Team 15
Trevor Lau, Celine Semaan, Alexander Williamson, & Jenna Rutberg

Northeastern University
College of Engineering
Cornerstone of Engineering
Fall 2020
Due: Week 1

Final Project Milestone 1

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For evaluation

Concerns	Comments	pts
Problem Statement	To design and successfully build a Rube Goldberg Machine. The machine needs to consist of six machines and result in a minimum of five energy transfers. When the machine has completed all steps, an overall final task must be met. The user of the machine will benefit from the final task that is met.	
General Goals	The general goals of the Rube Goldberg Machine are to: ● Include a name of the machine ● Have a minimum of eight steps completed ● Include at least six simple machines ● Complete at least five energy transfers ● Complete an end task ● Be creative ● Be complex	
Specific Goals	The specific goals of the Rube Goldberg Machine are to: ● Minimize cost of materials and work with the materials we have easily accessible due to the circumstances ● Plan and communicate our progress to each team member as we are all in different places ● Make sure all requirements and deadlines are met ● Achieve a final task/design that is creative	
Constraints	The constraints for the project are as follow: ● Space to store machine ○ Must be kept on the smaller size due to limited space ● Portability ○ Must be able to bring to class ○ Cannot be extremely fragile ○ Must be able to move and assemble easily ● Limited time in Maker Space due to COVID ○ Need to plan ahead ● Materials that we have access to ○ Limited due to COVID ○ Limited due to how we are all in different places ● Specific amount of time ○ Deadline 12/8 for presentation	

	○ Deadline 12/10 for report	
Literature / References / Similar work	**Source 1:** Link: https://www.nature.com/articles/s41593-020-0694-7#article-info Citation: Carey, C.M., Gagnon, J.A. CRISPR Rube Goldberg machines for visualizing cell lineage. *Nat Neurosci* (2020). https://doi.org/10.1038/s41593-020-0694-7 Research: ● Example of process analogous to Rube Goldberg machine on a molecular level ● Used to sort/show gene lineage, differentiate between steps of cell development ● Possible inspiration for allowing multiple tasks to be completed/sort objects? **Source 2:** Link: https://www.rubegoldberg.com/rube-the-artist/ Citation: “Who Is Rube Goldberg?” *Rube Goldberg*, Rube Goldberg Inc, 2018, www.rubegoldberg.com/rube-the-artist/. Research: ● Goal: solve simple task in complicated way **Source 3:** Link: https://study.com/academy/lesson/what-is-a-rube-goldberg-machine.html Citation: “What Is a Rube Goldberg Machine?” *Study.com*, Study.com, 2020, study.com/academy/lesson/what-is-a-rube-goldberg-machine.html. Research: ● Include concepts in physics such as: ○ Conservation of Energy ■ Energy is always transferred and kept constant in a system ■ Can transfer between different types of energy ○ Conservation of Momentum ■ Momentum remains constant as it moves between objects in a system	

	■ Ex. elastic collision between two balls is an example ○ Forces **Source 4:** Link: https://wonderopolis.org/wonder/what-is-a-rube-goldberg-machine Citation: "What Is a Rube Goldberg Machine?" *Wonderopolis*, National Center for Families Learning, 2020, wonderopolis.org/wonder/what-is-a-rube-goldberg-machine. Research: ● Chain reaction of events ● Ex. Turn on a flashlight ○ 125 steps ○ Toy rocket, meteor recreation, and fake fire used **Source 5:** Link: https://tinkerlab.com/engineering-kids-rube-goldberg-machine/ Citation: Rachelle. "Rube Goldberg Machine with Kids - TinkerLab." *TinkerLab*, TinkerLab, 2020, tinkerlab.com/wp-content/uploads/2015/03/Rube-Goldberg-Supply-List-Handout.pdf. Research: ● Good source for inspiration on how to: ○ Make machine ○ What materials to use ○ Etc **Source 6:** Link: https://www.livescience.com/49106-simple-machines.html Citation: Lucas, Jim. "6 Simple Machines: Making Work Easier." *LiveScience*, Purch, 7 Feb. 2018, www.livescience.com/49106-simple-machines.html Research: ● Background information on the six types of simple machines. ● Possible inspiration on usages for simple machines in overall design of the project.	

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<table>
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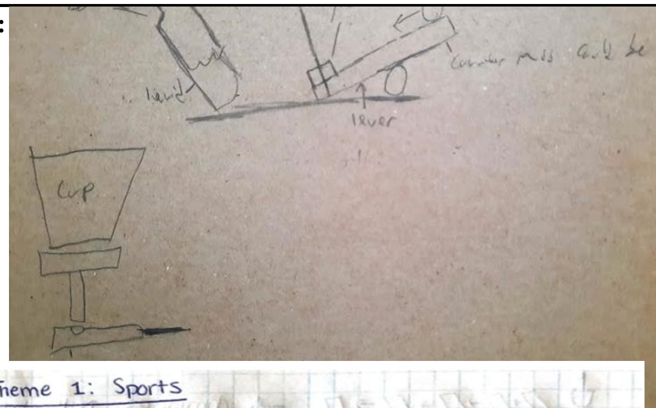
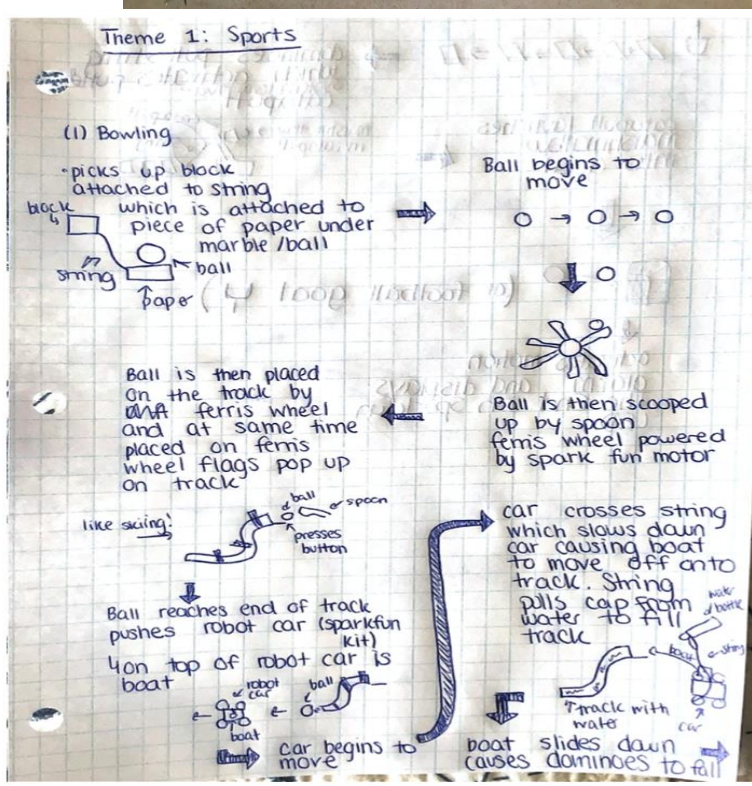
<tr><td>Diagrams / Drawings</td><td>

Sketch 1:



Sketch 2:



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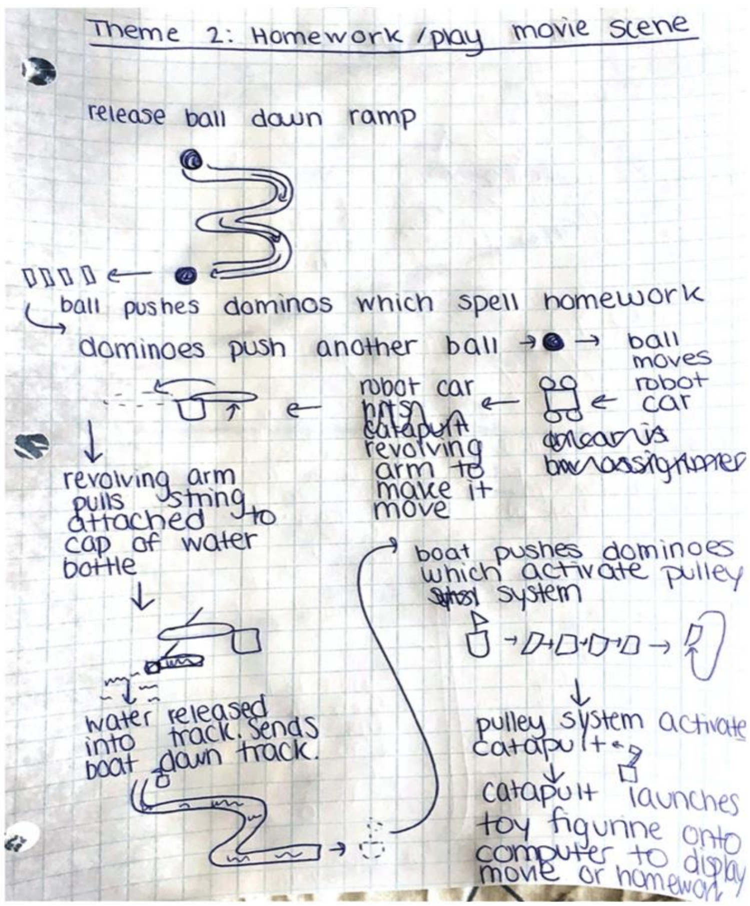
Sketch 3:



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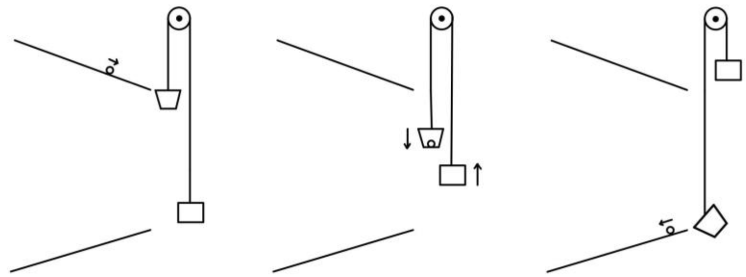
	Sketch 4: 	
Additional work	Additional work we completed this week was we brainstormed a list of possible ideas for the end task as well as what machines to possibly include in the final design. We also set up and organized a google folder so that we have everything in one place. Within this folder, we created a document to allow us to recap the progress made during each design meeting.	
Project Progress Concerns/Issues	Our concerns at the moment are: ● Trying to put our ideas into action and into a final design ● How we will carry out building the final project as some of us are remote and some are on campus ● Creating a project that is complex enough	
Total		

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Due: Week 2

Final Project Milestone 2

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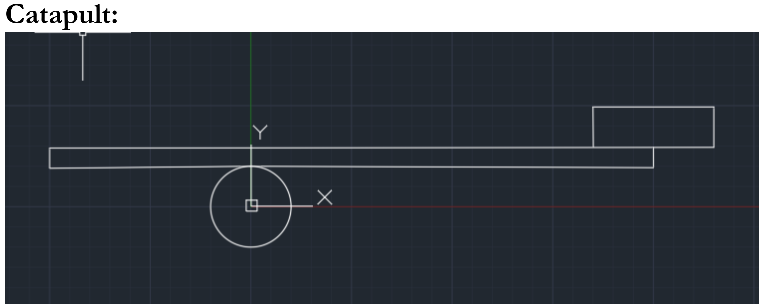
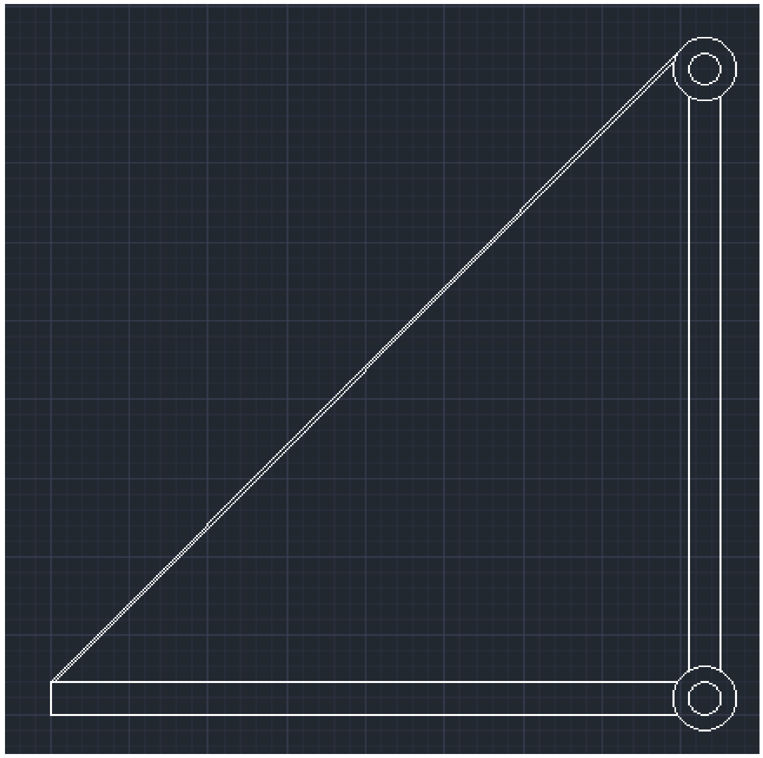
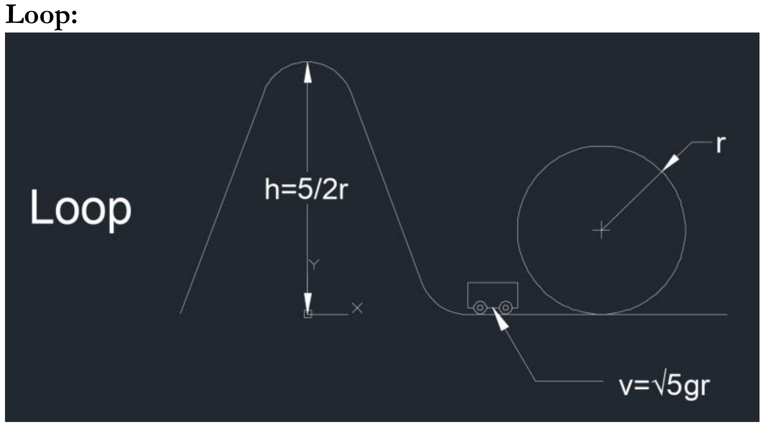
For evaluation

Concerns	Comments	pts

Alternative Designs	**Theme:** A Day at the Amusement Park
	Simple Machines:
	1. Wheel & Axle:
	    a. Ferris Wheel [Mechanical to PE to Mechanical]
	    b. Robot Car in Sparkfun Kit
	2. Pulley:
	    a. Drawbridge [PE to KE]
	3. Screw:
	    a. Elevator: Winds down then up
	    b. Cap of Water Bottle
	        i. Water bottle opens and cap unscrews
	        ii. Possible Idea: Water then flows into the ferris wheel and then into a cup where the added pressure in the cup presses a button under the cup to open a box at the end that unlocks a prize.
	4. Lever:
	    a. Catapult [PE to KE]
	5. Inclined Plane:
	    a. Ramp
	6. Loop:
	    a. Rollercoaster
	        i. Possible tracks for tires to go into
	Sensors:
	1. Motion Alarm
	2. Ultrasonic Sensor
	    a. String of lights to adjust distance
	Final Task:
	Option 1:
	1. Something falls off ferris wheel
	2. Hits button
	3. Box opens with prize	

	Option 2: 4. Something falls off ferris wheel 5. Falls in milk jug at end Option 3: 6. Something falls off ferris wheel 7. Use code to unlock something at end to reveal something Option 4: 8. Complete circuit to light a lightbulb Other Ideas: 1. Choose your own adventure at the beginning a. Domino = safe route b. Rollercoaster = crazy route 2. Theme Idea: Follow a car through a day at the amusement park 3. Booth where robot car hits button on ground which causes a lever to lift and place a prize or “popcorn” onto the car as the robot car continues on	
Final Designs	Our final design consists of: 1. A catapult launches an object onto a loop. 2. Loop allows object to lower elevation to drawbridge. 3. Object reaches drawbridge, goes up to top, hits something, and then comes back down to open drawbridge. 4. Since the drawbridge is now open, objects can enter and reach the ferris wheel. 5. Object rides on the ferris wheel, and then falls off onto another ramp. 6. Object reaches pulley and then carousel. 7. With this system, the object ends up in the wedge-like object that sits on top of a box with a button. 8. Several objects accumulate in the wedge-like object to allow for the box to open. 9. When the box opens, a surprise is revealed, and the final task is met. *Above is the basic concept for our design. We must still figure out the exact mechanisms that power each machine, and how they will work. Additionally, we must figure out how each machine connects to the next to allow for a smooth transition of power between the machines and a successfully met task.*	
Drawing 2D	**Catapult:**  	

