Summer 2016

JME 4110 Weight Powered LED

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Joint Engineering Program

University of Missouri–St. Louis ▪ Washington University in St. Louis

ELEVATE YOUR FUTURE.
ELEVATE ST. LOUIS.

This project demonstrates a way to get "free energy" – the only power source lighting an LED being a weight slowly falling to the ground. The design is relatively inexpensive and has no waste. It has numerous applications, especially in Third World countries that may not have access to any electricity, much less "clean" power.

JME 4110 Design Report Title

Weight Powered LED

By Herman, Rayseldi & Seidel

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1 INTRODUCTION

1.1 VALUE PROPOSITION

Our product is a gravity powered electric generator capable of powering a small LED that provides an eco-friendly and powerful way to provide light, aimed at people who live off the power grid and are concerned with the health risks and cost associated with the current standard, halogen lamps. Our product is unlike any gas generator that requires fuel to make electricity, or solar and wind powered generators that can only store energy under the correct conditions. Our product utilizes a back driven DC motor and gear train to attain a workable weight required to power the LED without compromising the efficiency or efficacy.

1.2 LIST OF TEAM MEMBERS

Group C: Emma Seidel, Samuel Rayseldi, Austin Herman

2 BACKGROUND INFORMATION STUDY

2.1 DESIGN BREIF

The purpose of this project is to create a design that produces enough energy to light an LED from a weight falling and turning a gear train that back drives a small DC motor. It should be relatively inexpensive and provide a workable amount of light. The design should be easy to operate by people of any age and physical ability.

2.2 SUMMARY OF RELEVANT BACKGROUND INFORMATION

Existing patent 1 – Pendulum system for producing light and power

www.google.com/patents/US20040196741

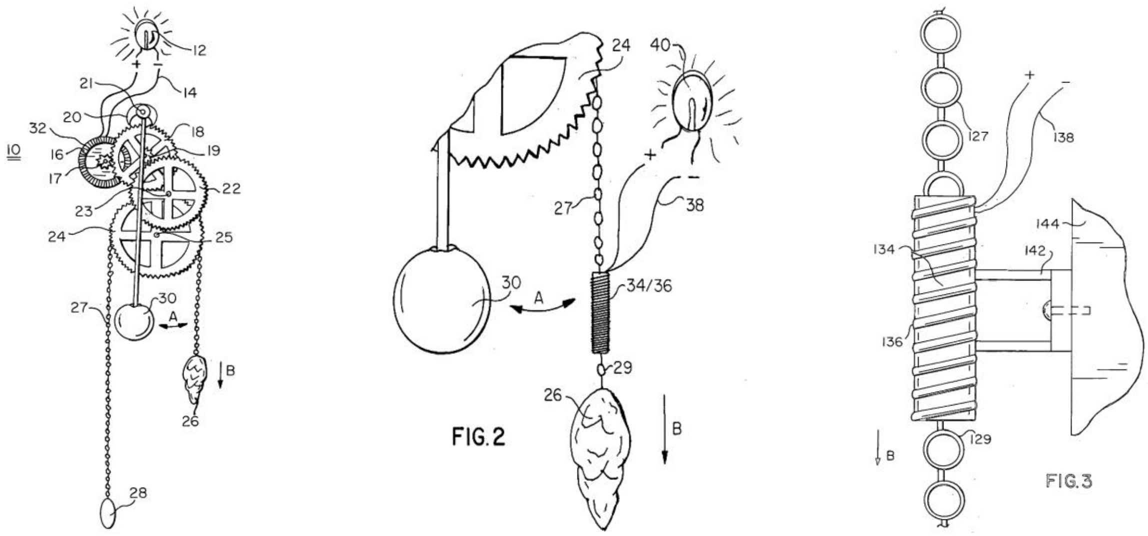


Figure 1: Existing design patent 1

Existing patent 2 – Gravity-powered electrical energy generators

http://www.google.com/patents/US20120212948

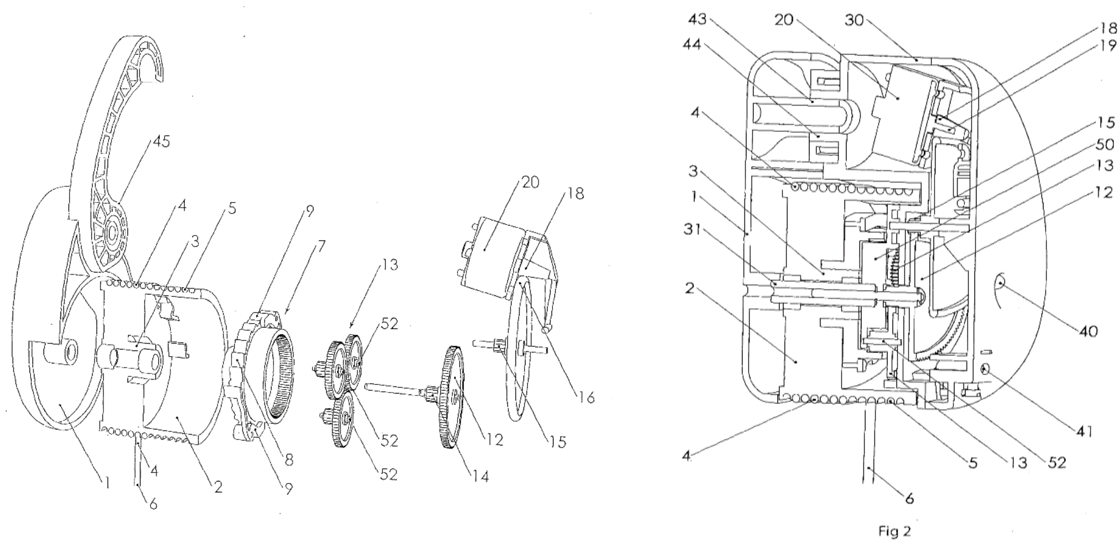


Figure 2: Existing design patent 2

3 CONCEPT DESIGN AND SPECIFICATION

3.1 USER NEEDS, METRICS, AND QUANTIFIED NEEDS EQUATIONS.

3.1.1 Record of the user needs interview

Table 1: User needs interview

<table>
<tr><td colspan="4">Project/Product Name: Weight Powered LED

Customer: Samuel Rayseldi
Emma Seidel
Austin Herman

Interviewer(s): Mark Jakiela
Date: 6/10/16

Address: Washington University
Willing to do follow up? Yes

Currently uses: Kerosene Lantern

Type of user: Individuals without access to other energy sources</td></tr>
<tr><td>Question</td><td>Customer Statement</td><td>Interpreted Need</td><td>Importance</td></tr>
<tr><td>How much of a space can you set aside for the light?</td><td>Small but good table lamp.

Someone should be able to read a newspaper laid out flat.</td><td>The WPL has a small footprint.

The WPL produces bright light.</td><td>4

4</td></tr>
<tr><td>Where in the house do you plan to place the gravity light?</td><td>Dining room table

Favorite reading chair</td><td>The weight can be physically separated from the WPL.

The WPL can be placed high enough to shine into a chair.</td><td>4

4</td></tr>
<tr><td>How tall of a room will this be used in?</td><td>Might be as low as 7 feet!</td><td>The WPL is useful at lower heights</td><td>5</td></tr>
<tr><td>What tasks are you planning on doing while using the light?</td><td>Primarily reading and writing on paper.

Secondarily cooking and cleaning food/dishes.</td><td>The WPL produces bright light.

The WPL stays on for a long time.</td><td>5

3</td></tr>
<tr><td>How high can you lift a weight?</td><td>Straight over my head with fully extended arms = 7 feet.</td><td>The WPL is useful at lower heights.</td><td>5</td></tr>
<tr><td>How heavy of a weight can you lift over your head?</td><td>Would be best to keep it 5 lbs and under.</td><td>The WPL is useful with a small weight.</td><td>5</td></tr>
<tr><td>What's the acceptable range for how long would you like the</td><td>I am guessing at least 15 minutes. Longer the better.</td><td>The WPL stays on for a long time.</td><td>4</td></tr>
</table>

light to last before it needs to be reset?			
What's the acceptable range for how long the time taken to reset the light should be?	Just seconds. Comparable to flushing a toilet.	The WPL resets quickly.	4
How long of a delay can there be between setting the weight and the light turning on?	Should be pretty immediate. Should not have the sense that you are “taking a break”.	The LED turns on within seconds of setting the weight.	5
Does the light need to be able to be used outside?	Basically NO, although in a lot of places the inside/outside distinction is a bit fuzzy.	The WPL has some weatherproofing.	4
What kind of climate will this be used in?	Almost any, so long as it is “indoor” use.	The WPL has some weatherproofing.	4
Does the light need to be portable?	Others will disagree, but I see it more like furniture: you set it up in that spot and use it in that spot. Future versions could be portable.	The WPL is portable.	1
What is an ideal lifespan for the product?	At least two human lives.	The WPL is easily repairable.	5
What is your ideal price range?	<= $2 when made in quantity. This will encourage foundations to fund mass production.	The WPL is inexpensive.	5
How important is it to have variability in brightness?	At this point is secondary. Would be nice, but not a must.	The WPL has multiple brightness settings.	2
How important is it to have more than one light run off of the same machine?	At this point is secondary. Would be nice, but not a must.	The WPL can run multiple lights simultaneously.	2
How important is it for the light to be mass producible?	Critically important. Mass producible with low tech means and material, AND eco-friendly. No money in this for you – just fame.	The WPL can be mass produced. The WPL is “green”.	5 4

How important do you think the ability to charge a phone with the light is?	I am guessing that this is a completely different power profile than a reading light (i.e. more power), but this would certainly be the next use.	The WPL can charge a phone.	2
How important do you think storing any excess energy is?	Personally, I think this is an unnecessary complexity. Again, maybe in the 3rd version.	The WPL stores excess energy.	2
How important is it that you can turn the light on or off as needed?	I guess a strong secondary importance. It will go out in a matter of minutes anyway.	The WPL can be turned off as needed.	1
How important is it that kids should be able to use the light by themselves?	Very important. You want to show that this device is allowing them to learn to read. Big Win!	The WPL is operable by people of all ages.	5

Table 2: Interpreted needs and importance

Need number	Need	Importance
1	WPL produces bright light	4
2	WPL is useful with a small weight	5
3	WPL stays on for a long time	4
4	WPL is useful at lower heights	5
5	WPL resets quickly	4
6	WPL stores excess energy	2
7	WPL is operable by people of all ages	5
8	WPL is portable	1
9	WPL has some weatherproofing	4
10	WPL is easily repairable	5
11	WPL is inexpensive	5
12	WPL can be mass produced	5
13	WPL can charge a phone	2
14	WPL is "green"	4
15	WPL can be placed high enough to shine into a chair	4
16	WPL has a small footprint	4
17	Weight can be physically separated from the WPL	4
18	LED turns on within seconds of setting the weight	5
19	WPL has multiple brightness settings	2
20	WPL can run multiple lights simultaneously	2
21	WPL can be turned off as needed	1

3.1.2 List of identified metrics

Table 3: Metrics, associated needs and values

Metric Number	Associated Needs	Metric	Units	Worst value	Best value
1	2, 5, 7, 8	Weight	kg	20	2
2	2, 3, 4, 7, 8, 15, 18	Height	m	3	0.3
3	8, 16	Area of base	m^2	1	0.1
4	1, 3, 6, 11, 19	Brightness	Lumens	20	500
5	1, 6, 13, 14, 18, 20	Produced power	W	0.3	3
6	1, 6, 13, 14, 18, 20	Produced voltage	V	1.7	3.4
7	9, 10	Expected lifetime	years	0.5	100
8	3, 6, 19	Light duration	minutes	5	60
9	5	Reset time	seconds	90	10
10	11, 12	Cost	$	50	0.5
11	10	Number of removable parts	%	0	100
12	11, 14	Made with recycled material	%	0	100
13	6	Can store energy	binary	0	1
14	7	Child safe	binary	0	1
15	9	Water resistant	binary	0	1
16	8	Portable	binary	0	1
17	13	Can charge phone	binary	0	1
18	12	Mass producible	binary	0	1
19	17	Weight can be physically separated from WPL	binary	0	1
20	19	Number of brightness settings	integer	1	3
21	21	Has off switch	binary	0	1

