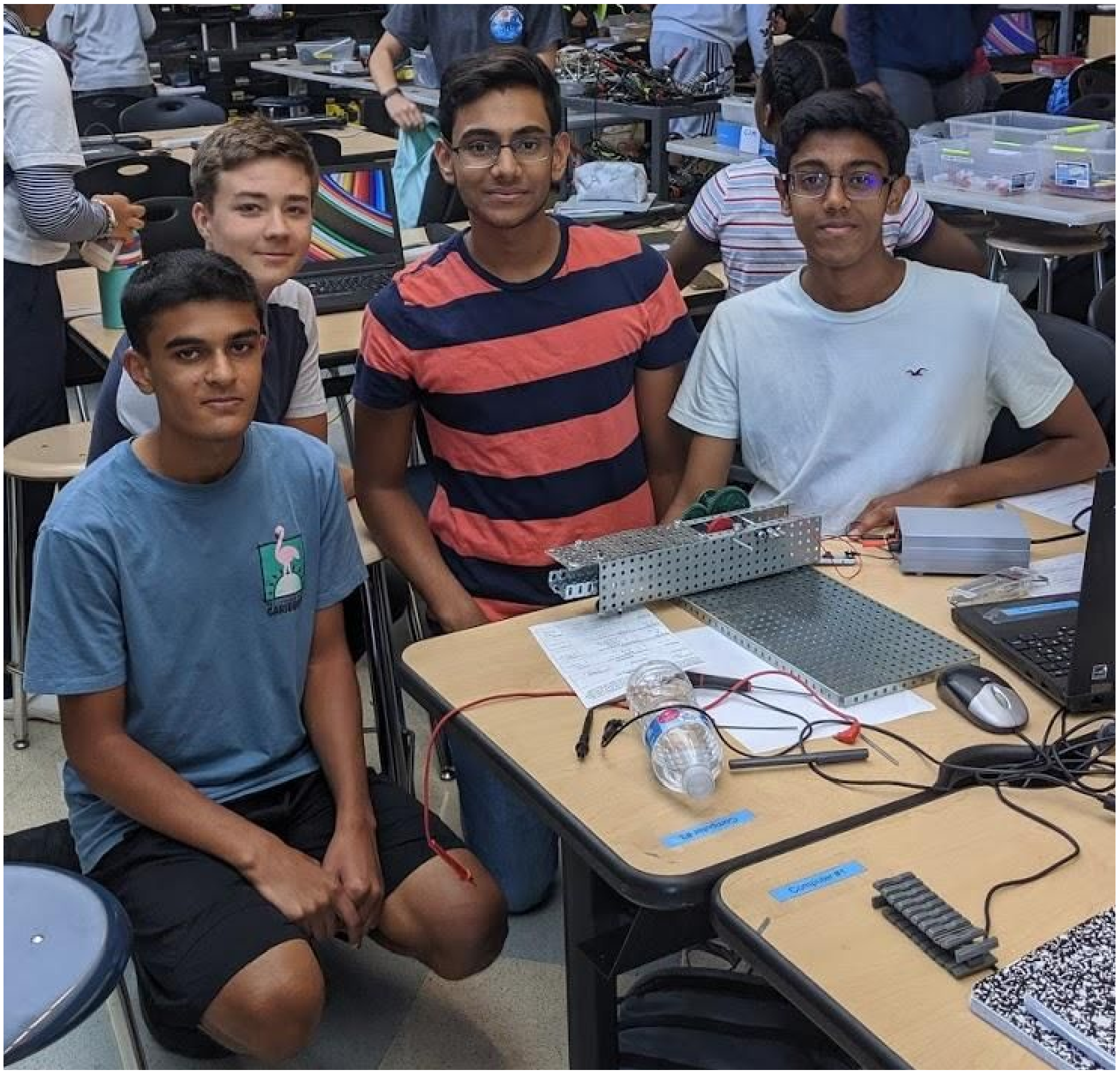
Project 1.2.5 - Mechanical Winch



Principles of Engineering - 6th period
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Table of Contents