	Drawbridge:  **Loop:**  		

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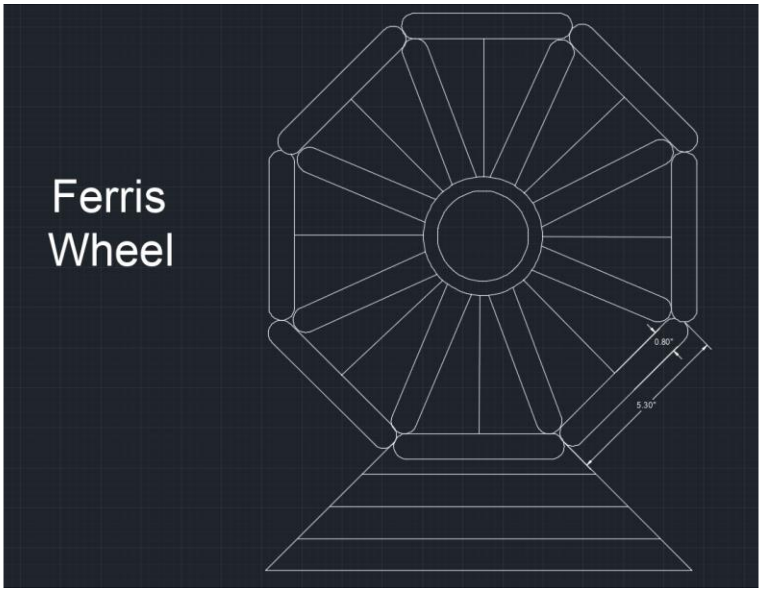
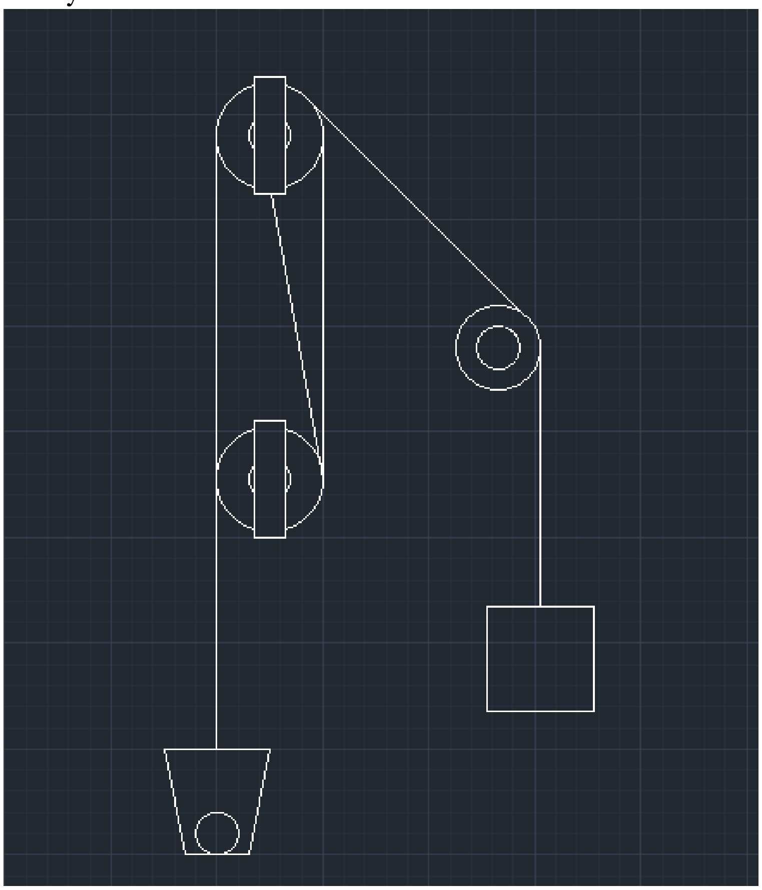
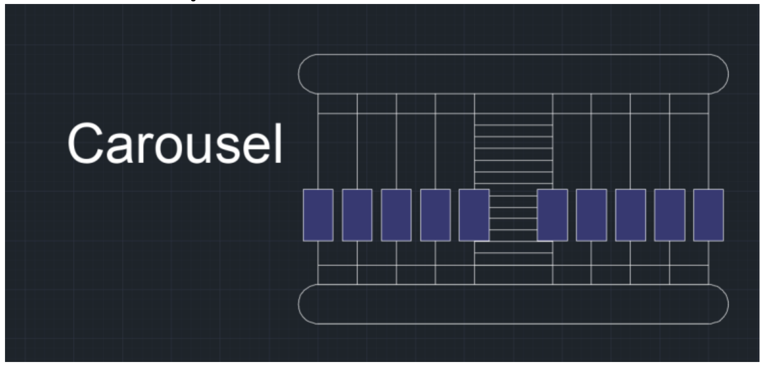
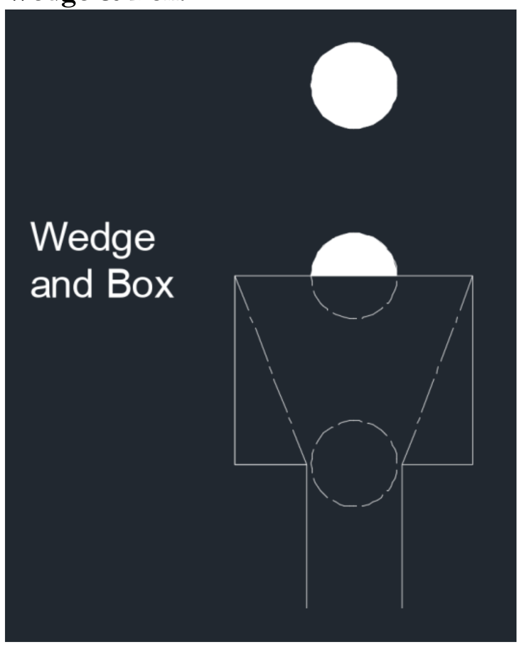
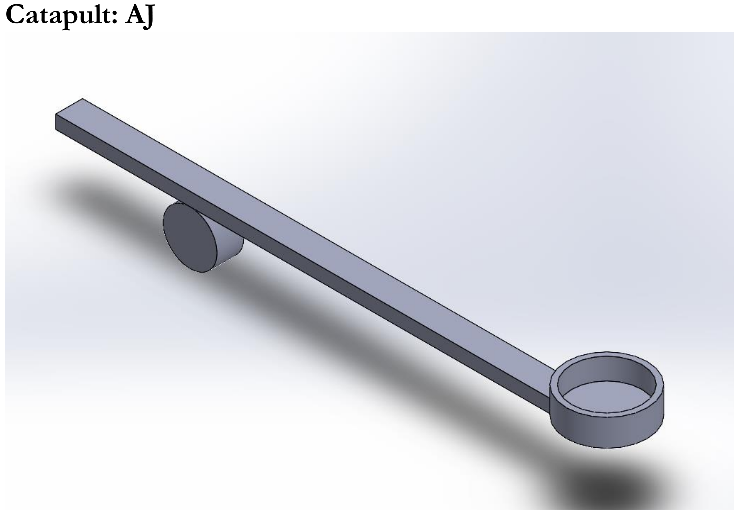
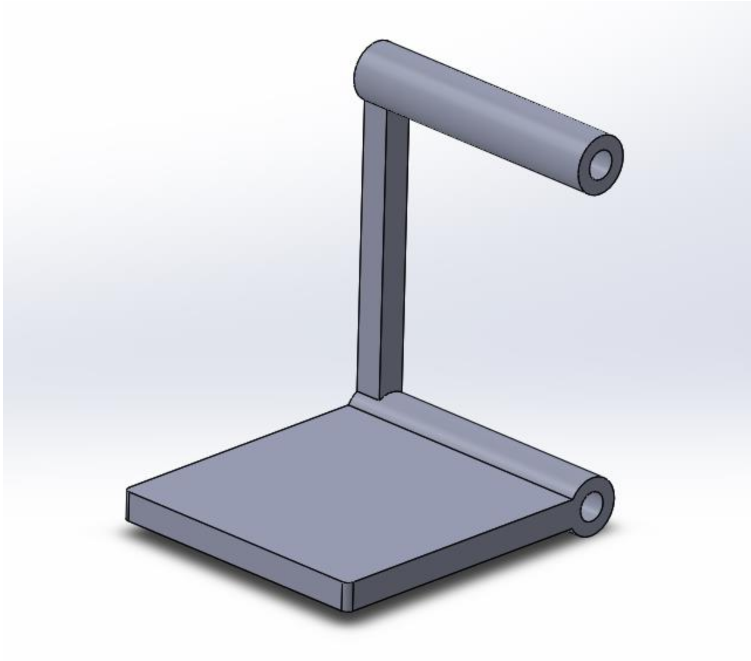
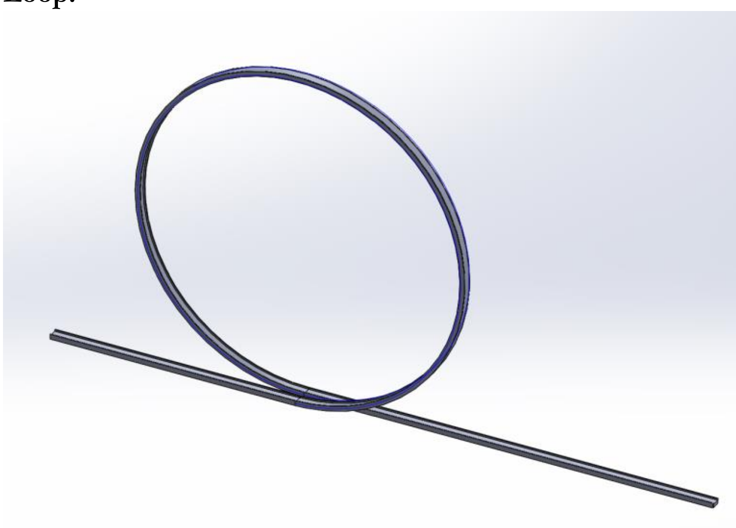
Ferris Wheel:



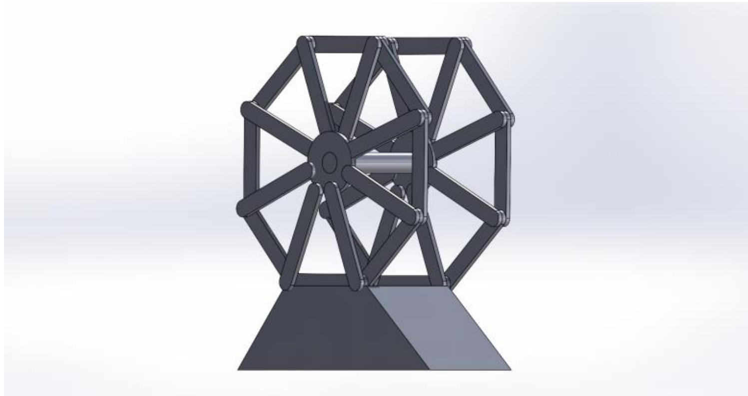
Pulley: Trevor

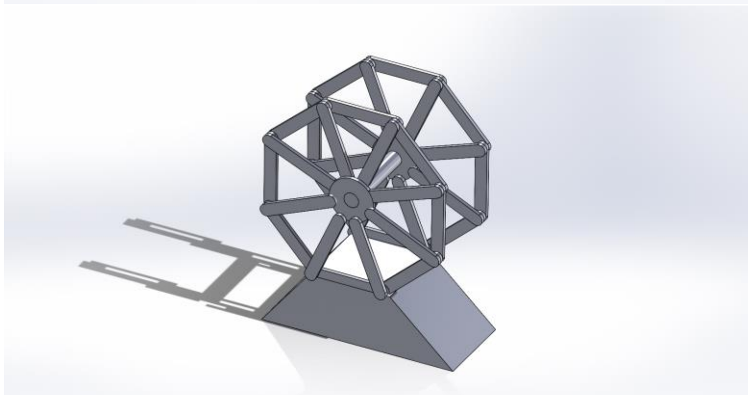


	Carousel/Merry Go Round:  **Wedge & Box:**  		
Drawing 3D	**Catapult: AJ** 		

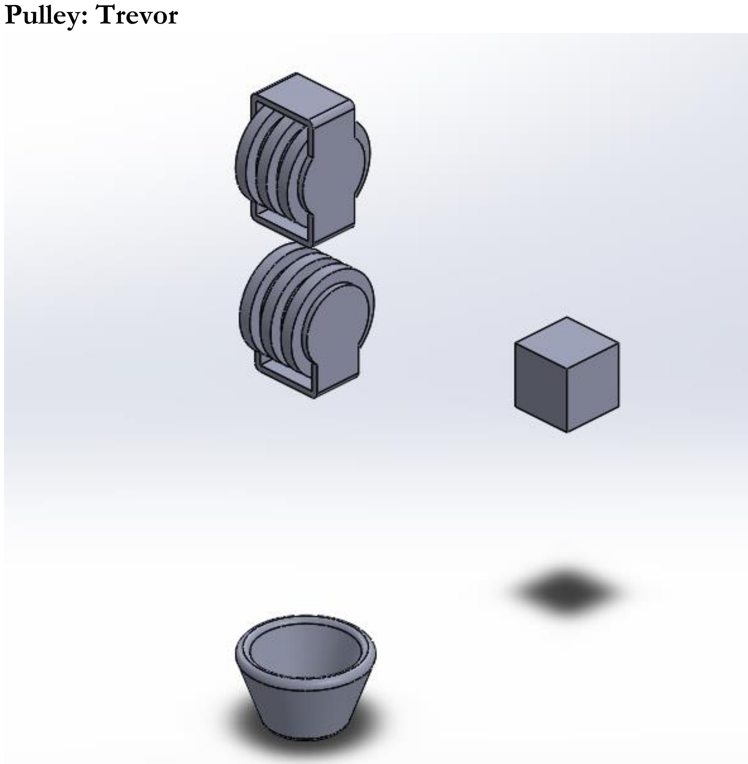
	Drawbridge: Trevor  **Loop:** 	

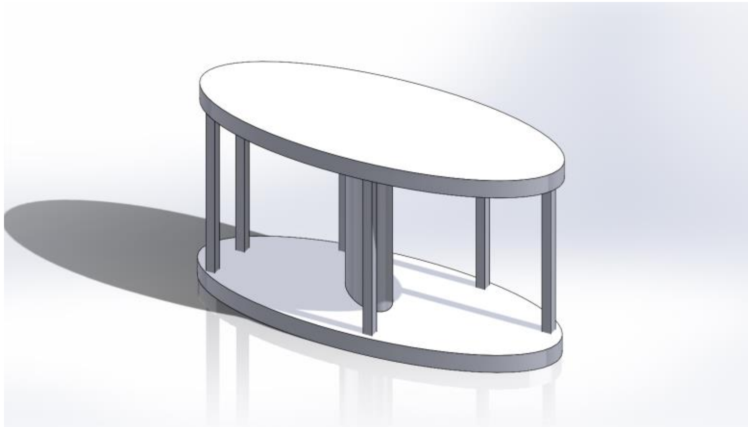
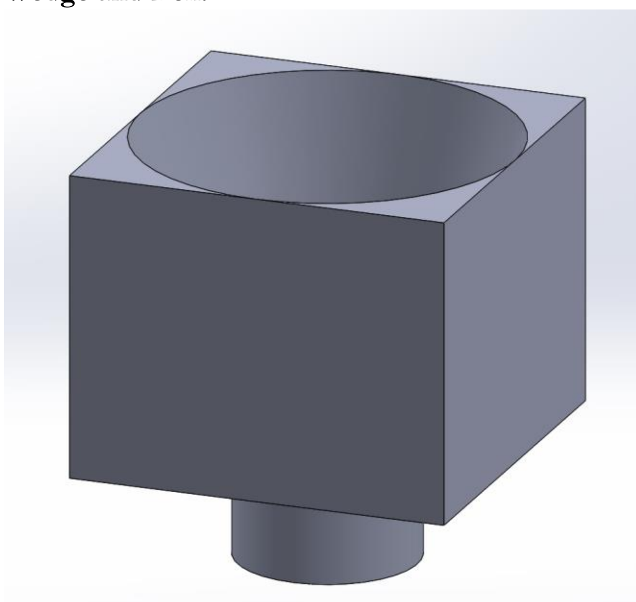
Ferris Wheel:





Pulley: Trevor



	Carousel/Merry Go Round:  **Wedge and Box:** 	
Science / concepts / theories	**Science/Concepts/Theories:** **Simple Machine: Lever => Catapult** **Source 1:** Link:https://www.real-world-physics-problems.com/catapult-physics.html Citation:"Catapult Physics." *Real World Physics Problems*, www.real-world-physics-problems.com/catapult-physics.html. Research: ● Traditional Mangonel Catapult: ○ Torsion or tension used to store energy ○ Upon release, causes rotation of arm, payload is launched at linear velocity of arm - once arm hits crossbar & stops rotation	

- Simpler catapults involve a fulcrum around which a lever is bent, with one end held in place, causing the other end to spring back into place when released.
- Hard to achieve consistent results, as torsion bundles/ropes become stretched, or the lever becomes deformed

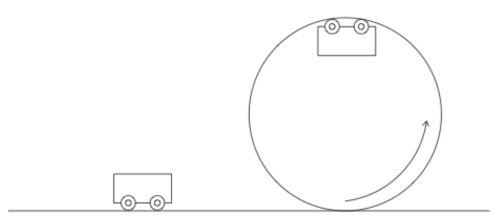
Source 2:

https://sciencing.com/a-catapult-work-4586404.html
Beck, Kevin. "How Does a Catapult Work?" sciencing.com, https://sciencing.com/a-catapult-work-4586404.html. 16 November 2020.

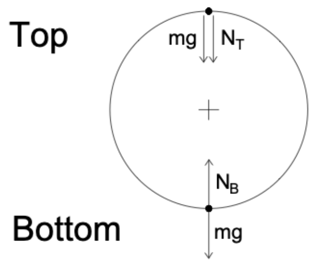
- Range R of a projectile launched from catapult:
  $R=(v^2\sin(2\theta))/g$
  θ being the angle of the arm of the catapult to the horizontal.
  Torque causes angular acceleration, longer catapult arm= greater linear acceleration at the end of the arm, increasing launch velocity.
  - Fixed end: elasticity causes arm to spring back once released
  - torque = rfsinθ - create mechanical advantage by placing fulcrum closer to one end of unfixed lever.

Loop:
Source 1:
https://www.youtube.com/watch?v=upjI5dw8_Es&ab_channel=MattAnderson

Source 2:
https://www.youtube.com/watch?v=mqRCz6qlnKs&ab_channel=GregJohnson



Free Body Diagram:



Where mg is the weight,
N_B is the normal force at the bottom of the loop,
N_T is the normal force at the top of the loop.

Where do you feel heaviest?
Bottom of the loop
Newton's Second Law of motion: $\sum F_{net} = m \cdot a$
$\sum F_r = mv^2/r$ because $a_c = v^2/r$
Where $\sum F_r$ is the sum of the force in the radial direction.
$m$is the mass of the cart.
v is the velocity of the cart.
r is the radius of the loop.
a_c is the centripetal acceleration.

Top of the Loop:

$$N_T + mg = mv^2/r$$
$$N_T = mv^2/r - mg$$

Bottom of the loop:

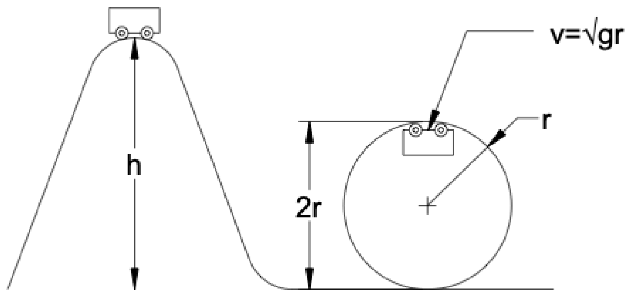
$$N_B - mg = mv^2/r$$
$$N_B = mv^2/r + mg$$

The normal force is bigger at the bottom than at the top, so you feel heavier at the bottom.