3.1.3 Table of quantified needs equations

Table 4: Happiness Equations

Design 1: Weight Powered LED		Metric																							
		Weight	Height	Area of base	Brightness	Produced power	Produced voltage	Expected lifetime	Light duration	Reset time	Cost	Number of removable parts	Made with recycled material	Can store energy	Child safe	Water resistant	Portable	Can charge phone	Mass producible	Weight can be separated from WPL	Number of brightness settings	Has off switch	Need Happiness	Importance Weight	Total Happiness Value
#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
1	WPL produces bright light				1																		0.042	0.05	0.002
2	WPL is useful with a small weight	1																					0.444	0.06	0.029
3	WPL stays on for a long time								1														0.364	0.05	0.019
4	WPL is useful at lower heights		1																				0.48	0.06	0.031
5	WPL resets quickly		0.2							0.8													0.841	0.05	0.044
6	WPL stores excess energy													1									1	0.03	0.026
7	WPL is operable by people of all ages	0.2	0.2												0.6								0.785	0.06	0.051
8	WPL is portable	0.2		0.1													0.7						0.889	0.01	0.012
9	WPL has some weatherproofing															1							1	0.05	0.052
10	WPL is easily repairable							0.2				0.5	0.3										0.509	0.06	0.033
11	WPL is inexpensive										0.9		0.1										0.799	0.06	0.052
12	WPL can be mass produced											0.1							0.9				0.98	0.06	0.064
13	WPL can charge a phone																	1					0	0.03	0
14	WPL is "green"					0.2	0.2						0.6										0.23	0.05	0.012
15	WPL can be placed high enough to shine into a chair		1																				0.48	0.05	0.025
16	WPL has a small footprint			1																			1	0.05	0.052
17	Weight can be physically separated from the WPL																			1			0	0.05	0
18	LED turns on within seconds of setting the weight									1													0.931	0.06	0.06
19	WPL has multiple brightness settings																				1		0	0.03	0
20	WPL can run multiple lights simultaneously				0.1	0.4	0.5																0.122	0.03	0.003
21	WPL can be turned off as needed																					1	0	0.01	0
Units		kg	m	m^2	m/m^	w	V	yr	min	s	$	%	%	binary	binary	binary	binary	binary	binary	binary	intege	binary	Total Happiness		0.57
Best Value		2	0.5	0.1	500	3	3.4	100	60	10	0.5	100	100	1	1	1	1	1	1	1	3	1			
Worst Value		20	3	1	20	0.3	1.7	0.5	5	300	100	0	0	0	0	0	0	0	0	0	1	0			
Actual Value		12	1.8	0.1	40	0.5	2	10	25	30	15	80	30	1	1	1	1	0	1	0	1	0			
Normalized Metric Happiness		0.44	0.48	1	0.04	0.07	0.18	0.1	0.36	0.93	0.85	0.8	0.3	1	1	1	1	0	1	0	0	0			