Table of Contents	2
Design Brief	3
Screenshots of Code & GUI	4
Figure 1	4
Figure 2	5
Figure 3	6
Figure 4	8
Figure 5	9
Photos of Design	10
First Prototype	10
Final Prototype	11
Efficiency Calculations	13
Final Design Solution	14
Functionality	15
References	16

Design Brief

Client
Local construction company

Designers
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Problem Statement
It can be impossible, dangerous, or time-consuming to lift heavy items in construction zones using manual labor, especially when these objects weigh more than 300 pounds.

Design Statement
Design, build, and test an electric winch system that can lift a weight that is at least 100 grams at least 30 centimeters vertically.

Constraints
- Be able to lift at least 100 grams of mass.
- Lift at least 30 centimeters over the side of a table.
- Use VEX or FT to build, powering the design with an FT motor.
- Turn off and on with a switch.

Deliverables
- Physical prototype to demonstrate to clients
- Working NetLogo simulation program of the prototype
- Neat, professional documentation

Screenshots of Code & GUI

Figure 1

Globals used throughout the program. These include the drum turtle, weight turtle, change in time, weight force, input drum power, and angular velocity. The weight_force, power, and angular_speed variables can also be monitored by the observer throughout the duration of the program.

```
; Define globals.
globals [
  Drum ; Drum turtle.
  Weight ; Weight turtle.
  delta_t ; Change in time.
  weight_force ; Force of the weight.
  power ; Power of the drum.
  angular_speed ; Angular velocity of the drum.
]
```

Figure 2

The setup command that starts the timer and creates all the visuals on the screen such as the drum, the weight, the table, the audience members, and a dot that is later used to create a link between the drum and the weight. The weight is shifted to the left by the radius of the drum to align it with the dot. The drum is in the shape of a clock and is scaled appropriately to the input drum size determined by the slider.

```
; Setup command
to setup
  ; Clear world of all agents.
  clear-all

  ; Reset the tick number.
  reset-ticks

  ; Define change in time.
  set delta_t 0.01

  ; Make background black.
  ask patches [set pcolor black]

  ; Create drum.
  create-turtles 1 [
    set shape "clock" ; Change the shape of turtle to a clock.
    set size drum_size * 16 / 4.5 ; Set size of turtle.
    set color 77 ; Set the color to light blue.
    set heading -90 ; Set the direction to -90 degrees to face the dot.
    set ycor 10 ; Move the drum upwards.
  ]

  ; Create weight.
  create-turtles 1 [
    set shape "box" ; Change the shape of the turtle to a cube.
    set size 5 ; Set size of the weight.
    set color 77 ; Set the color.
    set xcor -1 * pi / 8 * drum_size * 16 / 4.5 ; Set x coordinate back by the radius of the drum so it is aligned
    set ycor -10 ; Move the weight on the ground to start.
  ]

  ; Create variable to store the drum.
  set Drum one-of turtles with [shape = "clock"]

  ; Create variable to store the weight.
  set Weight one-of turtles with [shape = "box"]

  ; Create tabletop.
  ask patches with [pycor = 10] [ ; Access all patches in line with the drum.
    set pcolor white ; Turn patches in line with drum white.
  ]

  ; Create table legs by accessing all patches in a line underneath both sides of the tabletop.
  ask patches with [(pxcor = -20 or pxcor = 20) and pycor < 10] [
    set pcolor white ; Turn patches that are part of the table legs to white.
  ]

  ; Create a dot on the left side of the drum.
  create-turtles 1 [
    set size 0 ; Make the dot invisible.

    ; Set x coordinate back by the radius of the drum so it is aligned with the left side of the drum.
    set xcor -1 * pi / 8 * drum_size * 16 / 4.5

    set ycor 10 ; Align the dot with the drum's height.
    create-link-with Weight ; Create a line linking the left side of the drum to the weight.
  ]

  ; Create audience members.
  create-turtles 50 [
    set shape "person" ; Use the person shape.
    set size 5 ; Make the people a small size.
    set xcor random-xcor ; Move them at a random location horizontally.
    set ycor -23 ; Keep them under the table at the bottom of the screen.
  ]
end
```

