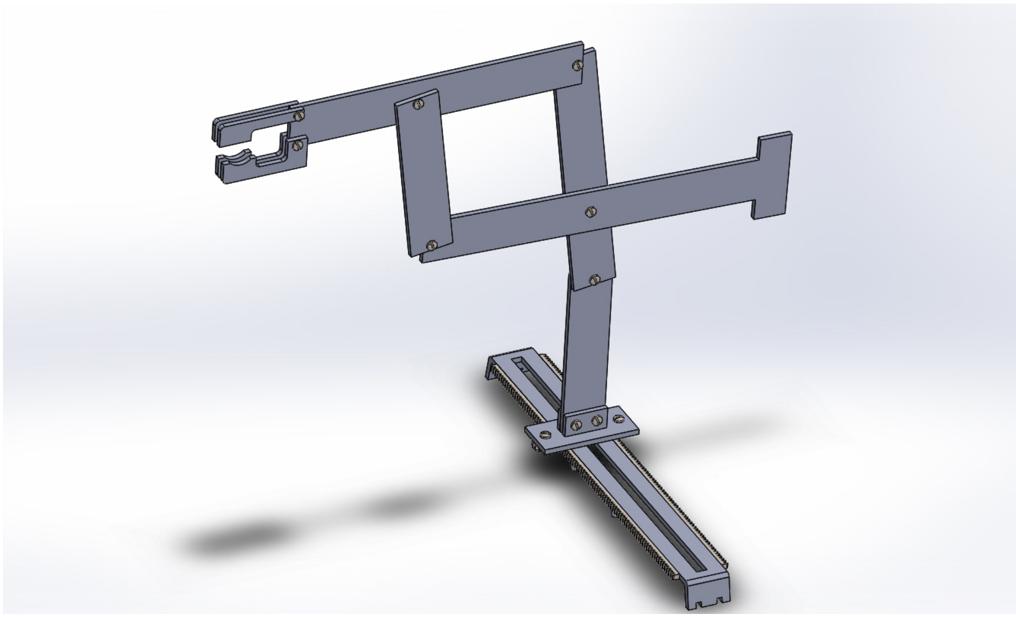


Figure 14: Final CAD assembly

Pictured in Figure 14, is the assembly drawing of the final sketch from SolidWorks. This sketch and overall assembly were chosen as a result of the

Engineering Calculations & Ergonomics

In order to determine the dimensions of each individual part, calculations had to be made. A total of 8" x 10" of acrylic sheet was provided, with a thickness of 0.125". Initially it can be predicted that the lifting system (the four bar linkage) will have the biggest dimensions. From the calculations here are the dimensions for each subsystem:
In the Appendix (figure 24) , please find the drawing dimensions fitting of all parts in 10x8 inch space.

The four bar linkage/ T-Grip: The four bar linkage consists of 5 members including the T-grip. All members have a width of 1 with different lengths, thus area calculation would be :

$$Length\ (part\ 1 + part\ 2 + part\ 3 + part\ 4 + part\ 5) \times width = total\ area$$

$$(4in + 6\ in + 7\ in + 4in + (8 + 1.5)in) \times 1\ in = 30.5in^2$$

The total area for all 5 parts of the four bar linkage subsystem is 30.5 in^2

The Clamp:

The clamp consists of four pieces in order to be able to hold the ball and place them in their corresponding bins. Clamp treated as rectangles with further cuts thus calculations made with larger dimensions.

Bottom: $2\ in \times 0.75\ in = 1.5\ in^2$, quantity 2 therefore $1.5\ in \times 2in = 3\ in^2$

Top: $2\ in \times 0.5\ in = 1\ in^2$, quantity 2 therefore $1\ in \times 2\ in = 2\ in^2$

Total area $5\ in^2$

Base: The base consists of one part that has a width of 1 in and a length of 9.59 in, the base also includes the rack and gears thus the area is

$$1\ in \times 9.59\ in + 0.5\ in \times 1\ in + 2(0.25\ in \times 9\ in \times 0.16\ in) + 2\pi(0.280625)^2 = 11.2748\ in^2$$

Slider: The slider only has one part that is 2.25 in by (1+0.31) in resulting in an area of

$$2.25in \times 1.31in = 2.9475\ in^2$$

Total: When adding all the areas calculated above ($30.5\ in^2 + 5\ in^2 + 11.2748\ in^2 + 2.9475\ in^2$) we get a total area of

$$49.72\ in^2 < (8\ in \times 10in) = 80\ in^2$$

Force calculation:

In order to be able to lift the balls, there must be enough applied force to resist gravity. The mass of each ball is given (assume the mass of the styrofoam ball is 1gm, the mass of the plastic ball is 3gm and the mass of the metal ball is 23gm.), from that the force can be calculated.