3.2 FOUR (4) CONCEPT DRAWINGS

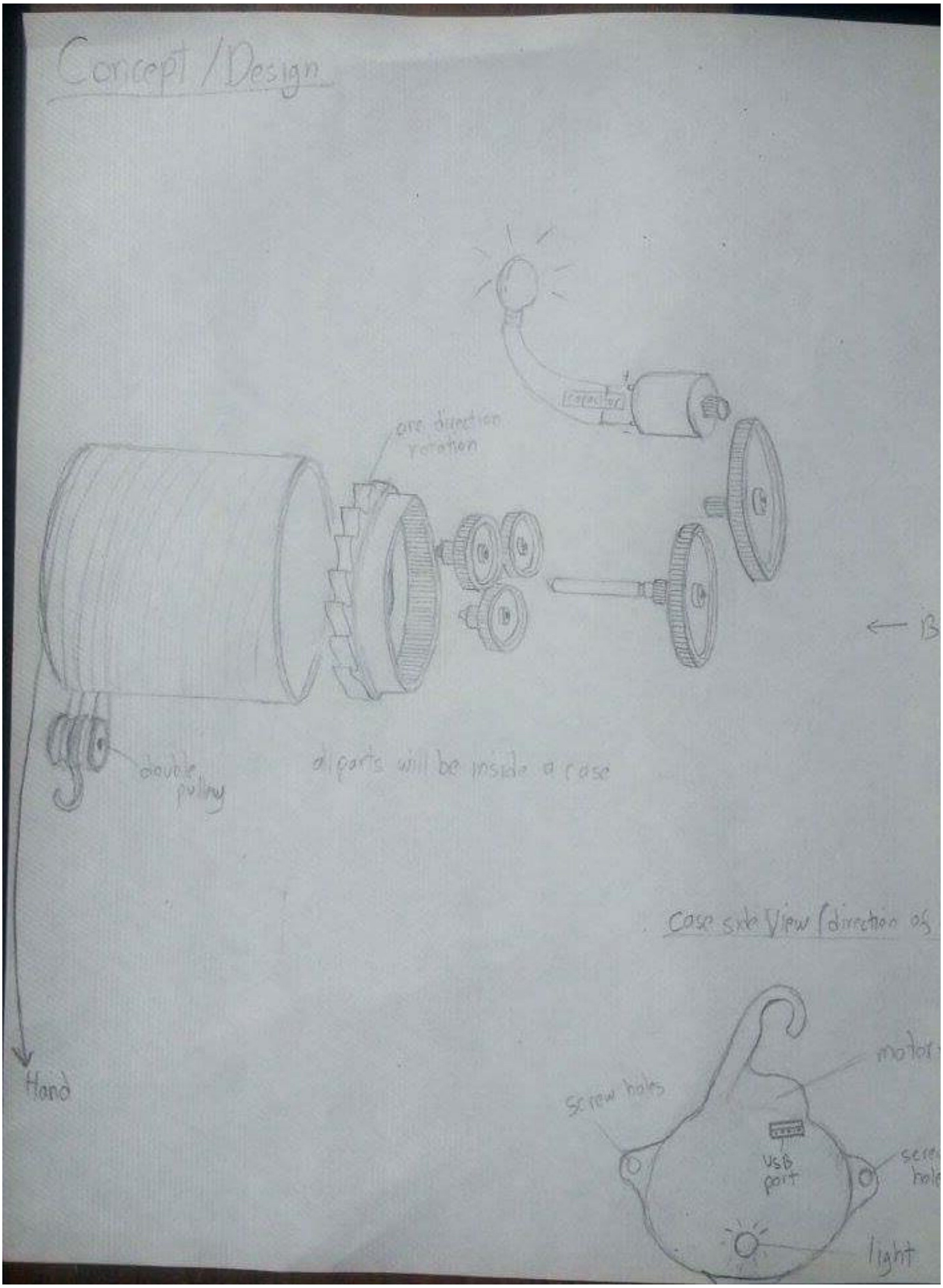


Figure 3: Concept drawing 1

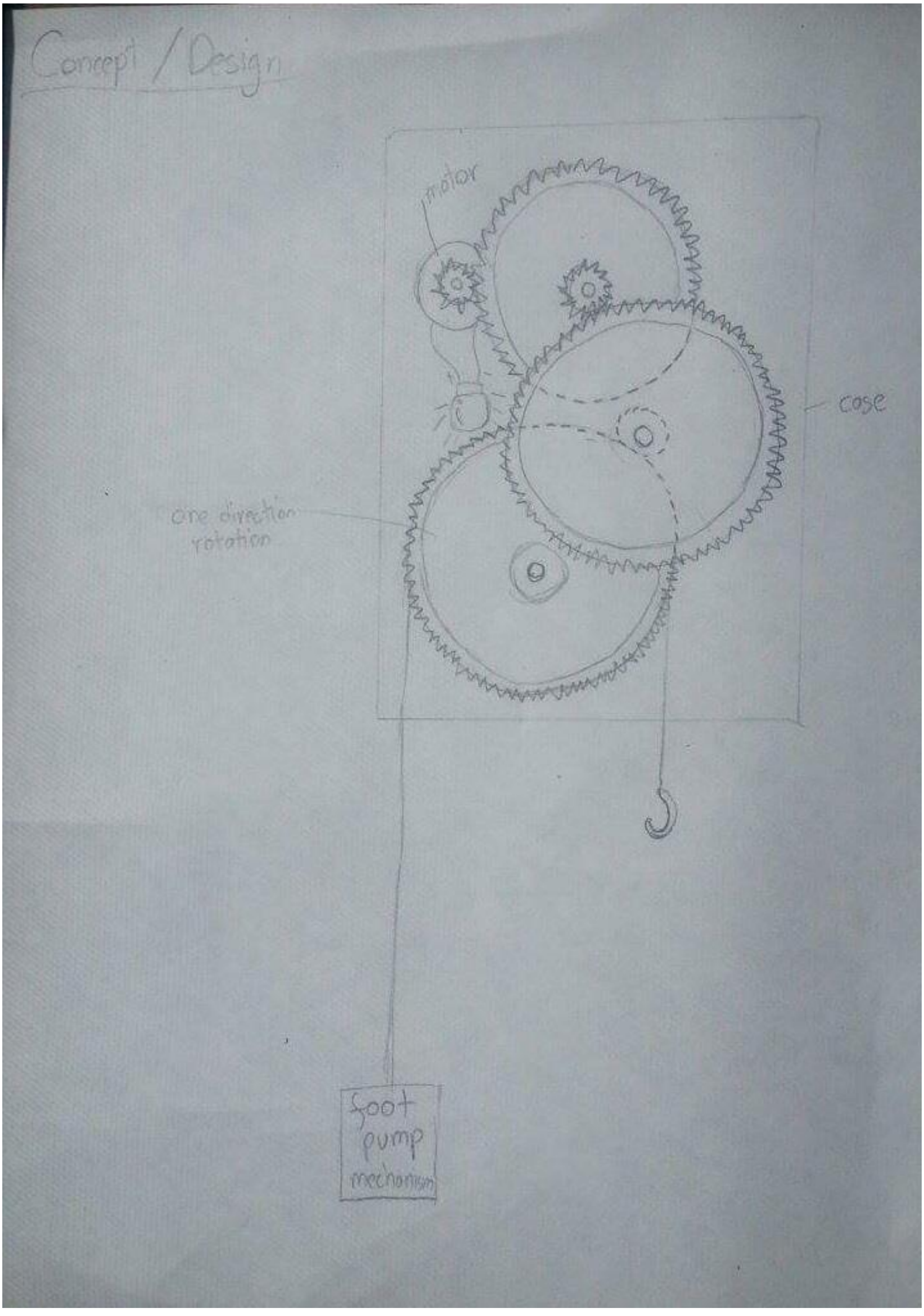


Figure 4: Concept drawing 2

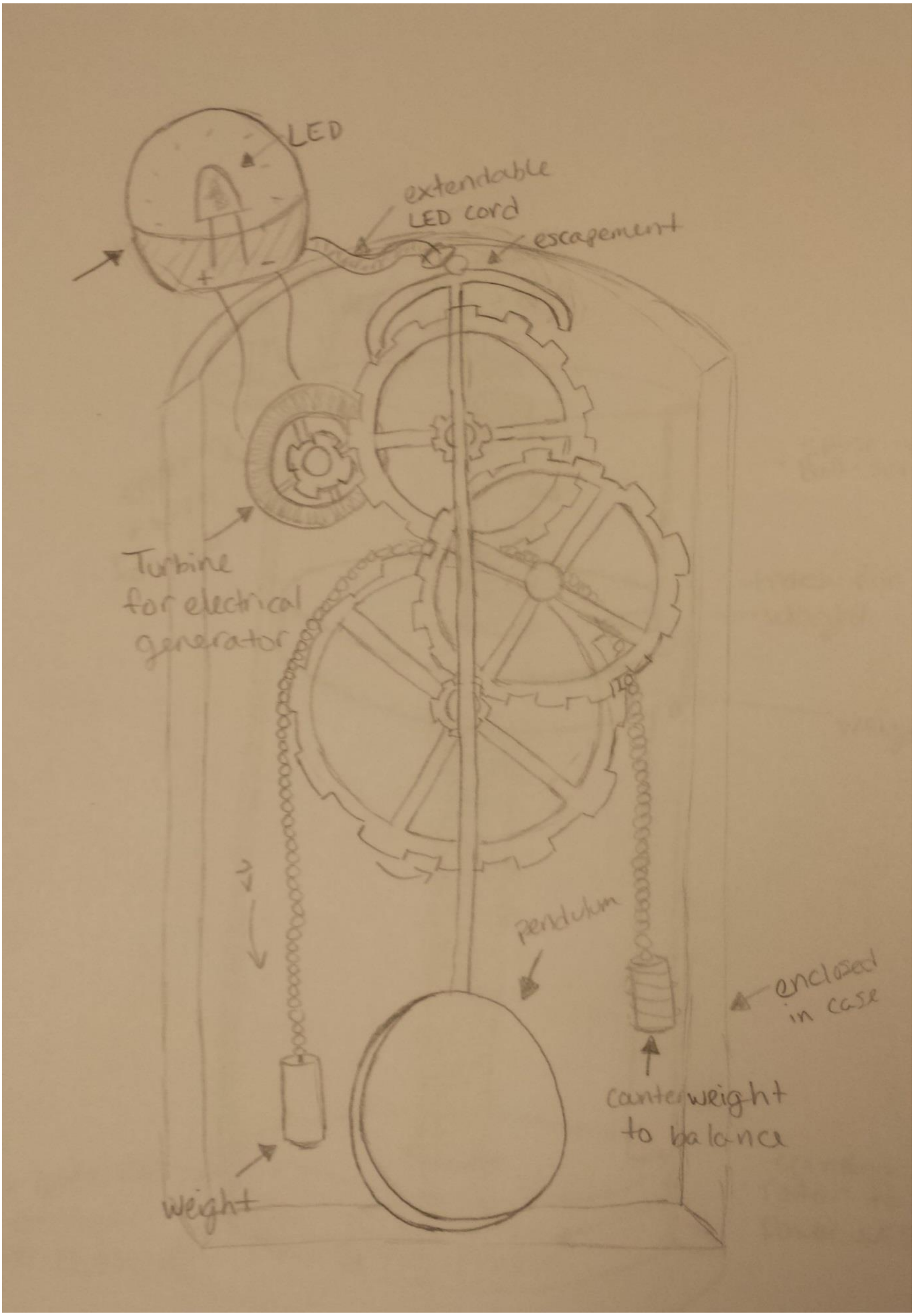


Figure 5: Concept drawing 3

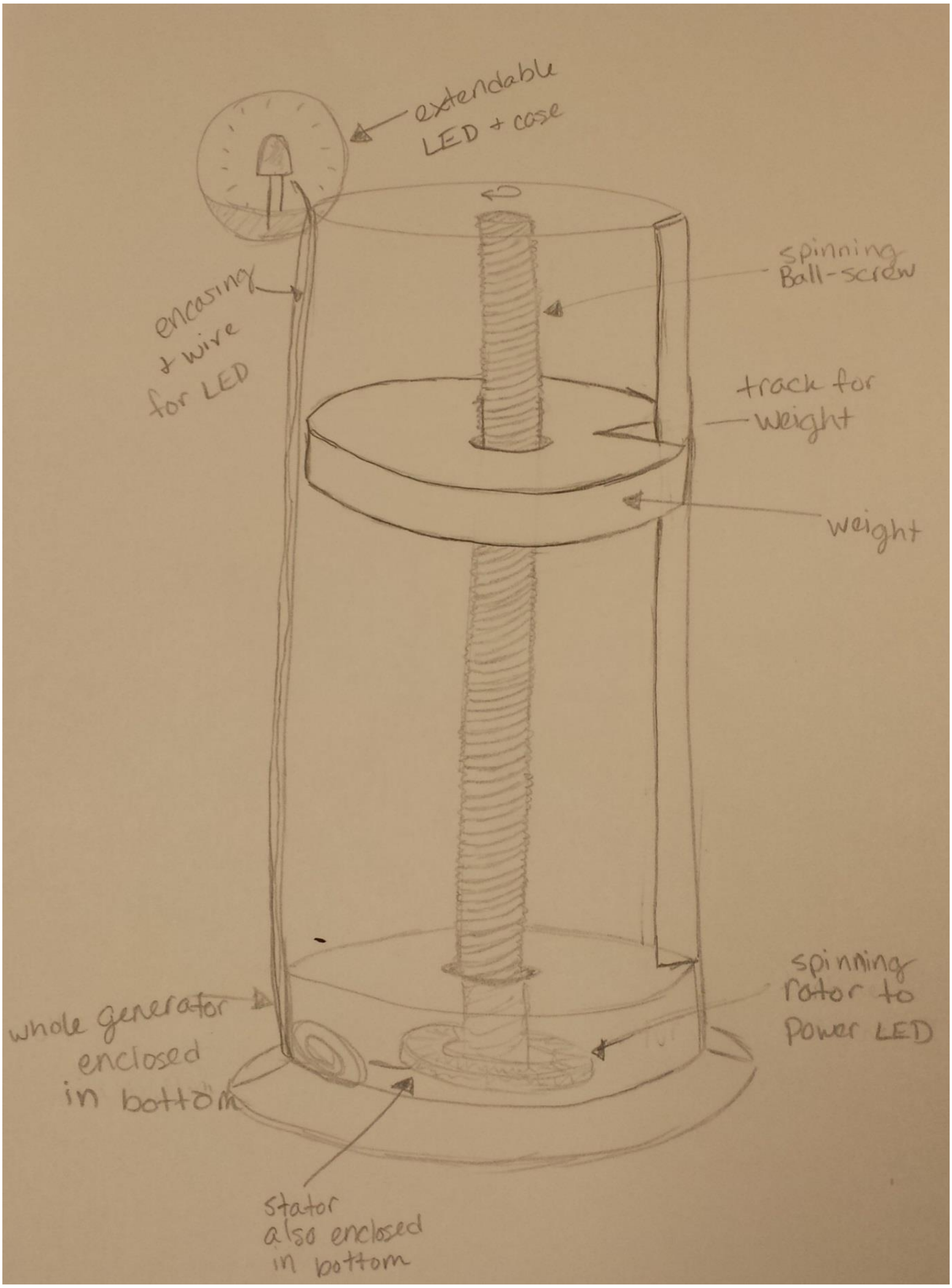


Figure 6: Concept drawing 4

3.3 A CONCEPT SELECTION PROCESS.

3.3.1 Concept scoring

Table 5: Concept screening

Design 1: Multiple Pulley System		Metric																							
		Weight	Height	Area of base	Brightness	Produced power	Produced voltage	Expected lifetime	Light duration	Reset time	Cost	Number of removable parts	Made with recycled material	Can store energy	Child safe	Water resistant	Portable	Can charge phone	Mass producible	Weight can be separated from WPL	Number of brightness settings	Has off switch	Need Happiness	Importance Weight (all entries should add up to 1)	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21			
1	WPL produces bright light				1																		0.0417	0.05	0.0022
2	WPL is useful with a small weight	1																					0.4444	0.06	0.0289
3	WPL stays on for a long time								1														0.3636	0.05	0.0189
4	WPL is useful at lower heights		1																				0.48	0.06	0.0312
5	WPL resets quickly		0.2							0.8													0.8408	0.05	0.0437
6	WPL stores excess energy													1									1	0.03	0.026
7	WPL is operable by people of all ages	0.2	0.2												0.6								0.7849	0.06	0.051
8	WPL is portable	0.2		0.1													0.7						0.8889	0.01	0.0115
9	WPL has some weatherproofing															1							1	0.05	0.0519
10	WPL is easily repairable							0.2				0.5	0.3										0.5091	0.06	0.0331
11	WPL is inexpensive										0.9		0.1										0.7988	0.06	0.0519
12	WPL can be mass produced											0.1							0.9				0.98	0.06	0.0636
13	WPL can charge a phone																	1					0	0.03	0
14	WPL is "green"					0.2	0.2						0.6										0.2301	0.05	0.012
15	WPL can be placed high enough to shine into a chair		1																				0.48	0.05	0.0249
16	WPL has a small footprint			1																			1	0.05	0.0519
17	Weight can be physically separated from the WPL																			1			0	0.05	0
18	LED turns on within seconds of setting the weight									1													0.931	0.06	0.0605
19	WPL has multiple brightness settings																				1		0	0.03	0
20	WPL can run multiple lights simultaneously				0.1	0.4	0.5																0.122	0.03	0.0032
21	WPL can be turned off as needed																					1	0	0.01	0
Units		kg	m	m^2	lm/m^2	w	V	yr	min	s	$	%	%	binary	binary	binary	binary	binary	binary	binary	integer	binary			
Best Value		2	0.5	0.1	500	3	3.4	100	60	10	0.5	100	100	1	1	1	1	1	1	1	3	1			
Worst Value		20	3	1	20	0.3	1.7	0.5	5	300	100	0	0	0	0	0	0	0	0	0	1	0			
1. Pulley system	Actual Value	12	1.8	0.1	40	0.5	2	10	25	30	15	80	30	1	1	1	1	0	1	0	1	0	Total Happiness	0.566	
	Normalized Metric Happiness	0.4444	0.48	1	0.0417	0.0741	0.1765	0.0955	0.3636	0.931	0.8543	0.8	0.3	1	1	1	1	0	1	0	0	0			
2. Foot pump system	Actual Value	10	2	0.75	40	0.5	2	10	20	15	12	60	50	1	1	1	0	0	1	0	1	0	Total Happiness	0.523	
	Normalized Metric Happiness	0.5556	0.4	0.2778	0.0417	0.0741	0.1765	0.0955	0.2727	0.9828	0.8844	0.6	0.5	1	1	1	0	0	1	0	0	0			
3. Pendulum system	Actual Value	5	1	0.1	30	0.4	2	100	30	60	20	25	25	1	1	1	1	0	1	0	1	0	Total Happiness	0.619	
	Normalized Metric Happiness	0.8333	0.8	1	0.0208	0.037	0.1765	1	0.4545	0.8276	0.804	0.25	0.25	1	1	1	1	0	1	0	0	0			
4. Ball screw system	Actual Value	20	1.5	0.1	75	3	3.4	100	30	300	100	10	20	0	1	1	1	0	1	0	1	0	Total Happiness	0.398	
	Normalized Metric Happiness	0	0.6	1	0.1146	1	1	1	0.4545	0	0	0.1	0.2	0	1	1	1	0	1	0	0	0			

3.3.2 Preliminary analysis of each concept's physical feasibility

Design 1 – Multiple Pulley System
This is the most physically straightforward of the designs. There are two physical elements that may cause difficulties. The first is the planetary gear system. This will be more difficult to set up initially but it will provide us with greater torque and power generation in a smaller package. The second is finding a supplier for the ratcheted gear in the correct size if we are to mass produce this for as inexpensively as possible.

Design 2 – Foot Pump System
There are two sections to this design: the foot pump mechanism and the actual LED system itself. For the main design, our largest mechanical hurdle will be to find gears that mesh together perfectly with such tolerances that they are replaceable but also for as inexpensively as possible. For our system as a whole, as was pointed out during our last conference we essentially have two different projects without much time in this summer session. Creating one will be taxing enough but designing and manufacturing both the foot mechanism and the LED system might be too much for this semester.

Design 3 – Pendulum System
While there are enough resources out there to design a pendulum system, there is a major question of whether the fact that this design utilizes non-continuous motion will be able to provide the same amount of power to a battery/LED system or even enough to keep it lit continuously.

Design 4 – Ball Screw System
There are two major hurdles to working on this design, especially in the time we have this semester. The first is that this is the most theoretical of the four designs. Therefore, there are a lot of things that will require experimentation and it is unclear if this will even work properly within the limits we have set for ourselves for usability, etc. The second is that we are trying to make this as inexpensively as possible and the cheapest we could find the central component to this design (the low friction ball screw) was 15 times the maximum we wanted to build the entire product for.

3.3.3 Final summary statement

WINNER: Concept 1 – Multiple Pulley System

When we started off using the happiness equations and estimating approximate metrics for the various designs, the pendulum system was the clear winner with a happiness value of 0.62. That was followed closely by the multiple pulley system at 0.57 and the foot pump system at 0.52. The ball screw system definitely came in last with a 0.40.

If we were to use these equations alone, we would almost certainly choose the pendulum system. However, there are too many unknowns about using a system with non-continuous motion. It would be an interesting project but it is not worth the risk of using the semester to build something that we do not know will actually be able to work at the end.

With or without the happiness equations it is easy to rule out the ball screw system. It is a fascinating concept and one that would certainly be fun to work with but due to the fact that there are too many unknowns that would require testing, like the pendulum system this would not be worth the risk to try and complete in the time we have remaining this semester. There is also the question of our typical user. If we are designing this system primarily for 3rd world countries, relief shelters and anywhere that electricity is generally unavailable, cost is certainly a large concern. Given the importance of that, the discrepancy in the required cost of our most integral part and our end goal cost is too great to make this a realistic design.

Between the multiple pulley system and the foot pump system, the happiness equations are not much help since all of our metrics were estimates to begin with. What really decides the question is that the hurdles we face with the pulley system will be easier to overcome than with the foot pump system. The fact that we have a shortened semester makes it imperative to focus on one design and getting it right rather than designing both a foot pump and an LED system. The issue with the planetary gear may be overcome with either changing the design to a double gear or by utilizing mass produced planetary gear systems, such as those found in electric can openers.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

The overall design measure for this project is the cost. Since we are designing this for use in Third World countries or countries not on the power grid, we want to keep the design as inexpensive as possible. However, we do not want to sacrifice another important metric (for example, brightness) so we found a balance between the price and the output of this design. Of course, since we only ordered unit quantities of our parts, they are more expensive than if the design were to be mass produced.

3.5 REVISION OF SPECIFICATIONS AFTER CONCEPT SELECTION

After deciding on the multiple pulley system, we looked at any additional needs that may have arisen due to this selection. While there are certainly considerations that we need to take into account for this design (pulley design, frictional loss, etc.) there were not any additional overarching user needs that we needed to add to our happiness equations.

The main reason for this is that this design is one of the most basic of our four original contenders. While some of the others had additional hardware needs, non-continuous motion or relied heavily on frictionless bearings or magnetic transference of the motion to electric charge, this design is much more practical by nature. Because of that all of our original user needs cover the general needs for this design and are even more encompassing than we would have created for this specific product.

Out of all of our user needs, there are a few that stand out as being very important to measure the overall performance of our final product. However, one of these stands above the others. Given that we are designing this product for 3rd world nations, aid relief organizations and anywhere that is completely off the grid, cost is a primary concern. Therefore, our overall performance measure for this particular design is that the weight powered LED is inexpensive.

While duration of the light, the height at which it can be used, and the ability to utilize it with a small weight are all very important, none of these matters if our primary users cannot afford it to begin with. If we design a wonderful light that does everything we want it to but it is out of their budget then it will never be of use to our market base.