Figure 3

The go command rotates the drum which causes the weight to move up based on various adjustable factors such as the mass of the weight, the size of the drum, and the voltage. The higher the voltage is, the larger the power will be, if the power is not high enough, the simulation will return an error which means that the power input to the machine is equivalent to the power required to sustain the force of gravity, stalling the motor and keeping the weight suspended in place. Using this power and dividing by the weight force, one can obtain the angular speed of the drum. With this angular speed, the drum can spin by the appropriate angle and the linear speed can be calculated by multiplying the angular speed by the radius of the drum. With the linear speed and the change in time, the weight is moved upwards by the appropriate linear distance. After this, some halt conditions are handled. Specifically, if the power is not sufficient enough to lift the weight, the simulation is stopped. The simulation will also stop if the weight reaches the height of the drum. Lastly, the audience members underneath the table are manipulated to randomly move left or right.

```
; Go command
to go
  ; Set the weight of the force by converting it from grams to newtons.
  set weight_force weight_mass / 1000 * 9.8

  ; Set the power using the electrical variables of voltage and current.
  set power voltage * 0.1235

  ; Set the angular velocity of the drum using the power (voltage * current) and the force of the weight, converted
  ; to newtons using the gravitational constant.
  set angular_speed power / weight_force

  ; Rotate the drum.
  ask Drum [
    ; Rotate using angular speed formula with the angular speed and change in time converted to degrees.
    set heading heading + ((angular_speed * delta_t * 360) / (2 * pi))
  ]

  ; Move the weight up.
  ask Weight [
    ; Use the angular speed and change in time to find the radians that the drum has rotated.
    ; Using this amount, find the linear distance travelled by multiplying it by the radius.
    set ycor ycor + (angular_speed * delta_t * 0.5 * drum_size * 16 / 4.5)
  ]

  ; If the power is not sufficient enough to lift the weight, the motor should stall.
  if power < 0.5 [
    ask Drum [set color red] ; Make the drum red.
    ask patch -12.5 15 [set plabel "Motor Stall"] ; Create a label informing the observer about a motor stall.
    stop ; Stop the simulation.
  ]

  ; End the program if the weight has reached the drum.
  if [ycor] of Weight >= 10 [
    stop ; Stop the simulation.
  ]
```

```
  ; Move all audience members.
  ask turtles with [shape = "person"] [
    ifelse random 2 = 0 [ ; Create a random chance between left and right.
      set heading 90 ; Half of the time, face right.
    ] [
      set heading -90 ; The other half of the time, face left.
    ]

    forward 0.3 ; Move forward at a constant rate.
  ]

  ; Advance the tick number using the change in time.
  tick-advance delta_t

  ; Wait delta_t seconds before moving to the next frame.
  wait delta_t
end
```

Figure 4

The simulation GUI as the simulation is running with the default parameters. The drum has a diameter of 5cm, the voltage of the power source is 9V, and the weight has a mass of 100g. The observer has a variety of information available to monitor, including the current elapsed time, number of rotations, downwards force of the weight, torque of the drum, power of the drum, angular velocity of the drum, and linear velocity of the drum. In this case, the motor has enough power to lift the weight and is successfully able to do so.