Mass of each ball:

$m_{styrofoam} = 1gm = 0.001\ kg$

$m_{plastic} = 3\ gm = 0.003\ kg$

$m_{metal} = 23gm = 0.023\ kg$

Gravitational Force Acting on ball:

$F_{styrofoam} = 0.001\ kg \times 9.81 m/s = 0.00981\ N = 0.0098\ N$

$F_{plastic} = 0.003\ kg \times 9.81 m/s = 0.002943\ N = 0.003\ N$

$F_{metal} = 0.023\ kg \times 9.81 m/s = 0.22563\ N = 0.226\ N$

As well, the applied force , friction force and the normal force can also be calculated:

Calculating the applied Force (the force applied by the rubber band):

$F_A = F_s = -k\Delta x,\ where\ \Delta x = 0.25in = 0.635cm$

$F_s = -(0.8\ \frac{N}{cm}) \times (0.635cm) = -0.508N$

$F_c = 2 \times F_s = 2 \times 0.508N = 1.016N$

Calculating the normal force (F_N):(when perpendicular)

In order to keep the ball in place in the claw there has to be a friction force(μ_s $is\ given\ as\ 0.2$),

with that information and using Newton's second law ($F = ma$) the normal force can be calculated as follows:

$\Sigma F = 0$

So,

$F_N \times \ \mu_s = mg$

$F_N = \frac{mg}{\mu_s}$

For the metal ball:

$F_N = \frac{m_{metal} \times g}{\mu_s} = \frac{(0.023\ kg\ m)(9.81 m/s)}{0.2} = 1.128\ N$

For the styrofoam ball:

$F_N = \frac{m_{styrofoam} \times g}{\mu_s} = \frac{(0.001\ kg\ m)(9.81 m/s)}{0.2} = 0.049\ N$

For the plastic ball:

$F_N = \frac{m_{plastic} \times g}{\mu_s} = \frac{(0.003\ kg\ m)(9.81 m/s)}{0.2} = 0.147\ N$

For order to keep each ball in place, the normal force for the metal ball needed is 1.128, for the styrofoam ball it is 0.049 N and finally for the plastic ball it is 0.147N.

Conclusions and Recommendations

In conclusion, the purpose of this design project was to create a mechanism to deliver styrofoam, plastic or metal balls with a diameter of ¾ inches to small boxes. This design had to meet the functional requirements set by the project outline. An additional component of this project was to include a simulation as well as a CAD illustration of the mechanism.

In order to meet the functional requirements of the project and create a successful prototype, it was imperative to brainstorm the different subsystems of the mechanism which were determined to be: claw, handle, life/movement and base. The subsystems were then explored in a morphological chart in order to understand the variety of design concepts that could be established. From the morphological chart, 8 unique design concepts were determined and processed through a weighted matrix in order to perform a design evaluation and determine the most effective design. After establishing a sketch of our final design, the dimensions of our mechanism were determined based on the constraints mentioned in our project outline. These parts were then built out in SolidWorks and assembled to see the illustration of our final design. The assembly was then used to simulate the functionality of the mechanism.

Our final design was chosen based on its unique advantages and originality. The clamp was chosen for its circular cavity dimensioned to the exact diameter of the balls it is required to carry, the 4 bar linkage was chosen for its simplicity and functionality when controlling the movement and lift of the entire system, the t-grip was chosen due to its ease of use, and the horizontal track allowed for the unique and functional lateral movement of the entire mechanism. Overall, the combination of these systems assembled together forms a mechanism that not only fulfills the functional requirements of the project but also adheres to any constraints and effectively completes the task it has been designed to accomplish.