4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT/ASSEMBLY DRAWING

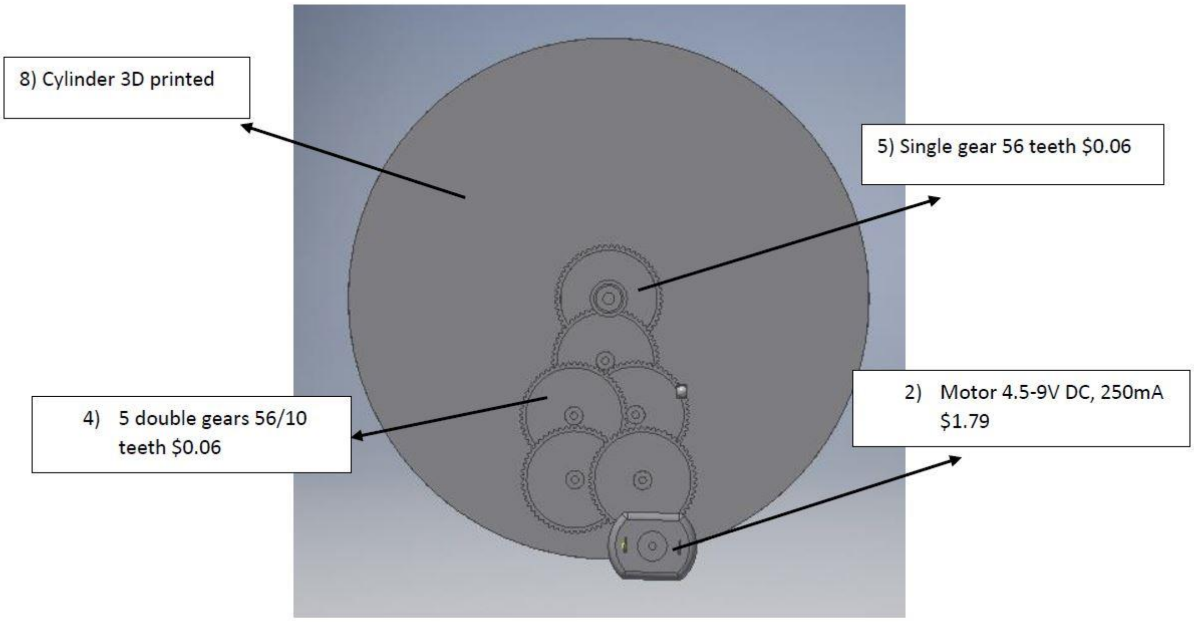


Figure 7: Initial Assembly Front View

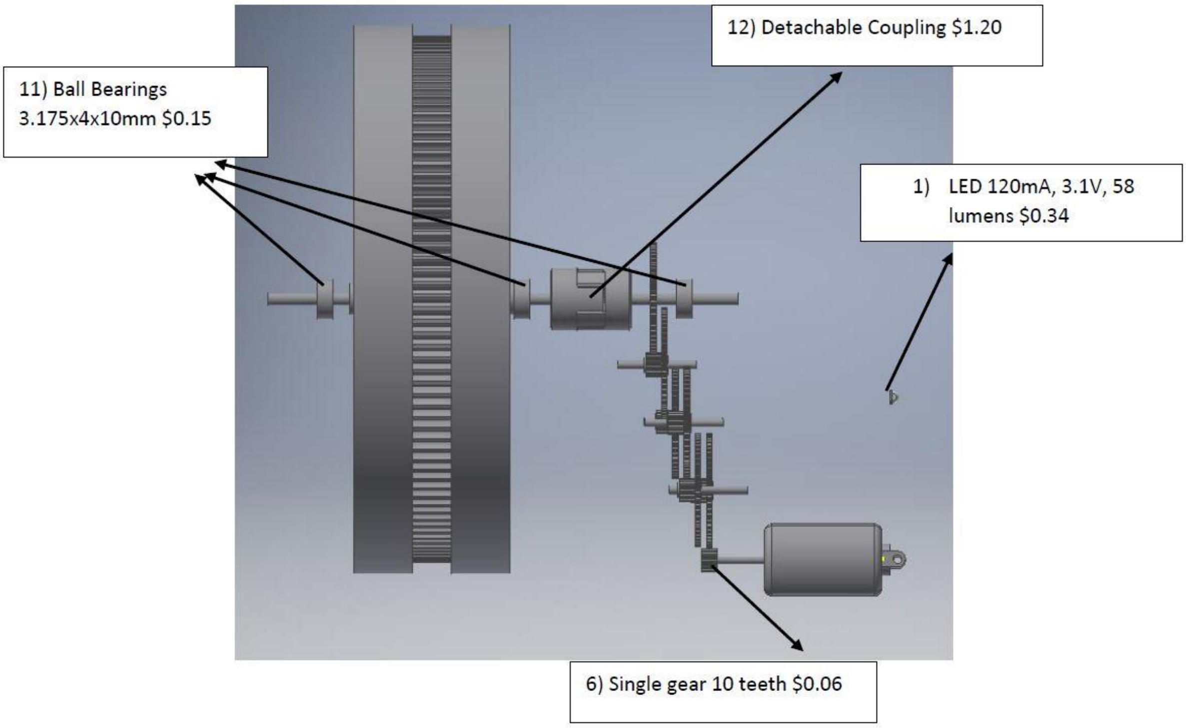


Figure 8: Initial Assembly Side View

4.2 PARTS LIST

Table 6: Initial Parts List

Local Part #	Name	Specifications	Supplier	Manufacturer Part #	Quantity	Unit Price	Total Price
1	LED	120 mA, 3.1 Vf, 58 lumens	Mouser Electronics	L128-4080CA3500001	1	$0.34	$0.34
2	Motor	4.5-9V DC, 250 mA	Adafruit	771	1	$1.79	$1.79
3	Resistor	27 ohm	Super Bright LEDs	CF1/4C220J	1	$0.14	$0.14
4	Gears	5 double gears	Amazon	Elec-A52-138	5	$0.06	$0.30
5	Gears	Single gear 56 teeth 10 teeth	Amazon	Elec-A52-138	1 1	$0.06 $0.06	$0.12
6	Gear Shaft	2mm shafts 3.175x120mm shafts	Amazon	a14031300ux0184	5 1	$0.12	$0.48
7	Cord	Timing belt	Amazon	GT2	5	$0.50	$2.50
8	Cylinder	Housing cylinder/pawl	3D Printed	N/A	1	$0.00	$0.00
9	Wire	Wire with aligator clips	Gateway Electronics	N/A	1	$0.25	$0.25
10	Casing	Casing for all components	3D Printed	N/A	1	$0.00	$0.00
11	Bearings	3.175 x 4 x 10mm ball bearings	Amazon	684ZZ	3	$0.15	$0.45
12	Detachable coupling	Lovejoy Jaw Coupling	Amazon	31163021	1	$1.20	$1.20
13	Hook	Carabiner	Manufacturer Express	EGSL018	1	$0.30	$0.30
						Total Price	$9.07