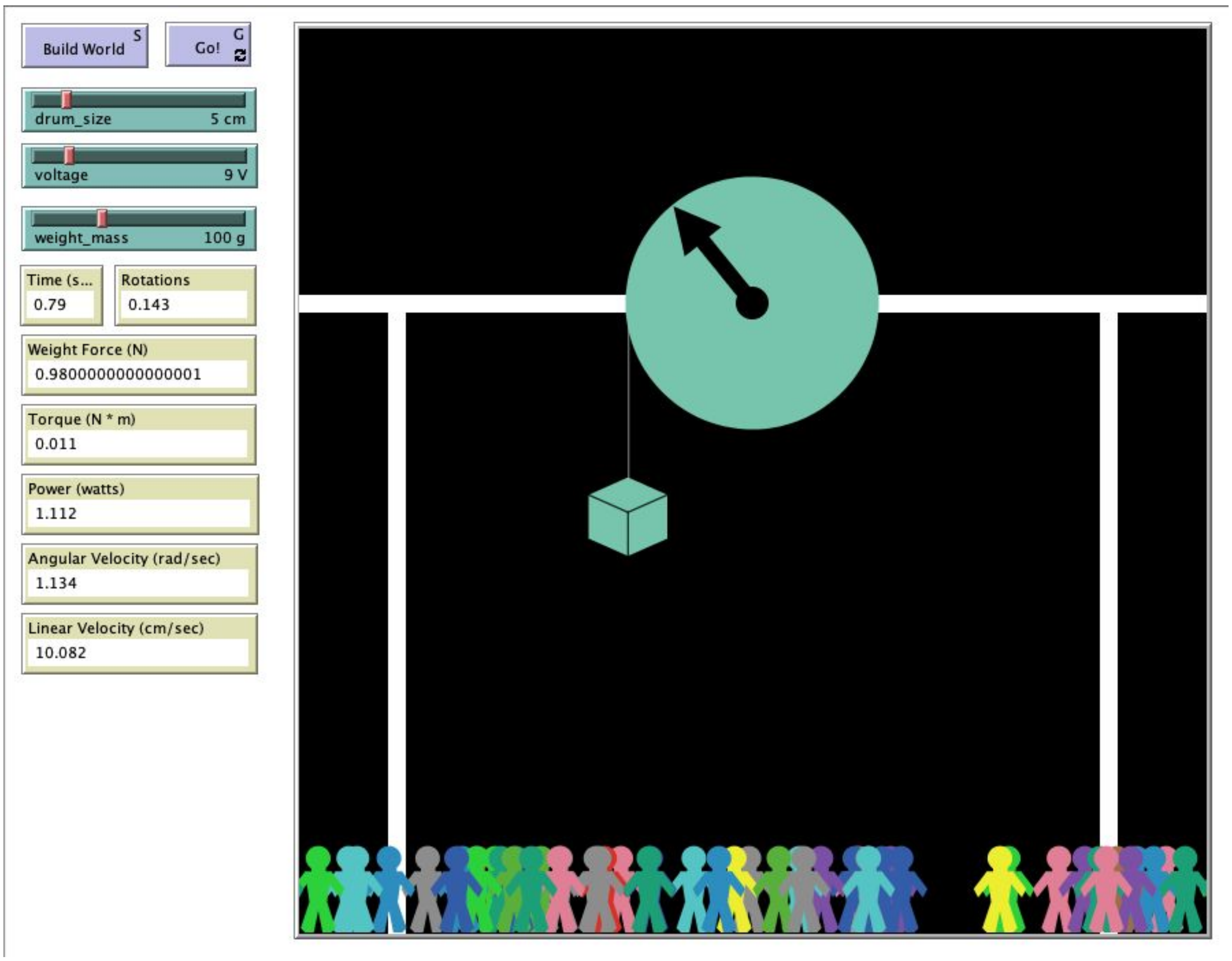
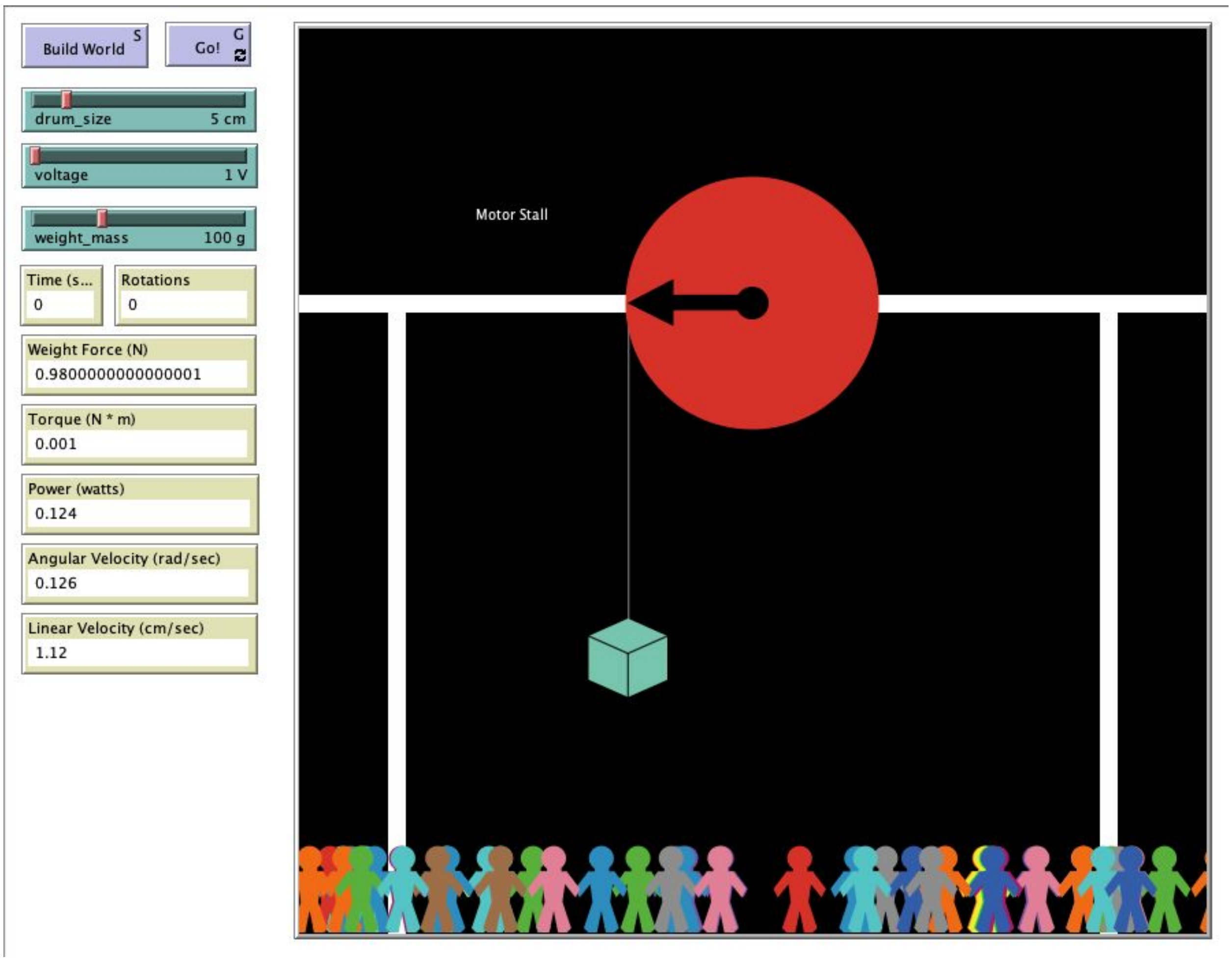