Moving forward there are a few recommendations that can be implemented in order to further improve this design. Although this current design meets the threshold of material use, in order to make a more cost effective design it is recommended to further reduce the surface area by scaling down or reconfiguring some subsystems in order to reduce the overall surface area. It is also recommended that the tip of the claw is adjusted so that entering and exiting the container the ball must be dropped into occurs with more ease, and can speed up the process. The final recommendation proposed in this report is to better the reach and motion of the mechanism, currently it is able to accomplish the task presented to it, but in order to make this a more versatile mechanism capable of performing various tasks, designing it to have a larger reach and range of motion would improve its efficiency.

Overall, this report has outlined how this group has followed the design process to design and iterate a mechanism to successfully perform the tasks outlined in the project description. The design effectively adheres to any functional requirements or constraints placed on the mechanism and successfully accomplished its goal.

Please find the YouTube link to the simulation here: https://youtu.be/snYRaUhx3TA

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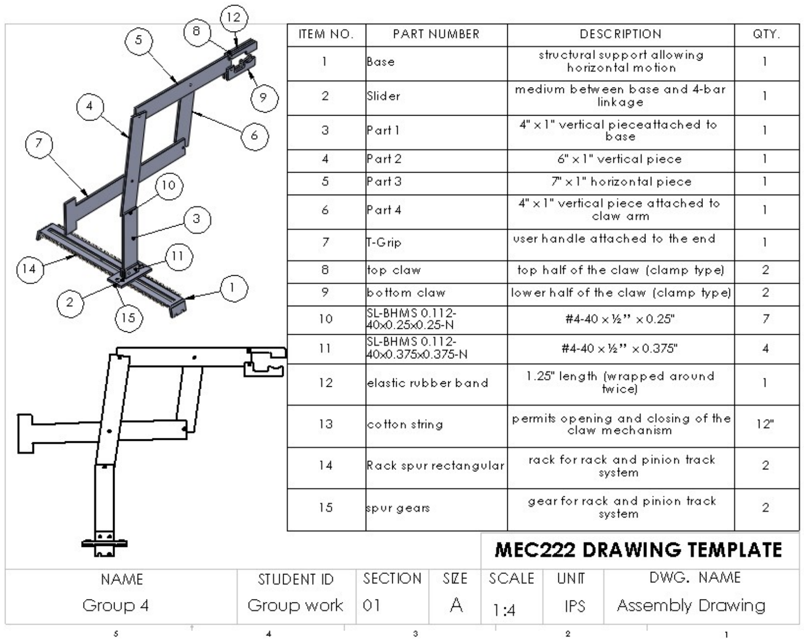
Appendix



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base	structural support allowing horizontal motion	1
2	Slider	medium between base and 4-bar linkage	1
3	Part 1	4" x 1" vertical pieceattached to base	1
4	Part 2	6" x 1" vertical piece	1
5	Part 3	7" x 1" horizontal piece	1
6	Part 4	4" x 1" vertical piece attached to claw arm	1
7	T-Grip	user handle attached to the end	1
8	top claw	top half of the claw (clamp type)	2
9	bottom claw	lower half of the claw (clamp type)	2
10	SL-BHMS 0.112-40x0.25x0.25-N	#4-40 x ½" x 0.25"	7
11	SL-BHMS 0.112-40x0.375x0.375-N	#4-40 x ½" x 0.375"	4
12	elastic rubber band	1.25" length (wrapped around twice)	1
13	cotton string	permits opening and closing of the claw mechanism	12"
14	Rack spur rectangular	rack for rack and pinion track system	2
15	spur gears	gear for rack and pinion track system	2