4.3 DRAFT DETAIL DRAWINGS FOR EACH MANUFACTURED PART

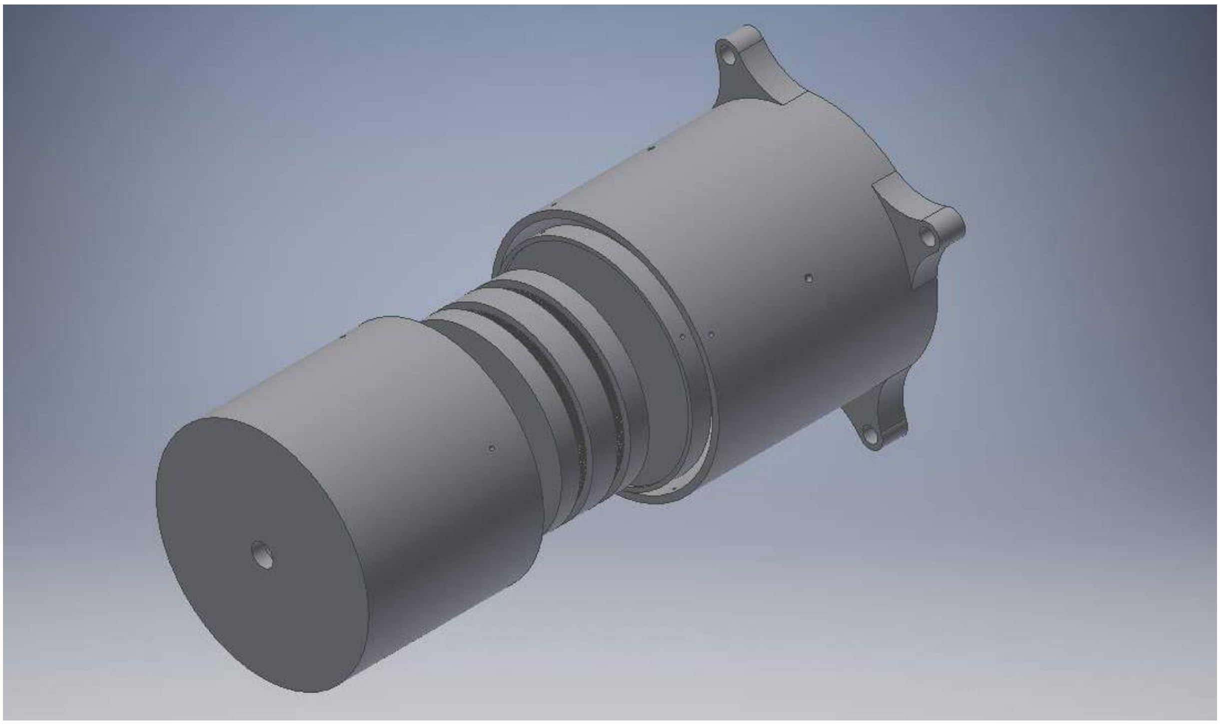


Figure 9: Initial Design Expanded View

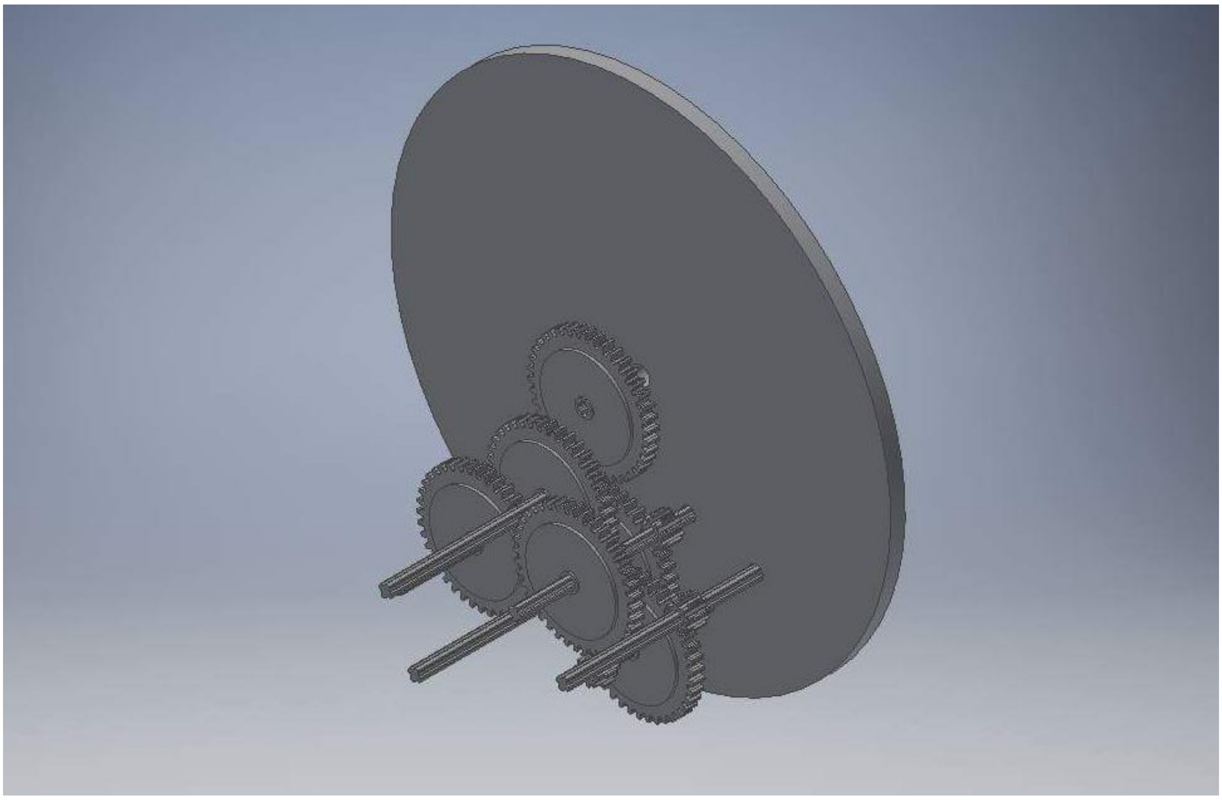


Figure 10: Initial Gear Train Drawing

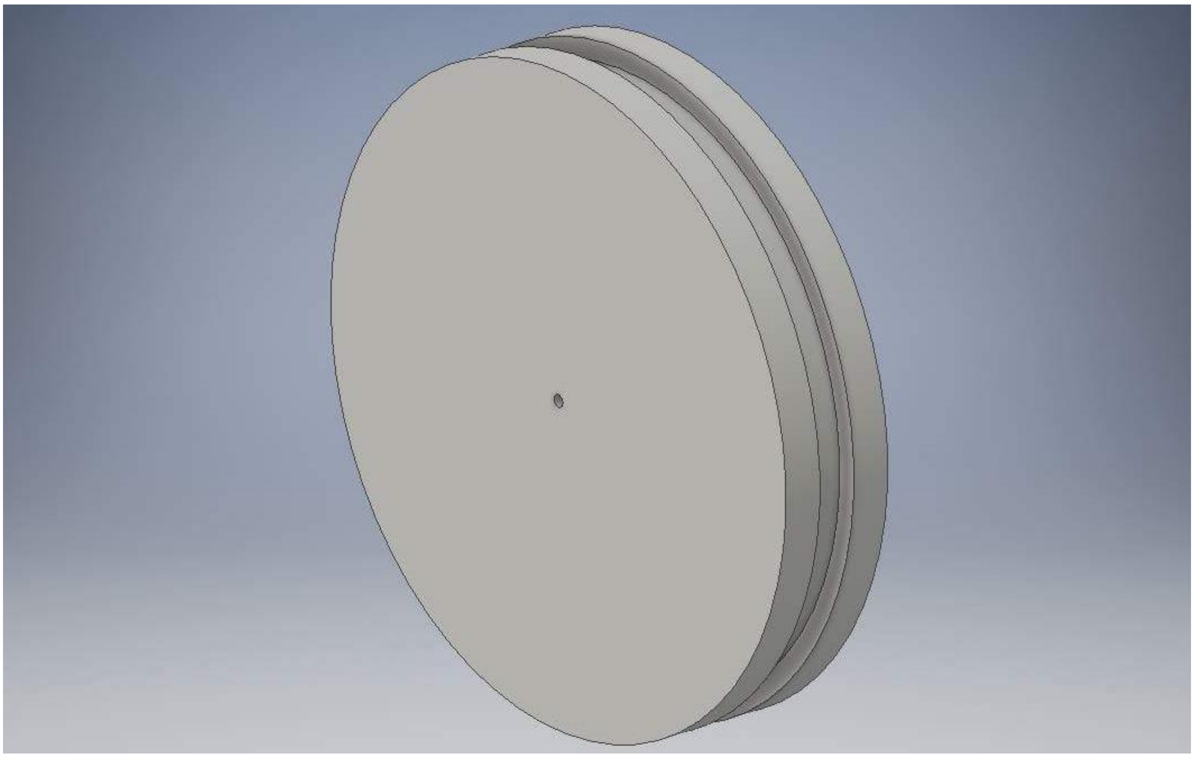


Figure 11: Initial 3D Printed Cylinder

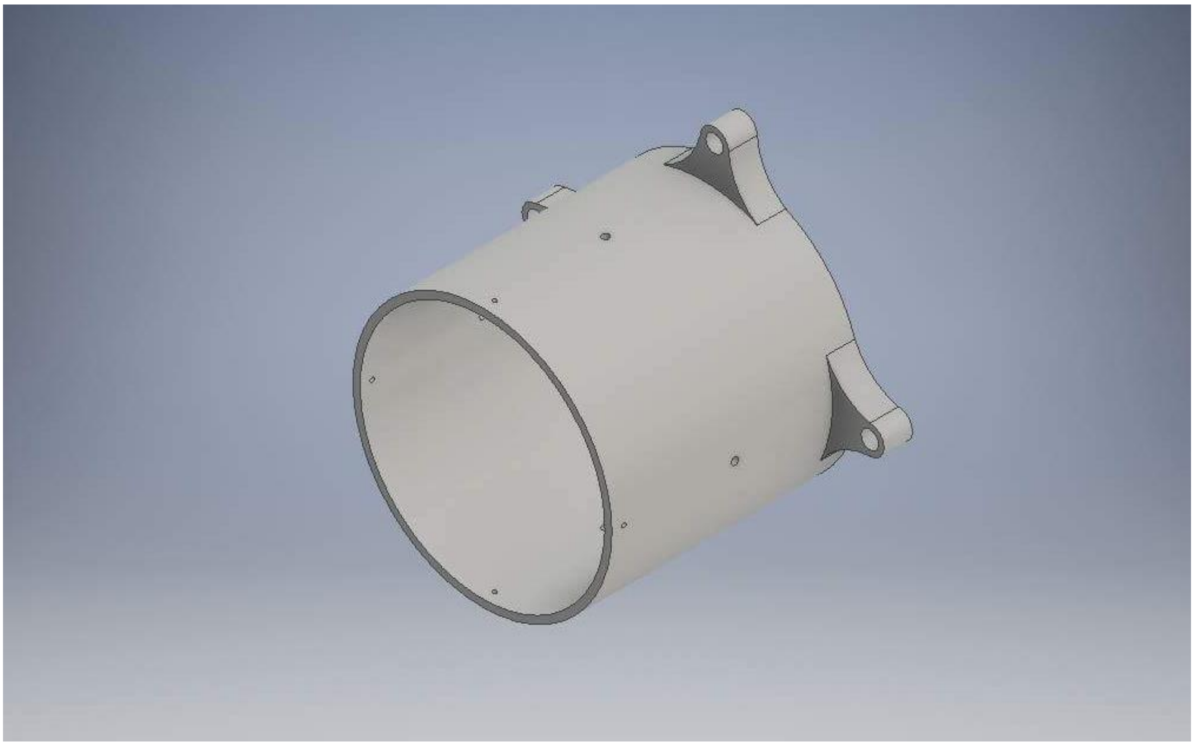


Figure 12: Initial Casing Drawing 1

Figure 13: Initial Casing Drawing 2

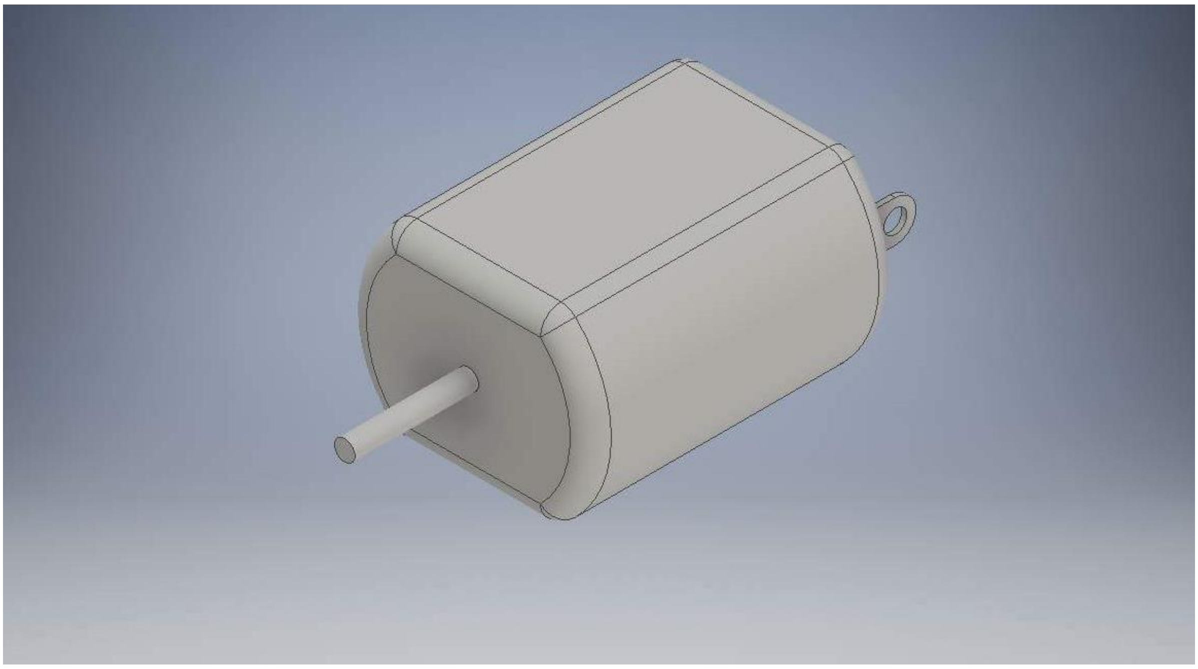


Figure 14: Initial Motor Drawing

4.4 DESCRIPTION OF THE DESIGN RATIONALE FOR THE CHOICE/SIZE/SHAPE OF EACH PART

1. Motor

We will have to do some experimentation with the motors to see which one works best for us, but we wanted a motor that would provide enough voltage and current to power the LED. We chose a toy DC motor that has the ability to be back driven and function as a generator.

2. LED

We chose a Lumiled high power LED, which produces more brightness (52 lumens) than the general 5mm LED without using more power than we can produce.

3. Resistor

The resistor is based on how much extra voltage we'll produce. If we got the maximum amount of voltage out of our motor, we'd need a 27 ohm resistor, based on the calculations below. However, chances are we'll find out when we start testing the design that we don't need the resistor and will be fine with the motor connected directly to the LED.

$$\text{Resistance} = \frac{\text{Input voltage} - \text{LED forward voltage}}{\text{LED current}} = \frac{6.0\text{V} - 3.1\text{V}}{0.12\text{A}} = 24.2\Omega,$$

$$\text{closest standard size} = 27\Omega$$

4. Gears

The gears we're using are built for use in RC cars and have a total gear ratio of approximately 1000. To determine whether they will fail or not, we used the Lewis equation. The torque of each gear decreased inversely with the gear ratio, so we calculated the torque on the first gear to see if it would fail or not, because if the first gear does not fail, the rest of them won't either.

$$\text{Torque}_{cylinder} = mass * acc * radius = 10\text{kg} * 9.81\frac{m}{s^2} * 0.0075\text{m} = 7.36\text{N} * \text{m}$$

$$\text{Torque}_{gear} = \text{Torque}_{cylinder} * \frac{r_{gear}}{r_{cylinder}} = 7.36 * \frac{60}{150} = 2.9\text{N} * \text{m}$$

$$D_p = \frac{diameter}{pitch} = \frac{60}{0.2} = 300$$

$$W_t = \frac{2T}{D_p} = 2 * \frac{2.9}{30} = 1.93$$

$$\sigma_t = \frac{W_t * P_d}{FY} = \frac{1.93 * 0.002}{0.003 * 0.5} = 2.58\ \text{N/m}^2$$

This value is many magnitudes lower than the shear strengths for most common plastics, so our gears should not shear under this torque loading.

5. Gear shaft

The shafts are 2mm in diameter to fit the gears and are made of steel so they don't shear under the load.   Each double gear will have its own shaft to rotate on.

6. Cord

The cord is originally intended as a timing belt in a 3D printer and is made of neoprene, reinforced with fiberglass. Neoprene has a tensile strength of approximately 7kg/mm^2. We're planning on lifting 10kgs and the cross sectional area of the belt at the thinnest spot is 6mm by 2mm, or 12mm^2, meaning we should be able to lift 7*12=84kg, giving us a factor of safety of 8.4.

7. Cylinder

The cylinder functions as another gear since the belt wraps around the outside. It is supported by the bearings and turns the gear inside it. The cylinder will have the highest torque applied to it. The cylinder will be 3D printed out of PLA, which has a shear modulus of 2.4 GPa.

8. Wire

We picked wire with alligator clips already attached to simplify the project a little. The wire connects the positive and negative sides of the motor to the positive and negative sides of the LED. If we use the resistor, it would connect to the positive side of the motor and another wire would be used to connect the resistor to the LED.

9. Casing

The casing is 3D printed and surrounds the inner cylinder and the contents.

10. Bearings

The bearings are used to let the cylinder rotate with little friction.

11. Detachable coupling

The detachable coupling lets us keep out shafts aligned when we slide the cylinder out during the wind up so we don't turn the gears and the motor the wrong direction. We chose Lovejoy jaw couplings because they are inexpensive but still will work well for our project with a little manipulation.

12. Hook

The hook is a carabiner, commonly used as a key chain or other use. It is very inexpensive, safe and easy to use. It also has a tensile rating of about 16kg, with an ultimate tensile strength of about 60kg, so it should work well for our application.

5 ENGINEERING ANALYSIS

5.1 ENGINEERING ANALYSIS PROPOSAL

5.1.1 Signed engineering analysis contract

MEMS 411 / JME 4110
MECHANICAL ENGINEERING DESIGN PROJECT

ASSIGNMENT 5: Engineering analysis task agreement (2%)

ANALYSIS TASKS AGREEMENT

PROJECT: Weight Powered LED

NAMES: Austin Herman, Emma Seidel, Samuel Rayseldi

INSTRUCTOR: Mark Jakiela

The following engineering analysis tasks will be performed:

• Determination of specific electrical components necessary to control the flow of electricity to properly light the LED without overheating the system through outside consultants and direct testing.

• Calculation of number of gears necessary to induce a particular RPM on the motor and the resulting gear ratio.

• Calculation of torque on the gears to determine if the induced stress will cause them to fail in shear.

• Determination of the minimum RPM necessary to properly light the LED through direct subsystem testing.

• Calculation of induced stress on casing to determine the best method of hanging the final product.

• Calculation of shear stress and bending moment on the supporting shaft to determine whether it will fail in shear or bending.

The work will be divided among the group members in the following way:

All of the work is being split equally among the group members on an as needed basis depending on who is best suited for a particular topic and who is in the best position to follow up on a particular analysis at any given time. Multiple group members are often collaborating on any given analysis, sharing ideas and double-checking work.

Instructor signature: ______________; Print instructor name: JAKIELA.

(Group members should initial near their name above.)

Figure 15: Analysis Contract

5.2 ENGINEERING ANALYSIS RESULTS

5.2.1 Motivation

The analysis tasks we performed were chosen because they were the areas we were most concerned about. We used the Lewis equation to find out whether the teeth of the gears we chose would shear or not. We also tested the bending moment and shear force on the cylinder shaft to determine whether it would fail. We looked at the components of the design we found to be most likely to fail to determine whether we needed to alter the design to make it stronger. We also tested the voltage output of the motor at different rotational speeds to determine what speed we would need to get enough power to light the LED.

5.2.2 Summary statement of analysis done

The analysis done for the main shaft and lego shaft are drawing shear and bending moment and calculate the shear and bending stresses using equation:

$$\sigma_f = \frac{FL}{\pi R^3} \qquad \tau = \frac{F}{A},$$

Determining torque at the motor is done by using equation:

$$\boldsymbol{Torque = Mass * g * r * p}$$

Where p = the diameter ratio of the gear train and r = radius of the cylinder

Calculating the strength of the gear is done using Lewis Equation

We want the weight to be heavy enough to run the motor without the LED blinking, but we also want it to be light enough so that the weight does not drop too fast. To obtain this data, we build the design and experiment using different weight and number of LEDs.