"Weightless feeling at the top:
$N_T = 0$; v =? (minimum velocity at the top)

$$N_T = mv^2/r - mg = 0$$
$$\underline{mv^2/r = mg}$$
$$\underline{v = \sqrt{gr} \simeq \sqrt{9.81r}}$$

Minimum height of the free fall to make it through the loop:
We ignore friction



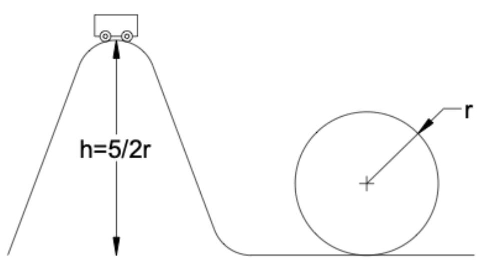
$E_g = E_k + E_{g'}$

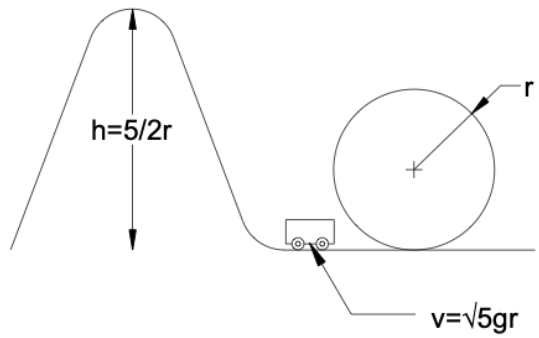
$$mg\boldsymbol{h} = 1/2mv^2 + mg2r$$

$$mg\boldsymbol{h} = 1/2m\sqrt{gr}^2 + mg2r$$
$$mgh = 1/2mgr + mg2r$$
$$\boldsymbol{h} = 1/2r + 2r$$
$$\boldsymbol{h} = 2\,1/2r = 5/2r$$

Minimum velocity to make it through the loop:
We ignore friction

$$E_k = E_g + E_k{}'$$
$$1/2mv^2 = mg2r + 1/2mv_c{}^2$$
$$1/2mv^2 = mg2r + 1/2m\sqrt{gr}^2$$
$$1/2mv^2 = mg2r + 1/2mgr$$
$$1/2v^2 = 2gr + 1/2gr$$
$$v^2 = 5gr$$
$$v = \sqrt{5gr} \simeq \sqrt{49.05r}$$





Simple Machine: Wheel & Axle

Ferris Wheel:

Source 1:

Link:
https://www.observationwheeldirectory.com/ferriswheelarticles/ferris-wheel-physics/#:~:text=Ferris%20wheels%20are%20large%2C%20non,wheel%20and%20always%20hang%20downwards.&text=The%20Ferris%20wheel%20spins%20upwards,the%20wheel%20back%20down%20again

Citation: "Ferris Wheel Physics." *Observation Wheel Directory*, 6 June 2013, www.observationwheeldirectory.com/ferriswheelarticles/ferris-wheel-physics/.

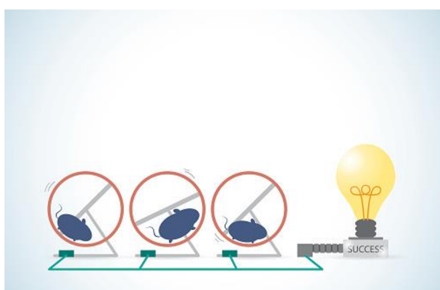
Research:

- Central axis to rotate about
- Seats hang down to allow for rotation
- To move up, motors and gears are used
- To move down, gravity is in play
- Centripetal acceleration is a part of how a ferris wheel works
    - "Acceleration towards center"
    - Keeps small objects in orbit around a larger object
        - Seats stay in orbit around the actual wheel of the ride
    - Centripetal Acceleration = W^2*R
        - W=angular velocity
        - R=radius of wheel
- Constant speed present but velocity vector changes due to position of wheel
- Feel lighter at top and heavier at bottom due to centripetal acceleration
    - Centripetal Acceleration points down at top and up at bottom

Source 2:

	Link: https://www.observationwheeldirectory.com/ferriswheelarticles/observation-wheel-technology/
	Citation: "Observation Wheel Technology." *Observation Wheel Directory*, 7 July 2013, www.observationwheeldirectory.com/ferriswheelarticles/observation-wheel-technology/.
	Research:
	● How do ferris wheels rotate?
	    ○ Hydraulic motors with electric pumps
	        ■ Power tires that are located along wheel
	        ■ Cause friction to make it rotate
	    ○ Computer is in control of each motor
	    ○ Emergency generator and battery back-up braking for worst-cases
	● How are ferris wheels held in place?
	    ○ Cables
	    ○ Dampers
	        ■ Prevent wind vibrations
	● Portability?
	    ○ Smaller wheels are used to allow for quicker assembly/disassembly
	● Appearance?
	    ○ Lights are often used to add to appearance
	        ■ LED lights typically
	Source 3:
	Link: https://amusementrides.org/design-mini-size-ferris-wheel-ride/
	Citation: "The Design Of The Mini Size Ferris Wheel Ride." *Premium Amusement Park & Funfair Ground Rides*, 22 Mar. 2017, amusementrides.org/design-mini-size-ferris-wheel-ride/.
	Research:
	● Made mostly out of steel
	● How are mini ferris wheels made?
	    ○ Same process as large-scale ferris wheels but on smaller scale
	    ○ Steps:
	        ■ Build frame
	        ■ Add support beams
	        ■ Spokes of wheel are added
	        ■ Support cables in between spokes
	            ● Creates an x-like pattern
	            ● Make sure to cross both the width and diameter of wheel	

	○ Ex. 16 seats leads to 8 spokes **Source 4:** Link: https://www.encyclopedia.com/science-and-technology/technology/technology-terms-and-concepts/ferris-wheel#:~:text=Here%20is%20a%20typical%20sequence,48%20riders%20in%2016%20seats Citation: “." How Products Are Made. . Encyclopedia.com. 16 Oct. 2020 .” *Encyclopedia.com*, Encyclopedia.com, 15 Nov. 2020, www.encyclopedia.com/science-and-technology/technology/technology-terms-and-concepts/ferris-wheel. Research: ● Steps to build a ferris wheel: ○ Build Frame ■ Base with two vertical beams ○ Add Support Beams ■ Adding electrical wiring is included in this step ■ Brakes are added ○ Spokes are added ■ Typically 16 pairs ■ Support cables added ○ Final touches completed **Source 5:** Link: https://www.livescience.com/49106-simple-machines.html#:~:text=In%20addition%20to%20reducing%20friction,the%20rim%20of%20the%20wheel Citation: Lucas, Jim. “6 Simple Machines: Making Work Easier.” *LiveScience*, Purch, 7 Feb. 2018, www.livescience.com/49106-simple-machines.html. Research: ● How does a wheel and axle work? ○ When force is applied to wheel, the force on the axle tends to be greater than force on wheel causing rotation ○ Reduces friction **Inspiration for Designing/Building a Ferris Wheel:** Links: *Without a motor ...* ● https://www.ehow.com/how_5527767_make-wheel-out-popsicle-sticks.html ● https://www.instructables.com/Cardboard-Ferris-Wheel/	

	• https://sciencing.com/do-color-affects-peripheral-vision-7925210.html *With a motor ...* • https://www.instructables.com/Unit-1-Final-Project-Ferris-Wheel/ **Inspiration to light a lightbulb:** *How to Build a Circuit …* • https://sciencing.com/light-bulb-work-battery-4798212.html • https://learning-center.homesciencetools.com/article/circuit-science-projects-for-elementary/ • https://www.wikihow.com/Make-a-Light-out-of-Batteries *With rotation …* • https://www.instructables.com/Simple-Generator-that-can-power-LED-bulb/ • https://envirolution.org/bicycle-generators-making-your-own-electricity/ • https://www.npr.org/sections/13.7/2016/12/08/504790589/could-you-power-your-home-with-a-bike • https://www.instructables.com/How-To-Build-A-Bicycle-Generator/ • https://www.seattleu.edu/scieng/physics/physics-demos/electricity-and-magnetism/induction---light-bulb/#:~:text=In%20this%20case%2C%20it%20is,the%20large%20U%2Dshaped%20magnets.&text=This%20induced%20current%20can%20be%20used%20to%20power%20the%20light%20bulb.  **Simple Machine: Wheel & Axle** **Carousel/Merry Go-Round:** **Source 1:**	

Team 15
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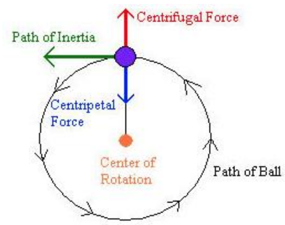
	Link: https://learning-center.homesciencetools.com/article/amusement-park-physics/ Citation: "Amusement Park Physics: Home Science Tools Learning Center." *Home Science Tools*, 2 Jan. 2020, learning-center.homesciencetools.com/article/amusement-park-physics/. Research: ● How does a carousel turn? ○ Centripetal Force acts on Ferris Wheel combined with Newton's Law of Inertia ■ Allows for rotation of carousel ■ Without centripetal force, objects in motion would continue moving in a straight line ● No rotation  ● **Source 2:** Link: http://www.historyofcarousels.com/carousel-facts/how-carousels-are-made/#:~:text=Carousels%20rotate%20on%20a%20stationary,with%20it%20the%20whole%20carousel Citation: "Carousel Construction - How Does a Carousel Work?" *How Carousels Are Made? - How Does a Carousel Work?*, www.historyofcarousels.com/carousel-facts/how-carousels-are-made/. Research: ● Center pole ● Motor ● Motor attached to two pulleys connected with a belt to turn gears **Inspiration for how a carousel/merry-go-round is built …** ● https://www.google.com/url?sa=i&url=http%3A%2F%2Fwww.madehow.com%2FVolume-4%2FCarousel.html&psig=AOvVaw3aRl3a6SaGiA413wHXQ15s&ust=1605370941640000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCNiWgPv2_-wCFQAAAAAdAAAAABAO ● https://www.google.com/url?sa=i&url=https%3A%2F%2Fopenlab.citytech.cuny.edu%2Fthe-buzz%2Ftag%2Fnew-york-		

	city%2F&psig=AOvVaw3aRl3a6SaGiA413wHXQ15s&ust=1605370941640000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCNiWgPv2_-wCFQAAAAAdAAAAABAU	
Calculations	Equations that will be used for our final design: ● Centripetal Acceleration ○ https://courses.lumenlearning.com/physics/chapter/6-2-centripetal-acceleration/ ○ $a_{centripetal} = \frac{v^2}{r}$ ○ $a_{centripetal} = w^2 * r$ ● Research on loops located in the above section. The research in that section explains how Newton's Second Law of Motion applies to Loops and Rollercoasters. The appropriate equations and calculations are located in that section along with free-body diagrams.	
Additional work	We began further finalizing our design, and working on our Final Project Milestone Week Three.	
Project Progress Concerns/Issues	The project concerns we have as of right now are… 1. Materials a. How will we find the appropriate materials to build our final project? b. Who will collect which materials? c. What resources on campus do we have access to? 2. Coordination of our Design a. How will we ensure timing is accurate with each simple machine in our design? b. How will we ensure each simple machine performs correctly and connects to the next machine smoothly? c. How will we make sure our project is consistent each trial? And the final task is met each trial?	
Total		