Figure 15: Assembly drawing

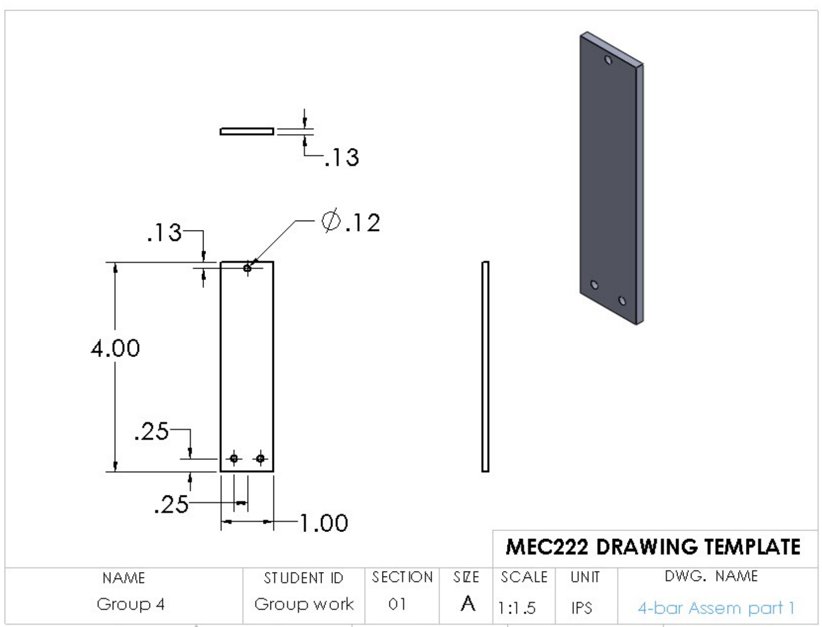


Figure 16: Four bar drawing #1

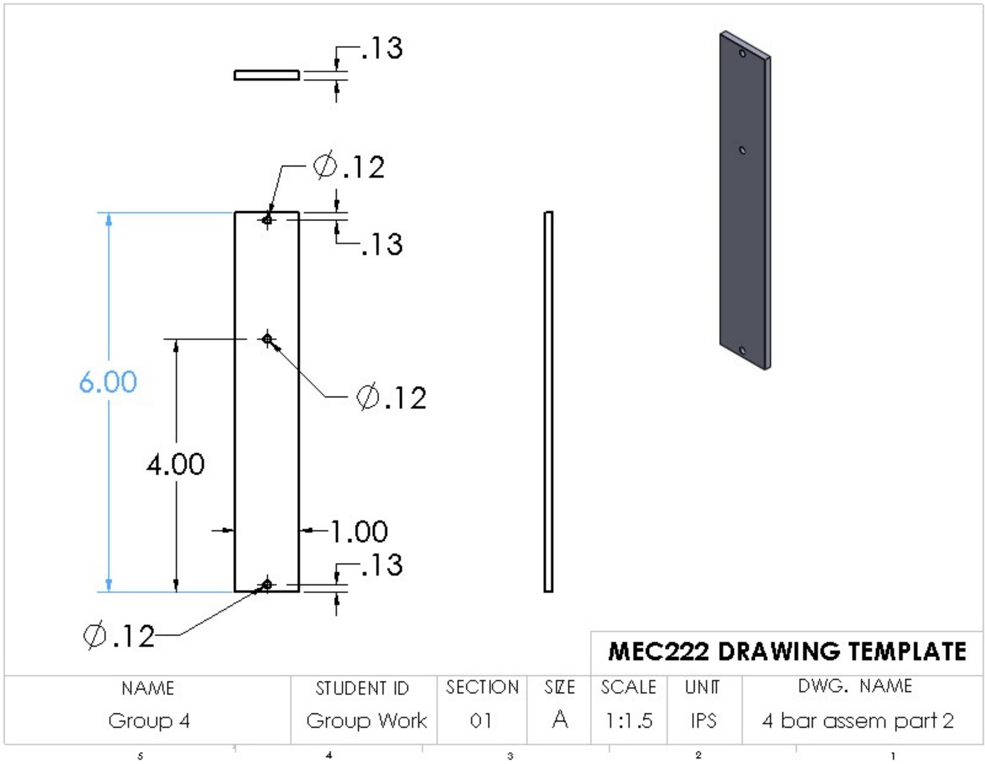


Figure 17: Four bar drawing # 2