5.2.3 Methodology

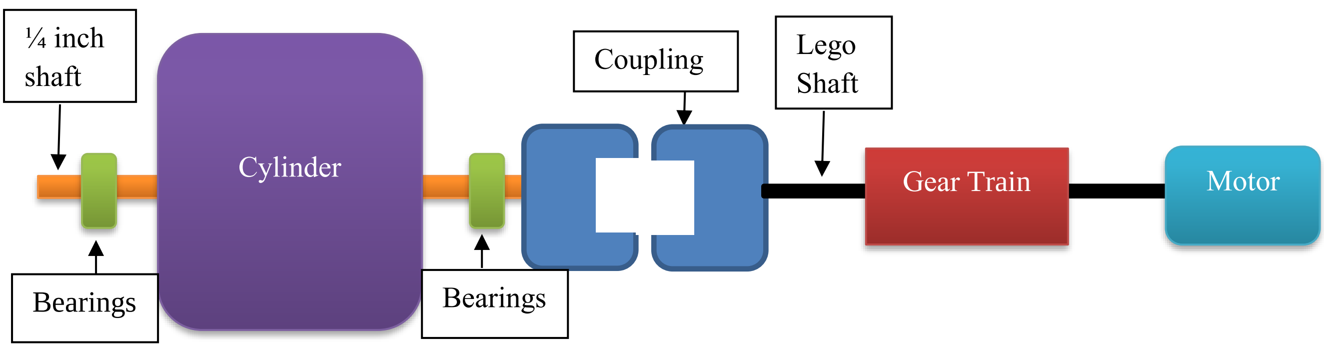


Figure 16: Overall Design Schematic

Main Shaft

Why test this part? Because when the coupling separates, the cylinder will give the whole weight and the bearings (connected to casing will be the only one to support the load)

Mass = 5 kg
Load = 49 N
Cylinder width = 65 mm
Bearings distance to cylinder (left and right) = 20 mm
Shaft diameter = 6.35mm (1/4 inch)
Shaft:
Modulus of Elasticity = 200 GPa
Shear Modulus = 80 GPa
Tensile Strength, yield = 415 MPa

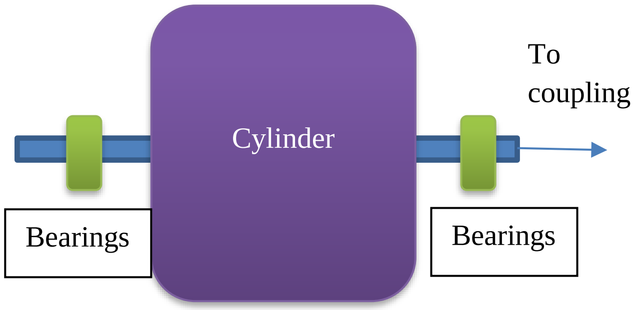


Figure 17: Main Shaft Schematic

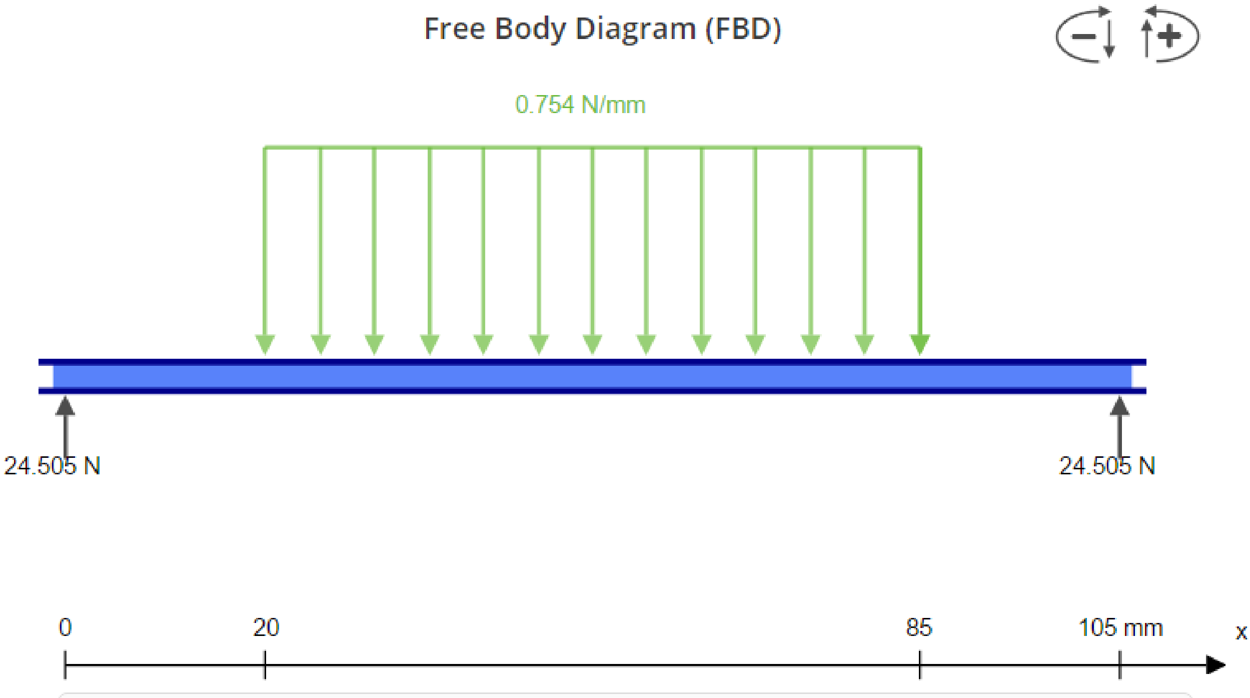


Figure 18: Main Shaft Free Body Diagram

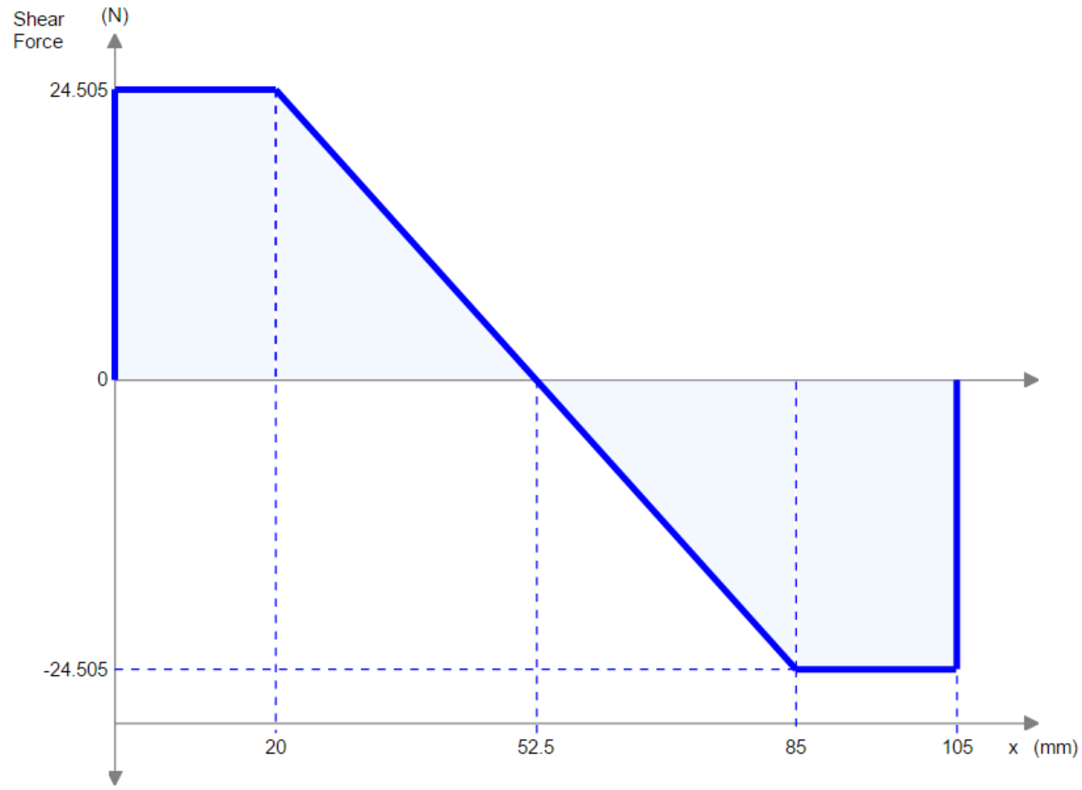


Figure 19: Main Shaft Shear Force Graph

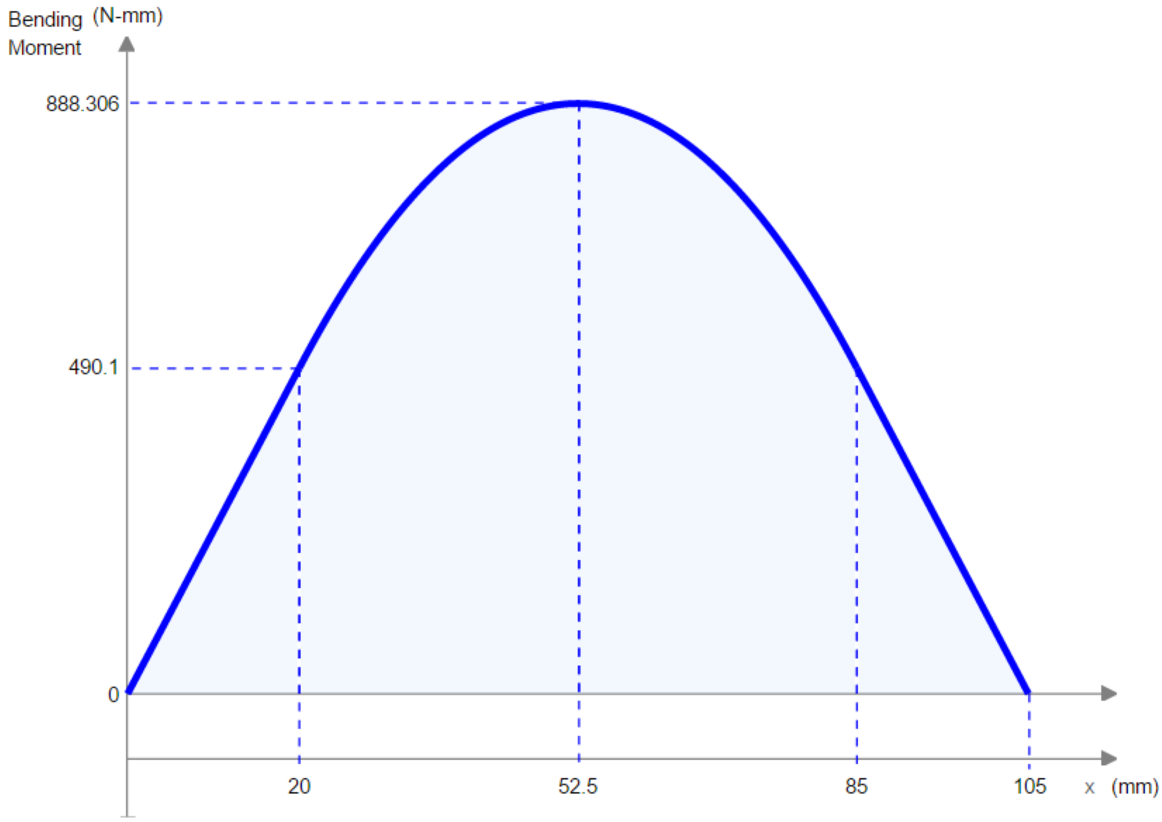


Figure 20: Main Shaft Bending Moment Graph

$$\sigma_f = \frac{FL}{\pi R^3}$$

$$= \frac{0.8883}{3.14*(0.003175)^3}$$ = 8.834 MPa < 415 MPa

$$\tau = \frac{F}{A},$$

$$= \frac{24.505}{\frac{1}{4}(0.00635)^2}$$ = 2.43 MPa < 80 Gpa

Gear Train

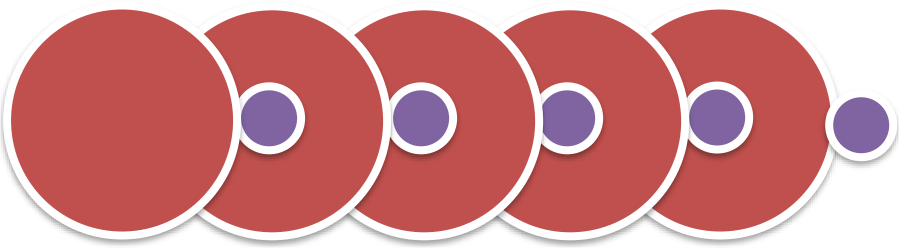


Figure 21: Gear Train Schematic

Bigger lego gear:
Diameter = 40mm
Number of teeth = 40

Smaller lego gear:
Diameter = 8 mm
Number of teeth 8

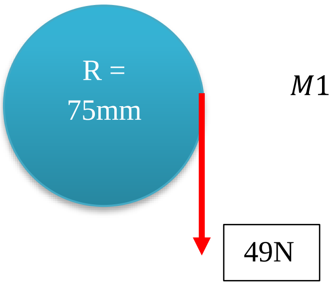
Total gear ratio = $(\frac{8}{40})$^5 $= 1 : 3125$

Torque produced at the motor = $mass * g * 0.075m * \frac{8}{40} * \frac{8}{40} * \frac{8}{40} = 5 * 9.81 * 0.075 * \frac{1}{3125} =$ $0.00176N.m$ = 12 g.cm

Minimum torque required to back drive the motor = 10g.cm

LEGO Shaft

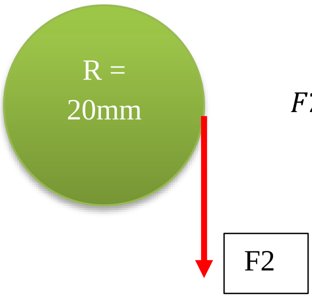
Moment produced by cylinder (connected to the first lego shaft)



$$M1 = F1\ x\ R1 = 49\ N * 0.075\ m = 3.675\ N.m$$

Figure 22: Cylinder Schematic

First LEGO Gear (40 teeth meshing with 8 teeth gear)



$$F2 = \frac{M1}{R2} = \frac{3.675}{0.02} = 183.75\ N$$

Figure 23: First LEGO Gear Schematic

Second LEGO Shaft

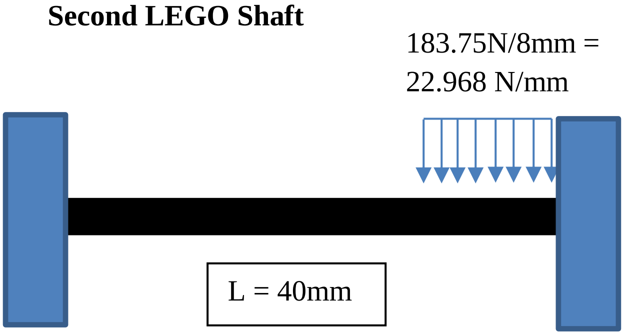


Figure 24: LEGO Shaft Schematic

Max Shear = 165.37 N

Max Bending = 587.968 N.mm = 0.588N.m

Assume Lego shaft is a cylinder with 4.8mm diameter

$$\sigma_f = \frac{FL}{\pi R^3}$$

$$= \frac{0.588}{3.14*(0.0024)^3} = 13.54\ \text{MPa} < 69\ \text{MPa}$$

$$\tau = \frac{F}{A},$$

$$= \frac{165.37}{\frac{1}{4}(0.0048)^2} = 28.71\ \text{MPa} < 2.344\ \text{GPa}$$

Circuits

In this design, we are using 2 small LEDs. All LEDs are arranged in parallel so that the voltage stays lower than in series.