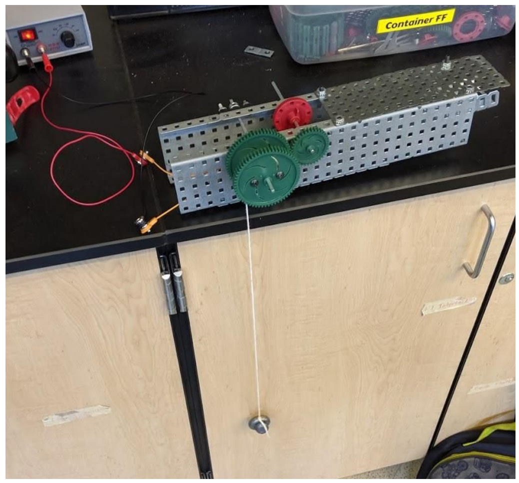
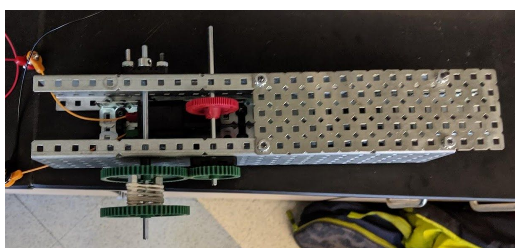
Figure 5