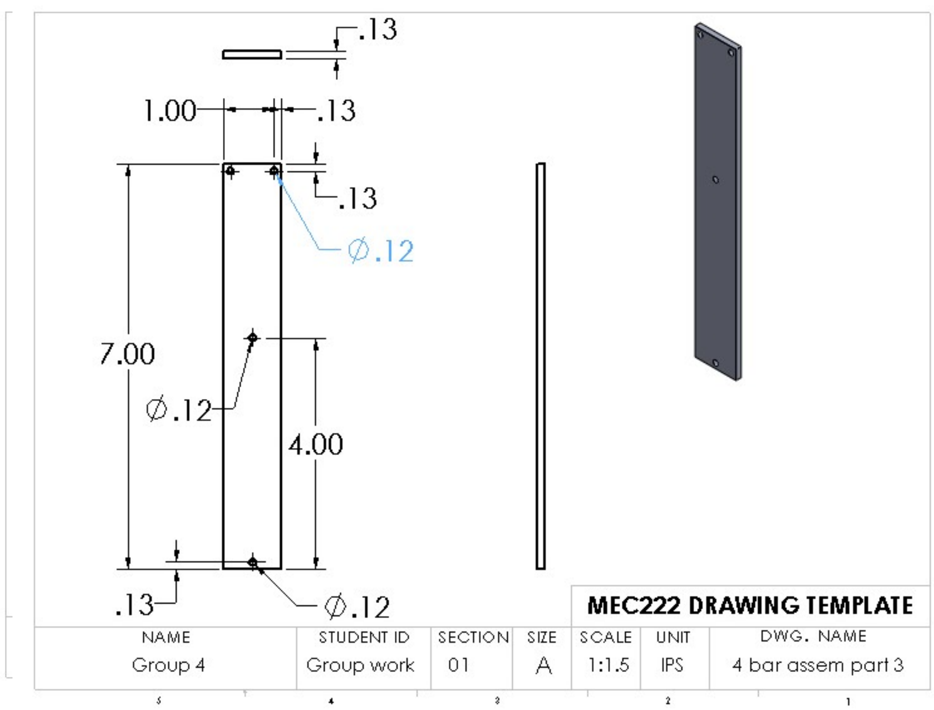


Figure 18: Four bar drawing #3

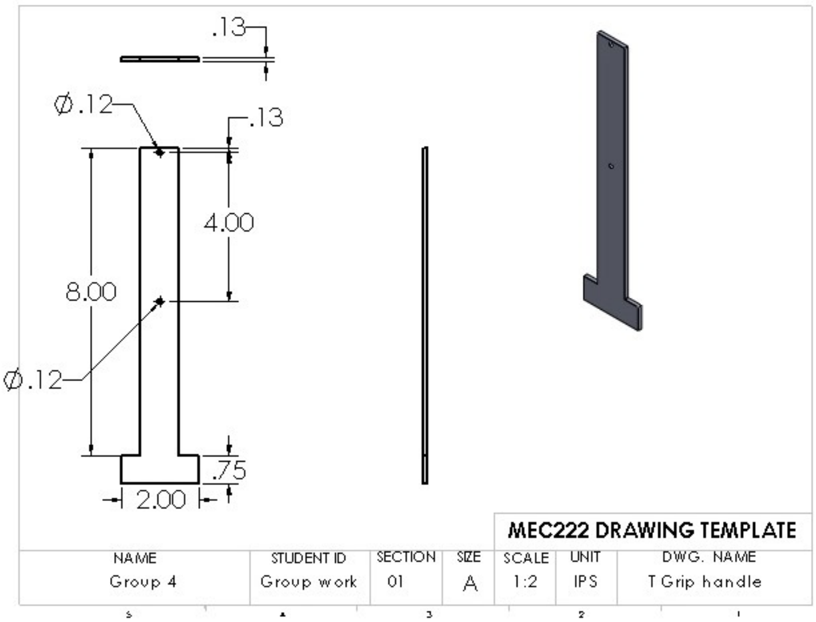


Figure 19 : T-grip drawing

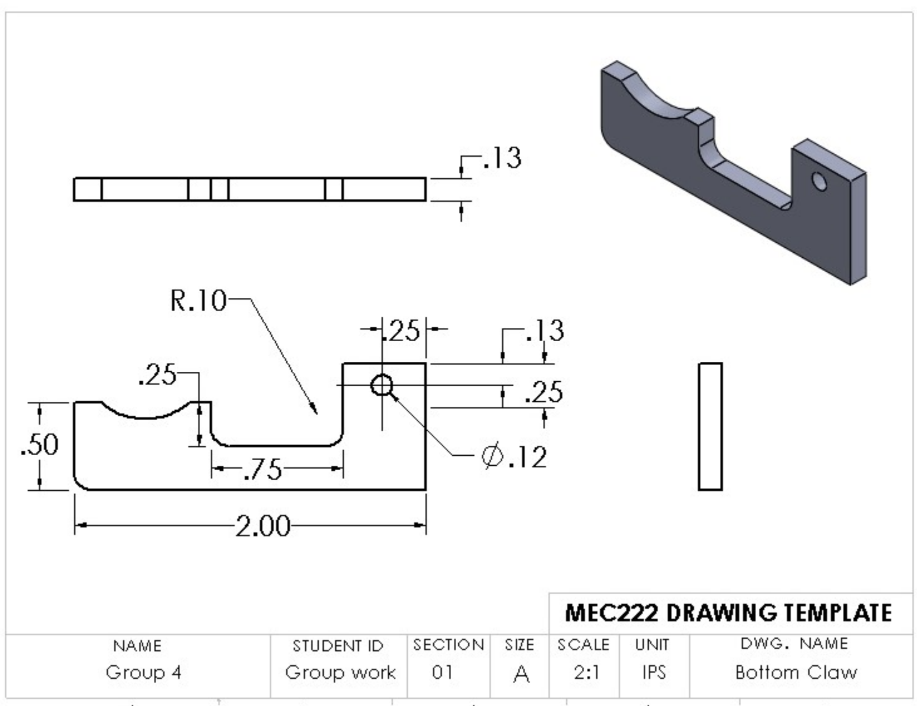