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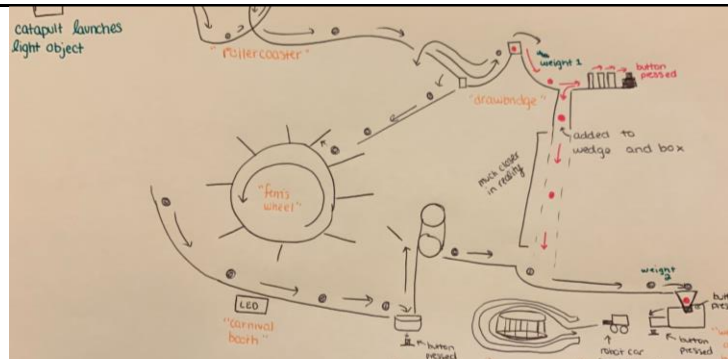
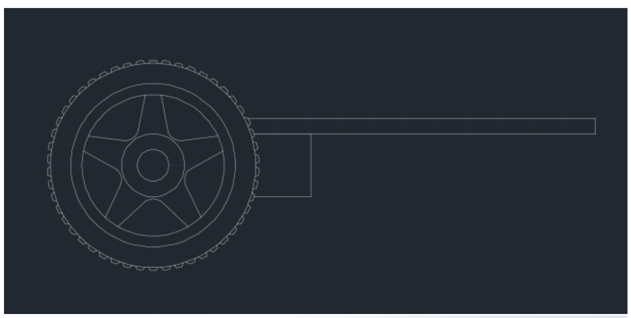
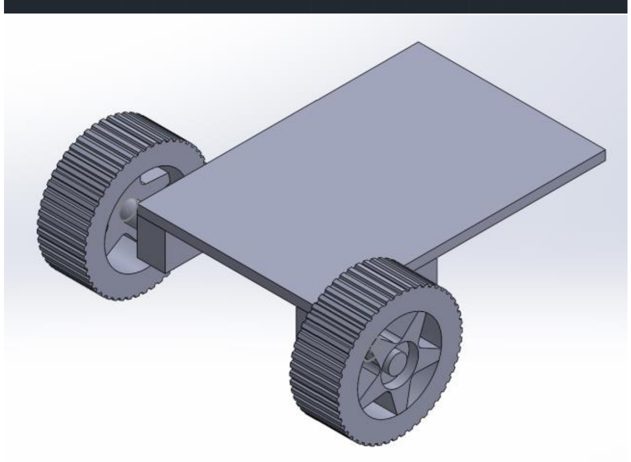
Northeastern University
College of Engineering
Cornerstone of Engineering
Fall 2020
Due: Week 3

Final Project Milestone 3

Upload e-file to the blackboard, the word or pdf file should be saved as m3_teamID

For evaluation

Concerns	Comments	pts
Final Design	1. An object dropped from the same height triggers the catapult. 2. Catapult launches the object, and the ball moves onto the hill located before the loop. 3. From the loop, the ball goes to the drawbridge and due to speed goes up to the top. At the top, the ball hits a container, which tilts and allows the ball to come out of the container. The ball which falls out of the container hits dominoes and then the dominoes fall onto a button to open the drawbridge. Ball that hits dominoes then slides back to the opening located before dominoes. This ball is then brought to the wedge and box. The drawbridge then opens and the original ball goes through the opening to the ferris wheel. 4. Ball rolls onto Ferris wheel which is constantly spinning by a motor. Ball rides onto Ferris Wheel until it falls out and is brought to ground. The ferris wheel motor is connected to the Sparkfun Kit which is located in a carnival booth. And this Sparkfun Kit also programs an LED. The LED is triggered by the passing of the ball from the Ferris Wheel to ground. 5. After the Ferris Wheel and Carnival Booth are passed, the ball drops into a basket of the Pulley. With added pressure from the ball into pulley, the button located under the basket is pressed. This button triggers the start of the motor powering the pulley. The pulley is a double pulley to add more power to lifting the basket up. 6. Halfway up, the basket of pulley hits a horizontal wall and then the basket tilts and releases the ball to slide onto the track. The ball slides down the track and is added to the wedge and then the box. This is now the second of weighted objects added to the wedge and box. 7. The box then opens as the button on the box has enough weight/pressure added to the wedge above the box. When the box opens, the door of the box releases onto the button that starts the robot car. Robot car is programmed to turn around	

	and the horizontal side of the car is able to circle the merry-go-round and hit the pillars on the merry-go-round to begin rotation.	
Final Drawing		
Drawing 3D – gtest2 (now due Dec. 1)	Our plan for Graphic Test 2 is to complete four drawings: 1. Catapult => AJ 2. Robot Car => Celine 3. Ferris Wheel => Jenna 4. Pulley => Trevor We plan to 3D print the pieces of the pulley for assembly.  	
Needed elements List	Ball: 1. (2) Marble Extra Track: 1. Cardboard	

<table>
<tr><td></td><td>2. Colorful Paper
Catapult:
1. Ruler
2. Light object (marshmallow) to start marble sitting on hill
Loop:
1. “Hill” before loop probably made of cardboard
2. Cardboard
3. Duct Tape
Drawbridge:
1. Cardboard
2. Dominos/Blocks of cardboard
3. Container at top
4. Object in Container
Pulley:
1. (2) 3D Printed Circular Smooth Gear thing
2. Basket
Carousel:
1. Pillar for car to hit
2. Fence structure around carousel to keep car in
Car:
1. Program for robot car
2. Hook/Stick on end of Robot Car to attach to merry go round
3. (4) AA Batteries
Wedge:
1. Cardboard or 3D print
2. Duct Tape
3. Know measurements of pencil case to ensure it can sit on top</td><td></td></tr>
<tr><td>Elements collected</td><td>Drawbridge:
1. Duct Tape
2. Sparkfun Kit: Button & Motor
3. String
Ferris Wheel:
1. Popsicle Sticks
2. Hot Glue
3. Cardboard
4. Construction Paper
5. Spark Fun Kit
Pulley:
1. String
2. Sparkfun Kit: Button & Motor
Carousel:
1. Cardboard
2. Construction Paper
3. Cardboard Discs
Robot Car:
1. SparkFun Kit
Box:
1. Pencil Case</td><td></td></tr>
</table>

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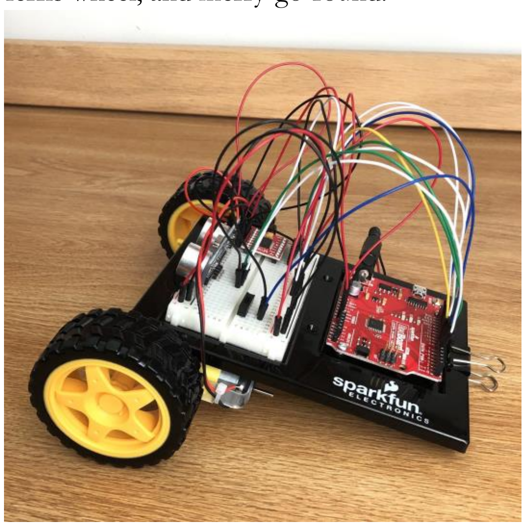
Any design / element issues	Coordination of our Design • How will we ensure timing is accurate with each simple machine in our design? • How will we ensure each simple machine performs correctly and connects to the next machine smoothly? • How will we make sure our project is consistent each trial? And the final task is met each trial?	
Additional work	We began building certain parts of our final project. The autonomous robot car is almost complete, and we began prototyping the catapult, ferris wheel, and merry-go-round. 	
Project progress concerns / Issues	Time Management • Planning appropriately for during and after Thanksgiving Break Materials • Finding and collecting all necessary materials	
Total		

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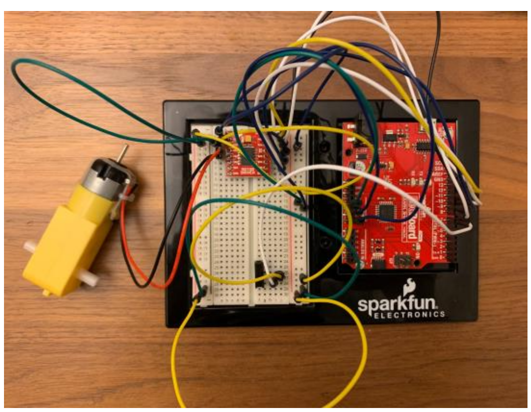
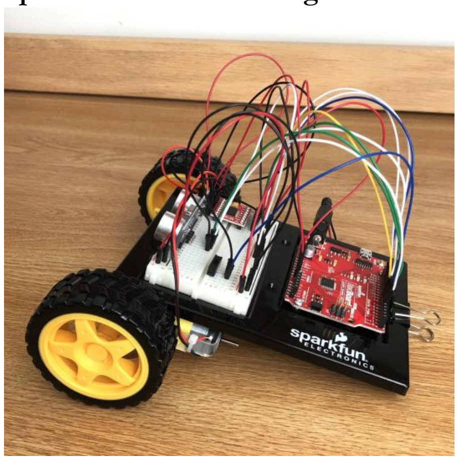
Northeastern University
College of Engineering
Cornerstone of Engineering
Fall 2020
Due: Week 4
Final Project Milestone 4 - Demo
Upload e-file to the blackboard, the word or pdf file should be saved as m4_teamID