The simulation GUI in the motor stall state. The drum has a diameter of 5cm, the voltage of the power source is only 1V, and the weight has a mass of 100g. The observer has information available to them as the simulation halts. In this case, the power available was only 0.124 watts. Since this did not meet a certain threshold, the motor would not have enough power to lift the weight, only to sustain it in place. As a result, the motor stalls and the simulation warns the observer of the error before halting the program.

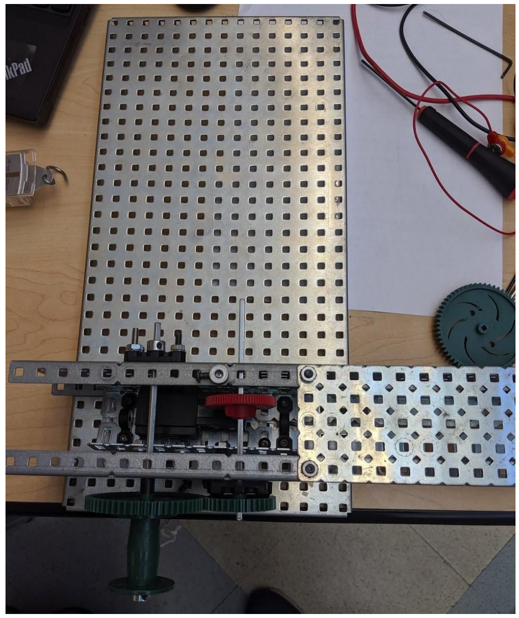


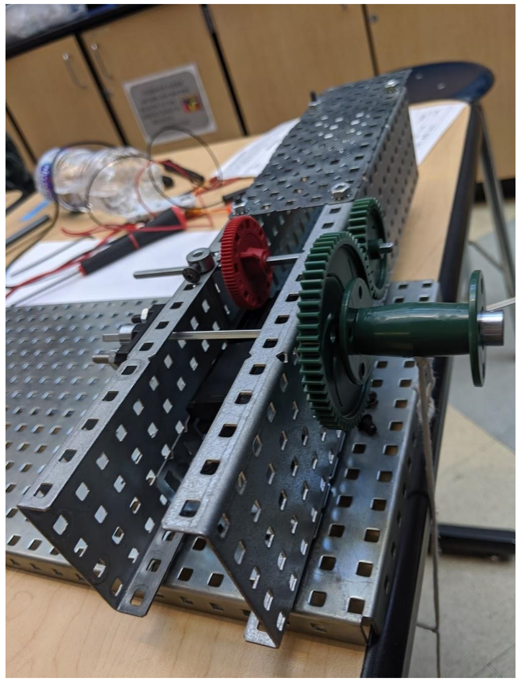
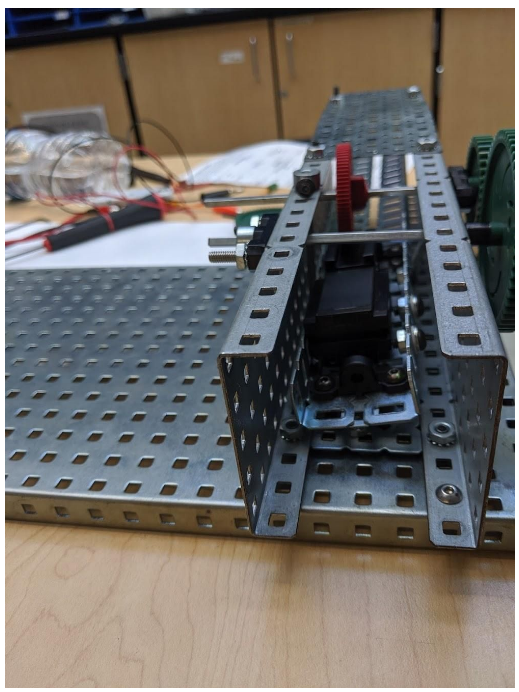
Photos of Design