Figure 20: Claw drawing part 1

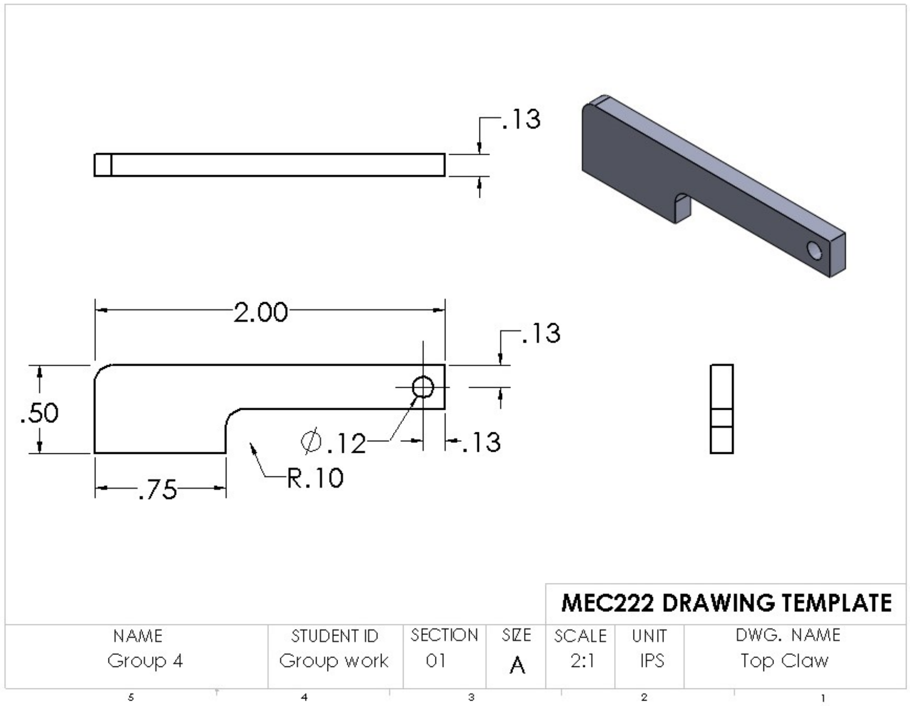


Figure 21: Claw drawing part 2

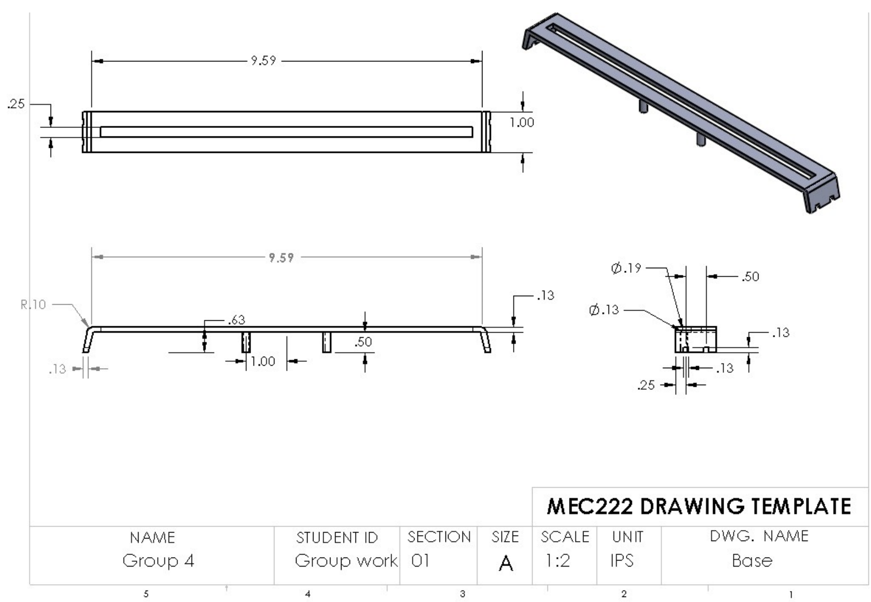