For evaluation

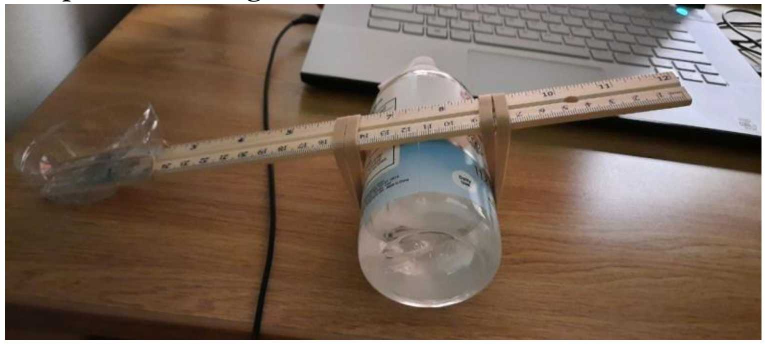
Concerns	Comments	pts
Elements Display	**Ferris Wheel Final Design:**  	

Sparkfun Car Final Design:

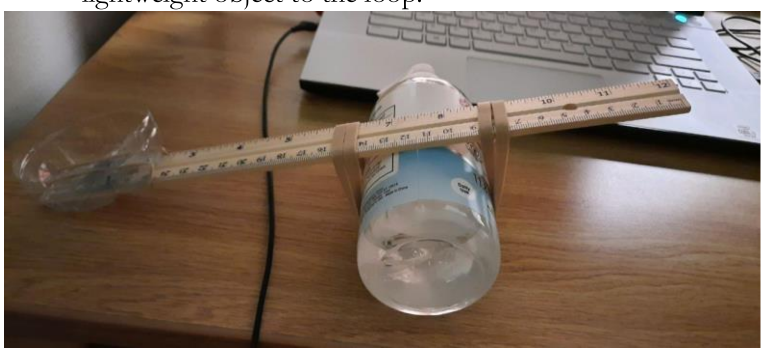


Loop Final Design:

Merry-Go-Round Prototype:

<table>
<tr>
<td></td>
<td>Catapult Final Design:
</td>
<td></td>
</tr>
<tr>
<td>Initial Assembly</td>
<td>As our machines are still in the process of being built, we have not yet created an assembly.

We have, however, planned how we will assemble them.

An object that we drop will land on the rightmost region of the catapult. This will cause the catapult to launch sending a lightweight object to the loop.

The loop will have a ball sitting on top of a “hill” located prior to the loop. The lightweight object launched from the catapult will hit the marble sending it into motion.

From the loop, the marble will continue onto the drawbridge. The marble will go up the slight incline and hit a

</td>
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</table>

container with another marble inside. The container will tip to the right and the second marble will fall out. This marble will knock over dominos that will fall on a button. The pressed button will start the motor of the drawbridge, and the drawbridge will open. The first marble will be on top of the drawbridge, and once it opens it will fall to the ferris wheel. The second marble will fall through the hole and follow the track to the wedge and box. The second marble will be the first weight added to the wedge and box to allow for the accumulation of weight to open the box.

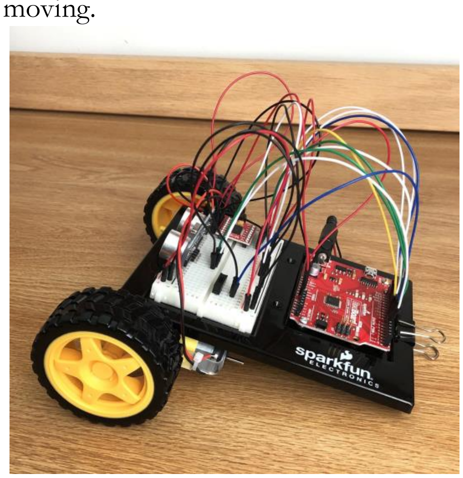
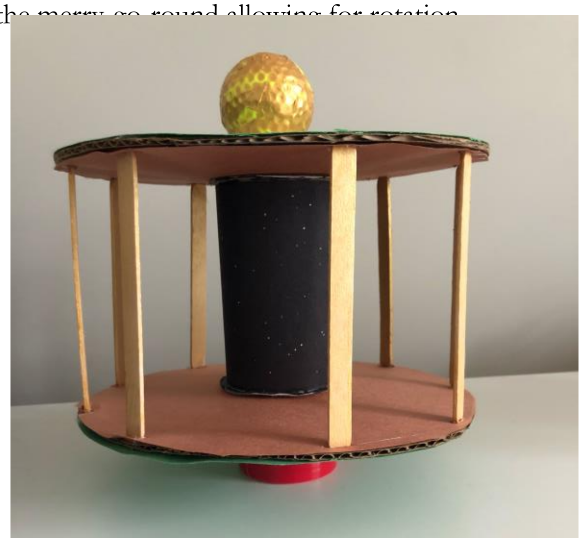
The above is on a second level raised above the first level. The rest explained below will be located on the lower level.

4. The first marble will fall onto the ferris wheel that is constantly rotating at a slow speed. The ferris wheel will bring the ball down to ground level and the marble will continue moving. The marble will go past the LED light or "carnival booth," and land in the basket of the pulley.

5. The pressure from the marble added to the basket will lower the basket onto a button. This button will turn the motor on that powers the pulley, and the pulley will begin moving.

As the basket is lifted, the marble returns to the second level.

6. The basket will be lifted to where it hits a piece of track that consequently tilts the basket. The marble falls out of the basket onto another piece of track that leads to the wedge and box. This is the piece of track that the second marble took before. The first marble is added to the wedge and box.
7. At this time, the wedge and box now has two marbles which is enough pressure to press the button on the box and open it. The door from the box opens, and lands on another button.

	8. This button sends a signal to the autonomous robot car to begin moving.  9. The robot car begins moving and follows the program uploaded to it. The program describes the movements for the robot car to circle the merry-go-round causing it to spin. The robot car has a piece attached to it that hits the pillars of the merry-go-round allowing for rotation.  10. The end task is met as the merry-go-round is rotating due to the robot car.	
Incomplete or complete demo	We have not yet tested our entire assembly of machines as they are still being built. We did, however, individually test the machines that have been built so far. **Catapult:** The catapult was tested, and was able to successfully launch an object. **Loop:** The loop is in the process of being tested. **Drawbridge:** The drawbridge is in the process of being tested. **Ferris Wheel:** The ferris wheel was tested using the motor and Arduino Program. It successfully rotates. The program needs to be adjusted to the appropriate speed to allow for a slower rotation.	

	Pulley: The pulley prototype works. The motor is working with the prototype. **Merry-Go-Round:** The merry-go-round rotates with an external force rotating it. It has not yet been tested with the robot car. **Wedge & Box:** We have not yet tested how many marbles are needed to open the box. We plan to later this week. **Robot Car:** The robot car is built. A program is still needed to allow for it to run. Additionally, the robot car needs to be tested alongside the merry-go-round to ensure it is able to rotate it.	
Data Collection Method	For each machine, we have been using a ruler to take measurements during and after construction. **Catapult:** Trial & Error: dropped object from various heights in multiple trials to get different consistent distances. **Loop:** Modifications to the original design: The minimum height of the hill prior to the loop was increased to ensure the marble makes it through the loop while taking into account possible miscalculations and rooms for error. The hill was placed at a steep angle to help with the velocity and to make sure we also take into account the friction and air resistance that could impact the expected velocity of the marble. **Robot Car:** Trial & Error: attach a stick or a string to the end of the robot car to potentially get the merry-go-round to spin alongside the car. For the program, test out different motor speeds and make one wheel spin slower than the other for the car to go in a circle. **Ferris Wheel:** Trial & Error: Dropping a ball from the same distance that the drawbridge would be located. This ensures that the Ferris Wheel is able to catch the ball and safely deliver it to ground level. The ball should continue to roll at this point. Testing out different motor speeds by adjusting the program will allow for the best speed to be found. **Merry-Go-Round:** Trial & Error: Testing the merry-go-round to ensure that it can spin with an external force present. Then replacing this force with the Sparkfun Robot Car to ensure that the car has enough power to fully push the merry-go-round. Additionally, checking that the program for the Robot Car is specific enough to form a circle around the merry-go-round to allow for rotation. **Pulley:** Trial & Error: Testing the motor speed with the pulley gears to ensure that the pulley properly works. Additionally, checking that the weight of the marble adds enough pressure to the basket to ensure that the basket is lowered and is able to press the button to start the motor. **Drawbridge:** Trial & Error, Calculations: Testing the motor speed with the entire drawbridge assembly to ensure that it works properly. The button must be pressed in order for the drawbridge to open. The initial ball that hits the cup holding the second ball must have enough force/speed to allow for the cup to be knocked over. The velocity must be calculated in order to test this and properly build the machine.	