First Prototype

Date & Electronic Signatures	Image	Explanation of change in design
Date: 10/17/19 Electronic Signatures: *Tanish Baranwal* **Oleg Bychenkov** *Kaushal Ramalingam* *Kabir Shah*	Side view 	Image of the first iteration of the prototype, with the improvised drum attachment due to shortage of winch pieces. In the center of the prototype is the motor which drives the red gear which in turn drives a gear system which spins the drum. The drum is not circular, but is closer to a rectangular piece in the middle of the two gears.
Date: 10/17/19 Electronic Signatures: *Tanish Baranwal* **Oleg Bychenkov** *Kaushal Ramalingam* *Kabir Shah*	Top-down view 	Top down view of the first working prototype. This shows the gear system in full view and it is clear that there are only three interacting gears. It also shows the way the red gear is attached to the Fisher Tech motor.

Final Prototype

Date & Electronic Signatures	Image	Explanation of change in design
Date: 10/19/19 Electronic Signatures: Tanish Baranwal Oleg Bychenkov Kaushal Ramalingam Kabir Shah	Top-down view 	Top down view of the prototype which displays the final design. It shows the new winch piece that we were able to acquire. We also added the large base plate as a counter weight to prevent the winch system from tipping over. The first iteration was also decidedly unstable and adding the baseplate stabilized the entire design.

Date: 10/19/19 Electronic Signatures: *Tanish Baranwal* **Oleg Bychenkov** *Kaushal Ramalingam* *Kabir Shah*	Side views  	Side views of the final prototype which displays the internal workings of the winch system. The motor is mounted on a custom build set of long L-brackets joined together with flat braces. The motor itself was not a suitable size to simply be attached to the vex parts, so two screws were added to one side of the motor to act as clamps to clamp the motor in tight. We then inserted the motor assembly into the main body of the winch and connected the gears and other components.

Efficiency Calculations

Variable	Value	Calculations
V	7.38 V	N/A
I	0.1235 A	N/A
F	4.88 N	$F = ma$ $F = 0.498\ kg \times 9.8\ m/s^2$ $F = 4.88\ N$
d	0.61 m	N/A
t	137.39 s	N/A
$W_{mechanical}$	2.98 J	$W_{mechanical} = Fd$ $W_{mechanical} = 4.88\ N * 0.61\ m$ $W_{mechanical} = 2.98\ J$
P_{out}	0.022 W	$P_{out} = Wt^{-1}$ $P_{out} = 2.98\ J \times 137.39^{-1}\ s$ $P_{out} = 0.022\ W$
P_{in}	0.911 W	$P_{in} = IV$ $P_{in} = 0.1235\ A \times 7.38\ V$ $P_{in} = 0.911\ W$
Efficiency	2.46%	$Eff = P_{out} \times P_{in}^{-1} \times 100\%$ $Eff = 0.022\ W \times (0.911\ W)^{-1} \times 100\%$ $Eff = 2.46\%$