Each LED

Voltage = 3.1V
Current = 20mA

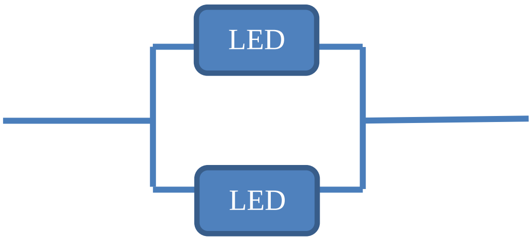


Figure 25: LED Circuit Schematic

Total Voltage = 3.1V
Total current =40mA

Lewis Equation

The gear most likely to fail in our gear train is the first gear because it has the highest torque applied to it. Since it is on the same shaft as the cylinder, it will have the same torque. We compared the calculated force on the gear to the shear strength of ABS (the material LEGOs are made of) to determine whether the LEGO gears would fail in shear or not.

$$\text{Torque}_{cylinder} = mass * acc * radius = 0.3\text{kg} * 9.81\frac{m}{s^2} * 0.075\text{m} = 0.22\text{kN} * \text{m}$$

$$\text{Torque}_{gear} = \text{Torque}_{cylinder}$$

$$P_d = \text{diametral pitch} = \frac{1}{modulus} = \frac{1}{1} = 1mm^{-1} = 1000m^{-1}$$

$$\text{F} = face\ width = 4\text{mm} = 0.004\text{m}$$

$$\text{Y} = 0.446$$

$$W_t = \frac{2T}{D_p} = 2 * \frac{0.22kN*m}{1000m^{-1}} = 0.44\text{ N}$$

$$\sigma_t = \frac{W_t * P_d}{FY} = \frac{0.44N*1000m^{-1}}{0.004m*0.446} = 246.6\frac{\text{kN}}{\text{m}^2} = 247\text{kPa}$$

$$\text{Strength of ABS (Acrylonitrile butadiene styrene)} = 34\text{ MPa}/3 = 11.3\text{MPa}$$

5.2.4 Results

Theoretically, neither the main shaft nor the LEGO shaft will break if we use a 5 kg weight. Both the flexural strength and the shear stress are below the yield stress and shear modulus we found online. The gear train should be able to still run the motor with given gear ratio. The results are somewhat too good to be true. A transmission of 1:3125 is a big deal to achieve with only small gear such as LEGO gear. It will be too much for the gear to handle the torque required to spin the motor.

Based on the calculations, we proceed to making the prototype and do some experimental analysis. It turns out that the LEGO shaft cannot resist the bending with only 1:125 gear ratio. The LEGO shaft also cannot handle the torsion given by the cylinder.

We think this happens because we assumed that the LEGO shaft has a round cross-section instead of a plus cross-section.

5.2.5 Significance

Each analysis was used to determine the most fundamental or most important engineering aspect of some section of the original design. We utilized these analyses to alter that design to make sure the final product either functioned properly or operated at its highest efficiency.

- We also decided to use the small DC motor instead of the LEGO motor instead of the motor we originally planned on, because it requires a lower torque and thus a smaller weight and less chance of gear or shaft failure.

- We did not have to alter the design because of the bending or shear force on the main shaft because it was already strong enough to withstand the forces applied to it. However, because of the torsional forces on the LEGO shaft, we had to reduce the gear train and the weight required to make the light work.

- In the original design we included a small plastic gears instead of the LEGO gears. Our analysis indicated that these would not withstand the applied torque, so we altered the design to use the LEGO shaft and standard, more durable, LEGO gears instead. The LEGO gears are much sturdier due to the wider face width and larger gear teeth. Along with using the LEGO shaft, the final design includes a custom printed shaft adapter to allow the LEGO shaft to properly fit in the coupler.

- In the original design we used a gear train with 6 gears plus the cylinder to allow for maximum drop time. The revised design only included half of that due to the calculated torsion on the gear shafts. A larger gear train means we would need to add more weight to the cylinder to turn the motor. That added weight was too much for the LEGO shafts to handle.

- Furthermore, the revised design utilized 3 gears in the gear train plus the cylinder. Prototype testing found that the torsion applied to the LEGO shaft was too great given the shape and material of the shaft, so the final design only utilized 2 of those 3 gears.

6 RISK ASSESSMENT

6.1 RISK IDENTIFICATION

- As we are 3D printing some of the essential components of the prototype, the printing will be slow and subject to availability of the printers. This may delay other aspects of our production schedule, causing problems with completing the prototype in a reasonable period of time.

- Any breakage in the internal structure of the device would cause the weight to fall, possibly causing harm to any person or object below it.

- Too much weight being hung from the device could cause it to fall from its moorings - either ceiling or wall - as the weight is interchangeable.

- Costs of the individual components - including 3D printing some of the parts - could bring the cost of the entire device outside of the feasible ability for our target demographic to purchase it.

- Pulling/lifting a weight to a height every time the device is to operate could cause shoulder and back issues for the user.

6.2 RISK ANALYSIS

- Utilizing standard engineering equations for stress and strain on the components of the device most at risk of breaking - including using Lewis equations to account for the stress on the gears - we determined that up to a given maximum weight limit the device is at a very low risk of dropping the weight onto a person or object below. As long as we make the user aware of the maximum weight limit this was designed for, the risk should remain tolerable. However, given that the weight is interchangeable, it is still possible that the device could be used outside of its intended parameters and cause damage.

- 3D printing is a risk purely for the prototyping phase of the design. Were this to go into mass production, there are other much quicker and less expensive (on a per unit basis) options that we can utilize to form the components necessary. This remains a scheduling risk for the prototyping and project phase but much less of one for the production phase.

- The device does use a weight at a height to operate but it is a height that is directly proportional to the length of time the user would like the device to operate for and the higher the device operates at, the dimmer the light will be. The nominal use for this product will be at around head height for an adult but even so that would present an ergonomic risk if the user needed to lift the weight that high. The way the device is designed, however, allows the user to attach the weight while on or near the ground and to pull the weight up while keeping their hands and arms within whatever region is most comfortable for them so as not to cause any strain on the user. As with the issue of weight causing the device to break, it is possible that a user could strain their muscles while using this device but as long as we provide direction on how it is intended to be used this should not happen.

6.3 RISK PRIORITIZATION

When weighing the risks against each other, it became a question of how much impact each risk would have overall. Our first priority quickly became making sure that the device does not break through normal operation. This is for two reasons. The first is that if a user was hurt by a falling weight this would be much drastic than muscle strain, a delay in production or a rise in cost. The second is that if the device fails to function, nothing else about it matters since the other risks are now moot. Following breakage we needed to make sure that we could reasonably complete a functioning prototype in a reasonable time period so the delays due to 3D printing became a major second priority despite this not necessarily affecting any final mass production. Any possible user strain trailed behind the other risks mostly because it is easily avoided as long as we provide direction on how to use the device.

7 CODES AND STANDARDS

7.1 IDENTIFICATION

Ergonomics – Manual handling, ISO 11228, 2007; International Standards Organization

LED Modules for General Lighting – Safety Specifications, IEC 62031, 2014; International Electrotechnical Commission

Energy and water conservation standards and their compliance dates, 430.32, 1995; Electronic Code of Federal Regulations

7.2 JUSTIFICATION

While there are many codes and standards that cover some aspect of the parts and/or function of the product, ISO 11228 plays an important part as this covers the direct human interaction with it. ISO 11228 part 2 includes the ergonomic standard for pushing and pulling. Given that this design requires the human operator to pull with a given force in order to lift the weight whenever they would like to restart the device, it is imperative that this be taken into consideration.

Safety in all facets must always be a consideration when designing a new product. IEC 62031, LED Modules for General Lighting – Safety Specifications, covers electrical safety requirements for LEDs that don't contain an integral control gear which would include this product design.

Beyond safety considerations, both electrical and ergonomic, the US federal government has set standards for energy efficiency minimums for a wide variety of products. While this product is designed to be run on human power, there is nothing in the standard that makes this distinction so it will still apply.

7.3 DESIGN CONSTRAINTS

7.3.1 Functional

The choice to switch from the small RC car gears to the slightly larger LEGO gears was made because we were concerned about the life cycle of the smaller gears and because they had a face width of only 1 millimeter, it was almost impossible to ensure they were aligned properly.

7.3.2 Safety

The circuit should be designed to prevent any chance of overheating of the LEDs or motor to prevent potential fire hazards. The weight should also fall at such a pace that it is not dangerous to stand near it.

7.3.3 Quality

Because we want this product to be able to withstand many uses, we ended up changing the gear train design and outer casing design. Originally, we also planned to suspend the entire product from the ceiling or a wall, but because of the extra complications that caused we decided it would be better to build the entire design on a piece of wood for added stability and ease of placing.

7.3.4 Manufacturing

Our design was made with mass producing in mind. Therefore, nothing in this design is incredibly difficult to manufacture. The most complicated or difficult to manufacture parts were printed with rapid prototyping. In the future, if this product were to be mass produced, the 3D printed materials could be made out of plastic from a cast.

7.3.5 Timing

This design had a lot of unknowns, mainly dealing with the back driven motor, so we ended up changing our design multiple times. In the end, because of the shortened summer semester and the wait time from the materials we ordered from the internet, we went with the simplest design because we did not have time to add extra features that were not vital to the design.

7.3.6 Economic

A large factor in this design is the cost. We designed this as inexpensively as possible under the circumstances we had. The cost of our product came out just under $30, which is more than we'd like but still the least expensive for making only one prototype. The cost would go down dramatically if the parts were bought in bulk instead of singularly.

7.3.7 Ergonomic

Since this device is meant to be operated by people of all ages and physical abilities, one of the things we spent a lot of time designing was the best way to lift the weight back up to reset the light. We eventually decided on a design that involves only pulling down a rope to wind the cylinder back up because that is the easiest and least stressful way to get the weight back to its original position and restart the cycle.

7.3.8 Ecological

Our design uses virtually no energy and is completely green. The entire concept was to create a design that does not use regular electrical energy but somehow creates useable energy with little to no cost. Furthermore, there are no harmful emissions from this product, unlike the current alternative, halogen lamps.

7.3.9 Aesthetic

We chose the brightest and most efficient LEDs we could find to get the maximum amount of light for the little amount of energy we get from this design.

7.3.10 Life cycle

We wanted the product to be easy to repair, so having the working parts in the open as opposed to inside a casing makes it simple to find a broken part and replace or repair it. We also secured down any parts that were not meant to move to ensure there is no added chance of failure.

7.3.11 Legal

We designed our product totally different than the existing patents so there would be no issues with plagiarism or patent violation.

7.4 SIGNIFICANCE

The main constraints that affected our design were economic, manufacturing, life cycle and quality. We changed our original design multiple types to reflect this importance. Our design became much sturdier. We also had to find the balance between the economic and manufacturing constraints and the timing constraint. In regards to the cylinder shaft, we had to go with the fastest and easiest to manufacture part instead of the least expensive. Also, we ended up 3D printing less parts than we originally planned because of the quality concerns and the time taken to print the parts, since the printer we planned on using was broken for a large part of the semester.