Figure 22: Base drawing

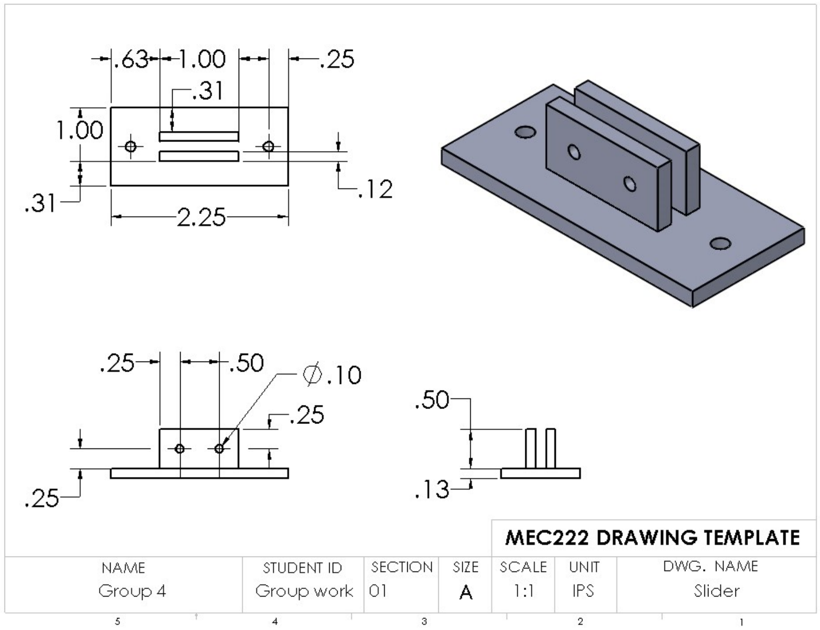


Figure 23: Slider drawing

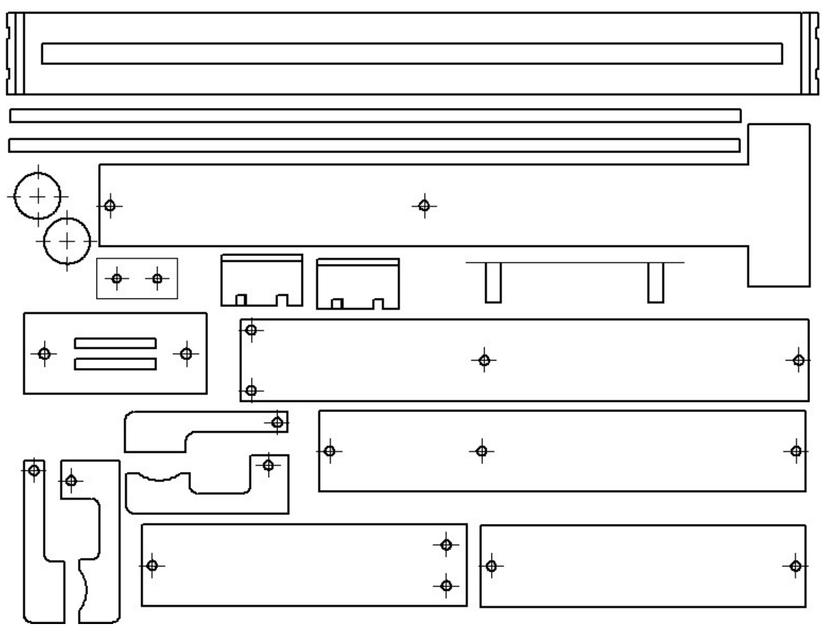


Figure 24: Drawing demonstration fitting