	Marble: Research, Estimate: We do not have access to a scale so we will estimate the weight of the marble based on the packaging as well as average weights of marbles.	
Initial Data	We have not yet collected quantitative data besides measurements from our machines as they are not all completely built yet. We have, however, tested some of our machines and we plan to test more in the coming days. We will outline the data that can and will be collected from our machines: **Catapult:** We will collect data for how far the ball is launched from the catapult. We will also collect data for how high the object that starts the catapult is launched from. **Loop:** We will collect data for how fast the ball is moving after we collect the marbles for testing. **Drawbridge:** We will collect data for the height that the ball reaches in order to hit the container and release the ball in the cup. We will also collect data for how fast each ball is moving, as well as how quickly the drawbridge opens. **Ferris Wheel:** We will collect data for how fast the ferris wheel is moving as well as the centripetal acceleration of the wheel. **Pulley:** We will collect data for how fast the pulley is moving, and how long it takes for the motor to begin moving once the button is pressed. **Merry-Go-Round:** We will collect data for how much speed/force is needed in order to have the merry-go-round spin. Sparkfun Robot Car: We will collect data for how fast the car needs to move in order to move the Merry-Go-Round.	
Theories and data analysis info	We will be using all of the research we completed before that is located above in the write-up for Final Project Milestone Week Two. We will outline the specific concepts we are using along with the equations here: **Catapult:** **Range of Projectile:** $v^2 sin(2\theta)/g$ (θ= initial angle of projectile with horizontal) ∑Torque= I$\boldsymbol{\alpha}$ $\omega = \boldsymbol{\alpha}(initial) + 2\boldsymbol{\alpha}(\theta)$ ($\boldsymbol{\alpha}$ initial will be zero) (θ = change in angle of ruler w/ horizontal) v=rω Torque =rfsin(θ)	

Assuming the torques are applied constantly throughout the motion, the sum of the torques is the sum of the integrals of the individual torques applied by the marble, center of mass of the ruler (as the pivot is not at the centerpoint) and dropped mass, from the initial angle to the final angle. (so $\int$(xxxxxxx)d$\boldsymbol{\theta}$)

The moment of inertia is assumed to be the moment of inertia of a rod about an axis ⅝ from one end, with an assumed mass of .012kg, and the moment of inertia of the marble (.0065kg) as a point mass - giving a Moment of Inertia of ~.004135

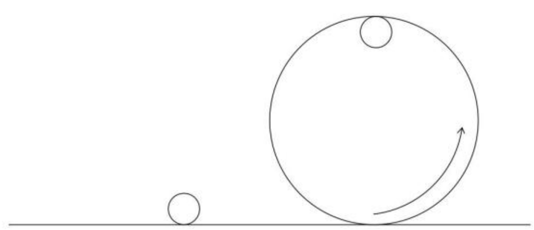
Given the mass of the object dropped, v can now be calculated.

Although the equation given for the range of a projectile is for when the projectile starts at ground level, by having the landing ramp be set at the same height as the catapult cup at launch, no additional work is needed.

While the height the object is dropped at also affects the launch velocity due to conservation of momentum, by keeping the height constant and only changing the mass of the object, we can eliminate this variable, causing the distance calculated to remain a constant factor of the actual distance travelled.

Assuming the mass of the dropped object is .1kg, the projectile travels ~4.65m (seems reasonably close to first tests with an object of estimated mass .1kg dropped from 1m)

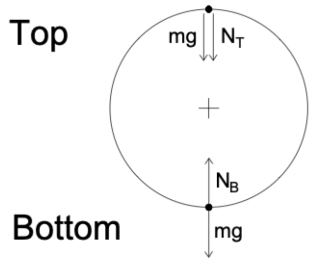
Loop:
Problem: What is the minimum height a marble needs to start at, if it is to *just* make it around the loop without falling over?



This assumes a friction on the surface, so the ball can ***roll without slipping***.

The first step is to determine the minimum speed the marble will need to just stay on the track when upside down (using centripetal force).
If we can find that minimum speed, then we can use energy conservation to figure out the height at which the marble should start to not fall over when upside down.

Free Body Diagram:



Where mg is the weight,
N_B is the normal force at the bottom of the loop,
N_T is the normal force at the top of the loop.

Forces acting on the marble:

Newton's Second Law of motion: $\sum F_{net} = m \cdot a$

$\sum F_r = mv^2/r$ because $a_c = v^2/r$
Where $\sum F_r$ is the centripetal force.
m is the mass of the marble.
v is the velocity of the marble..
r is the radius of the loop.
a_c is the centripetal acceleration.

Top of the Loop:

$$N_T + mg = mv^2/r$$
$$N_T = mv^2/r - mg$$

Bottom of the loop:

$$N_B - mg = mv^2/r$$
$$N_B = mv^2/r + mg$$

Minimum velocity at the top of the loop for the marble not to fall over:
$N_T = 0$; $v_{min} = ?$

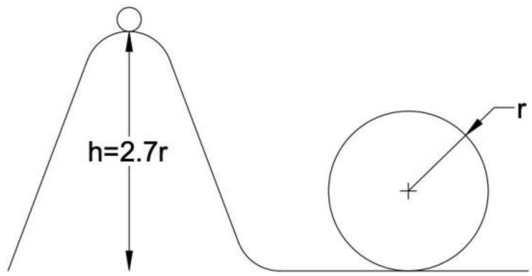
$$N_T = m{v_{min}}^2/r - mg = 0$$
$$m{v_{min}}^2/r = mg$$
$$v_{min} = \sqrt{gr} \simeq \sqrt{9.81r}$$

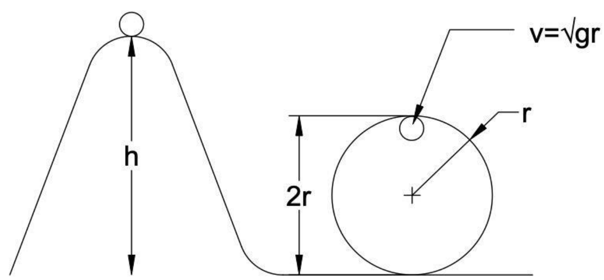
Minimum height of the hill for the marble to make it through the loop:
We ignore friction.

We know that:
E_g is the potential energy at the top of the hill and $E_g = mg\boldsymbol{h}_{min}$
$E_{g'}$ is the potential energy at the top of the loop and $E_{g'} = mg2r$
$E_{rotational}$ is the rotational energy and $E_{rotational} = 1/2Iw^2$

where $I = 2mr^2/5$ and $w = v/r$

$$E_g = E_{g'} + E_k + E_{rotational}$$
$$mg\boldsymbol{h}_{min} = mg2r + 1/2mv_{min}{}^2 + 1/2Iw^2$$
$$mg\boldsymbol{h}_{min} = mg2r + 1/2mv_{min}{}^2 + 1/2(2mr^2/5)(v_{min}{}^2/r^2)$$
$$g\boldsymbol{h}_{min} = g2r + 1/2gr + 1/5gr$$
$$\boldsymbol{h}_{min} = 2r + ((5+2)/10)$$
$$\boldsymbol{h}_{min} = 2.7r$$





Ferris Wheel:

- Centripetal Acceleration
  - https://courses.lumenlearning.com/physics/chapter/6-2-centripetal-acceleration/
  - $a_{centripetal} = \frac{v^2}{r}$
  - $a_{centripetal} = w^2 * r$

- Based on Final Design, the radius is 6.50 inches. The velocity is in the process of being calculated as the motor speed is still being adjusted. Once the speed is found, the centripetal acceleration of the Ferris Wheel can be calculated.

Merry-Go-Round:

- Centripetal Acceleration
  - https://courses.lumenlearning.com/physics/chapter/6-2-centripetal-acceleration/
  - $a_{centripetal} = \frac{v^2}{r}$
  - $a_{centripetal} = w^2 * r$

	• Based on the Final Design, the radius will be 7.50 inches. The velocity is dependent on the speed of rotation caused by the Sparkfun Robot Car. An average will be calculated once the car is programmed and moving. Once the velocity is found, the centripetal acceleration of the merry-go-round can be calculated.	
Final Report Writing Plan	We will each complete the following tasks: **Everyone:** Table of Contents, Design Approach and Methods for individual machines, Graphical Model, Design Details of our individual machines, Results/Outcome for each machine, Bibliography Individually, we will complete the following: **Trevor:** Results/Outcome (of entire Rube Goldberg assembly), Future Work **Celine:** Title Page, Design Details (Explanation of how the entire Rube Goldberg Machine Works), Analysis **AJ:** Design Approach & Methods (of how we came up with our design), **Jenna:** Abstract, Introduction/Background	
Member contribution (by each member)	Each week we completed the Final Project Milestone Document and the Final Project Milestone Update Presentation together. We held team meetings to which we all attended and participated. During these meetings, we worked on the Milestones and progressed our project. We all worked on the program for the Sparkfun Robot Car. Additionally, we all worked on the sections outlined above in the "everything" category of the final report plan. Individually, we completed the following tasks: **Trevor:** Completed scientific research, 2D and 3D drawings, prototyping, program, and building for the Pulley and Drawbridge. Completed the SolidWorks Drawing and 3D printing of the Pulley for Graphic Test 2. Will complete the sections of the final report outlined above. **Celine:** Completed scientific research, 2D and 3D drawings, prototyping, and building for the loop and the Sparkfun Robot Car. Also, started the initial 2D and 3D drawings for the Wedge/Box. Completed the SolidWorks Drawing of the Robot Car and Loop for Graphic Test 2. Will complete the sections of the final report outlined above. **AJ:** Completed scientific research, 2D and 3D drawings, prototyping, building for the Catapult and Wedge/Box. Completed the SolidWorks Drawing of the Catapult for Graphic Test 2. Will complete the sections of the final report outlined above. **Jenna:** Completed scientific research, 2D and 3D drawings, prototyping, building for the Ferris Wheel and Merry-Go-Round. Also, completed the program for the Ferris Wheel motor. Completed the SolidWorks Drawing of the Ferris Wheel for Graphic Test 2. Will complete the sections of the final report outlined above.	

Total		