Final Design Solution

Our final design consists of a Fischer Tech motor that is situated in between two C-Channels that secure it. The motor is connected to a Fischer Tech gear through a simple gear train which then rotates a smaller VEX gear on the exterior of the left C-channel because they are attached on the same axle. Through another simple gear train, the smaller gear rotates a larger gear train on the exterior which rotates the small drum situated on the same axle. Because the larger gear is being driven by the smaller gear, the larger gear rotates at a significantly lower angular speed, leading it to cover less distance and increase the lifting time significantly as well. Five measurements were taken in order to calculate our winch's efficiency: force, distance, time, voltage, and amperage. We found the weight of the attached objects in grams, which amounted to 498 grams, by using a digital scale. Converting 498 g to Newtons (the S.I. unit of force) yielded a force of 4.88 N. Next, we measured distance by using a meter stick to measure the distance from the floor to the surface of the table; this measurement yielded a value of 610 centimeters, which was converted to 0.61 m (the S.I. unit of distance). Next, time was found through using a stopwatch to measure the time in seconds the winch took to lift the objects the total distance of 0.61 m from the floor to the table. Our time was found to be 137.39 s (S.I. unit of time). Next, we measured the required voltage of the winch by measuring across the winch motor with a multimeter while the circuit was powered on. The measured voltage differed slightly with a value of 7.38 V from the nominal voltage of 7.5. Finally, current was measured by breaking the circuit connecting the motor to the power source and and putting the multimeter in series. Our multimeter measured a current of 123.5 mA which we then converted to 0.1235 A. First we calculated the total work of the system using the equation "$W_{mechanical} = Fd$" and multiplied the force 4.88 N by the distance of 0.61 m to obtain 2.98 J as our work value. Next, we calculated output power using the equation "$P_{out} = W/t$" and substituted 2.98 J for work and 137.39 seconds for time to get an output power of 0.022 watts. Then, we calculated input power by multiplying voltage and current ($P_{in} = IV$). Substituting 0.1235 A for current and 7.38 V for voltage yielded an input power of 0.911 watts. Finally, we calculated the total efficiency of the winch system by utilizing the equation "$Eff = (P_{out} / P_{in}) \times 100\%$". After substituting the values 0.022 W and 0.911 W for output and input power respectively, our calculated efficiency was 2.46% which is a reasonable value for our winch system.

Functionality

Our prototype was effective in lifting a weight of 4.88 N with an efficiency of 2.46%, with a base input power of 0.911 W and an output power of 0.022 W. When scaled up to a real life practical size, the design of the winch itself is inefficient materials-wise. Additionally, our design utilizes space inefficiently due to the challenges in incorporating the Fisher Tech motor with VEX parts. The slow speed at which the winch operates at is a benefit in real life because it means that heavier weights can be lifted with a less powerful motor, and the ascent of the objects being lifted will be more stable. Some things that would need to be changed or upgraded when scaling up the design to a practical size and setup include increasing the strength of the moving parts in the design and increase the contact area between the motor and the first gear to minimize slipping and wear and tear of the parts. Part of strengthening the moving parts is to switch gears to metal gears instead of plastic gears whose teeth can bend and break under high pressures. The efficiency of a mechanical system is decreased only when the input energy is converted into unusable energy such as heat and sound. Energy is lost when the moving parts rub against the frame, so the less moving parts in a system the less friction. This is the first and primary factor that affected the efficiency of the prototype. There are more than ten different gears in the prototype, with each on its own separate axle and connected linearly. This means that there are over twenty points of contact with the frame and other gears in the system, and therefore 20 points at where energy is lost through friction. This can be decreased by simply decreasing the number of gears in the system to at most two or three. The second source is from the connection between the Fisher Tech motor and the first third party gear. There is a very small surface of contact with very small teeth which increases the chance of the gear slipping which happened at higher weights. This can be improved by having the motor turn a worm gear so that there is a very large contact area between the gears. The final source of friction is the contact between the axles and the frame. These areas are making sounds as heavier weights were being lifted. A modification that can be made to this is lubricating and reinforcing such points of contact.

References

Boundless. (n.d.). Boundless Physics. Retrieved from https://courses.lumenlearning.com/boundless-physics/chapter/rotational-kinetic-energy/.