8 WORKING PROTOTYPE

8.1 DIGITAL PHOTOGRAPHS SHOWING THE PROTOTYPE

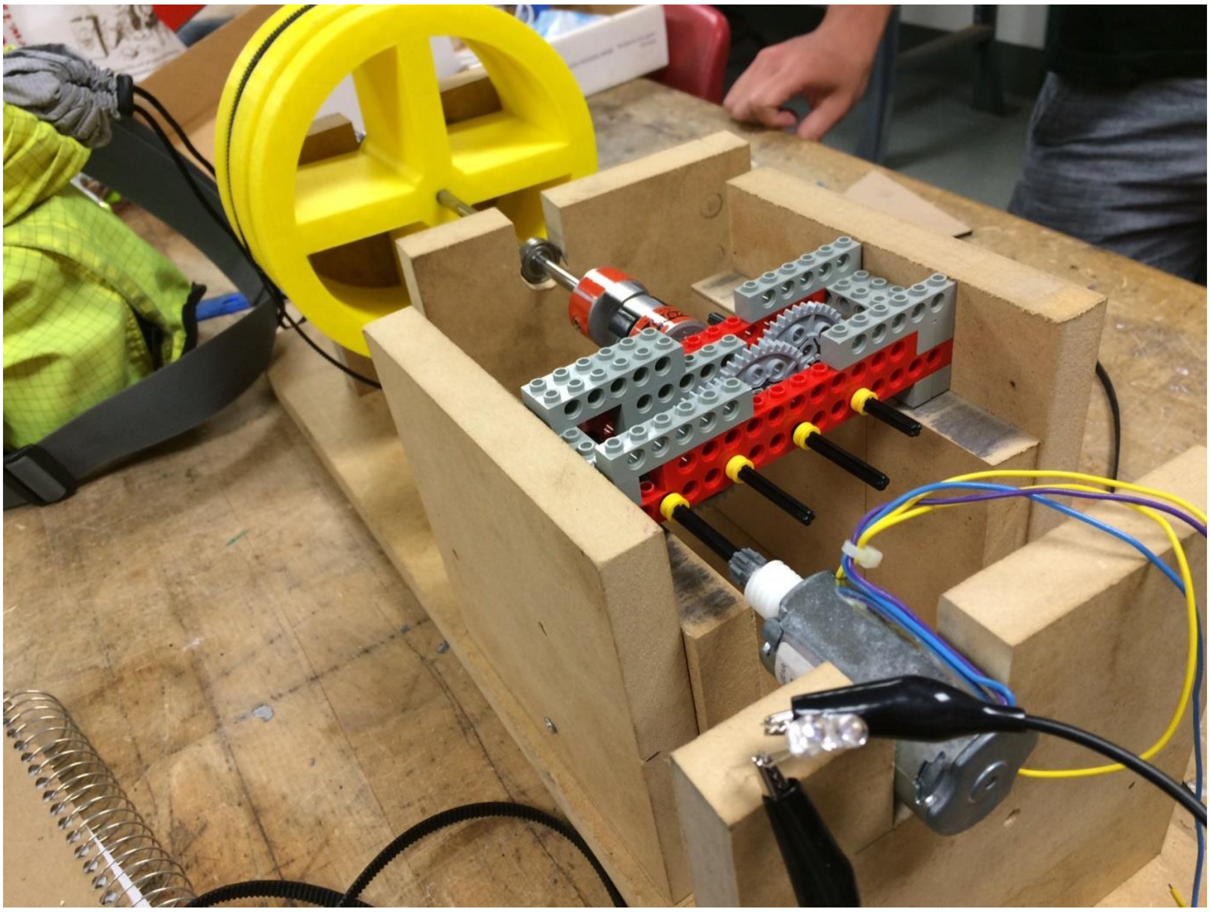


Figure 26: Working Prototype (isometric view)

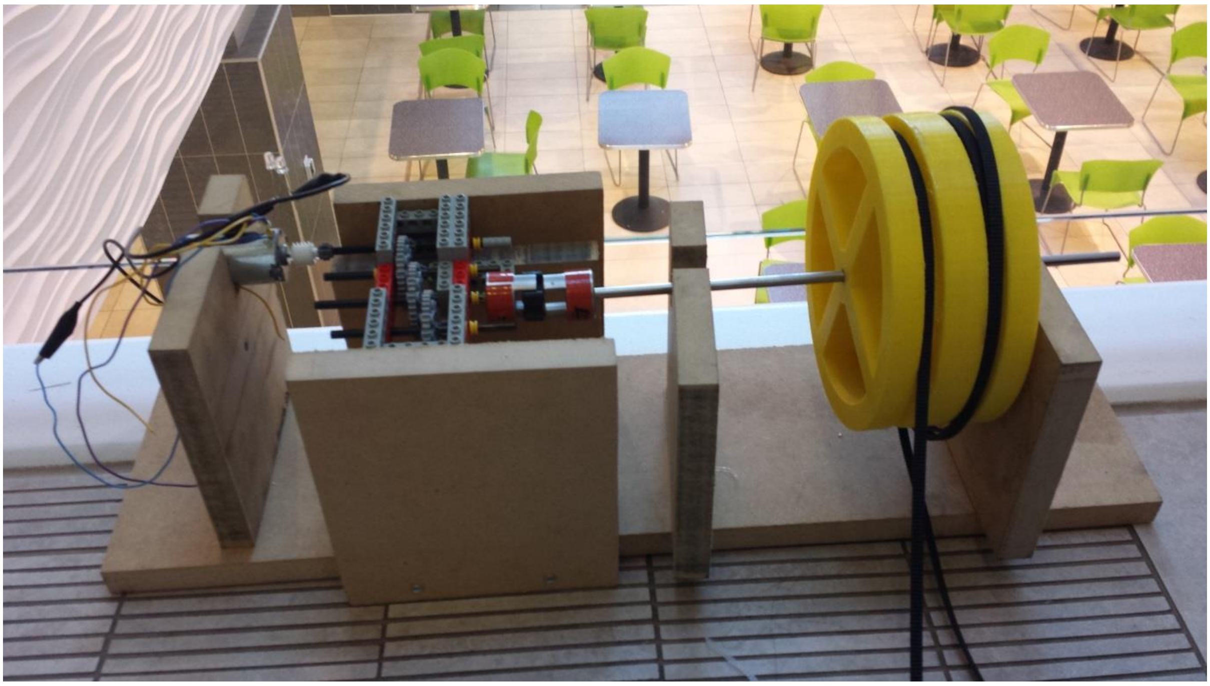


Figure 27: Working Prototype (side view)

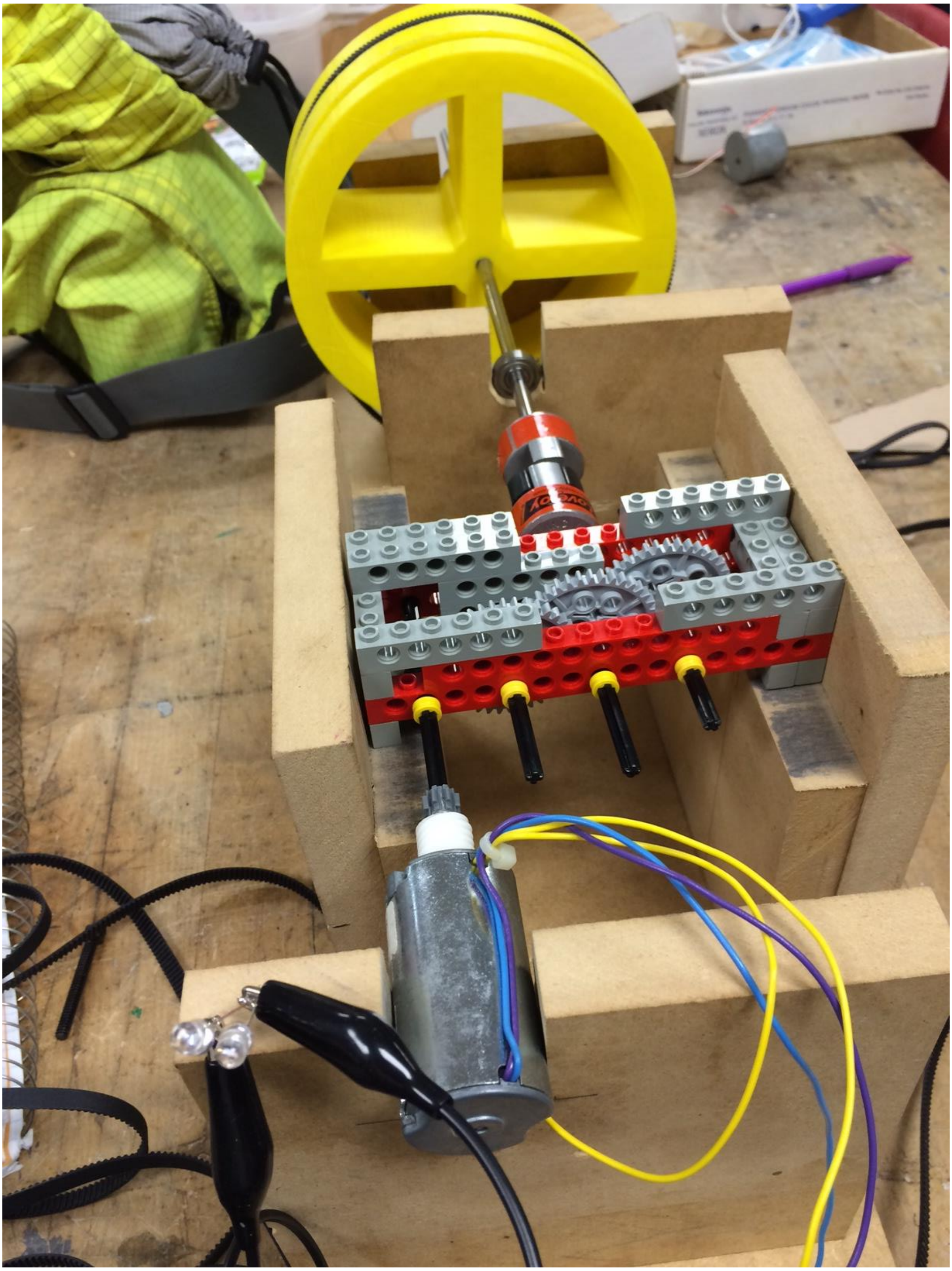


Figure 28: Working Prototype (front view)

8.2 A SHORT VIDEO CLIP THAT SHOWS THE FINAL PROTOTYPE PERFORMING

YouTube link: https://youtu.be/Fcvv1qWrvto

8.3 ADDITIONAL DIGITAL PHOTOGRAPHS AND THEIR EXPLANATIONS

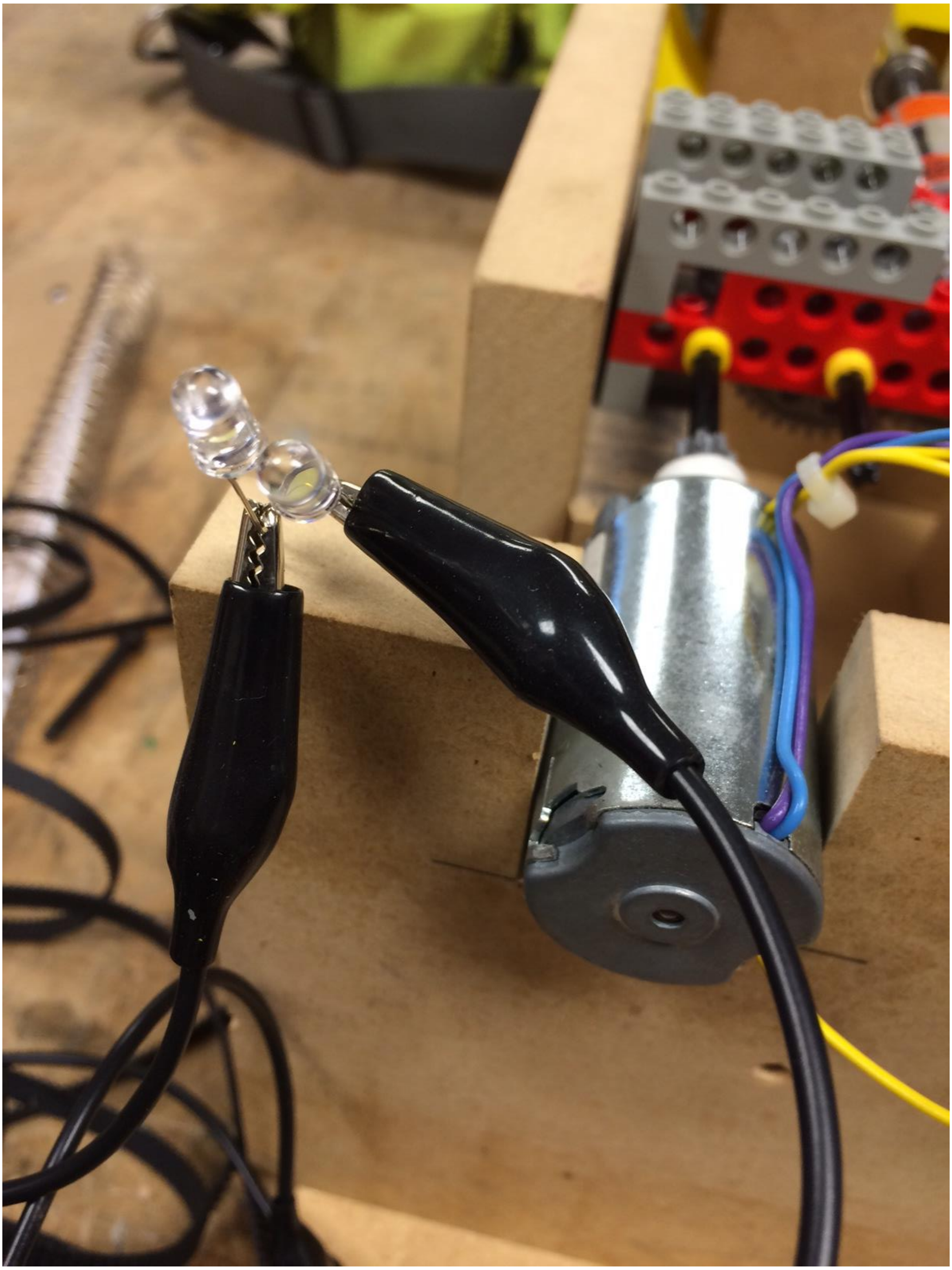


Figure 29: LEDs, Wires and Motor

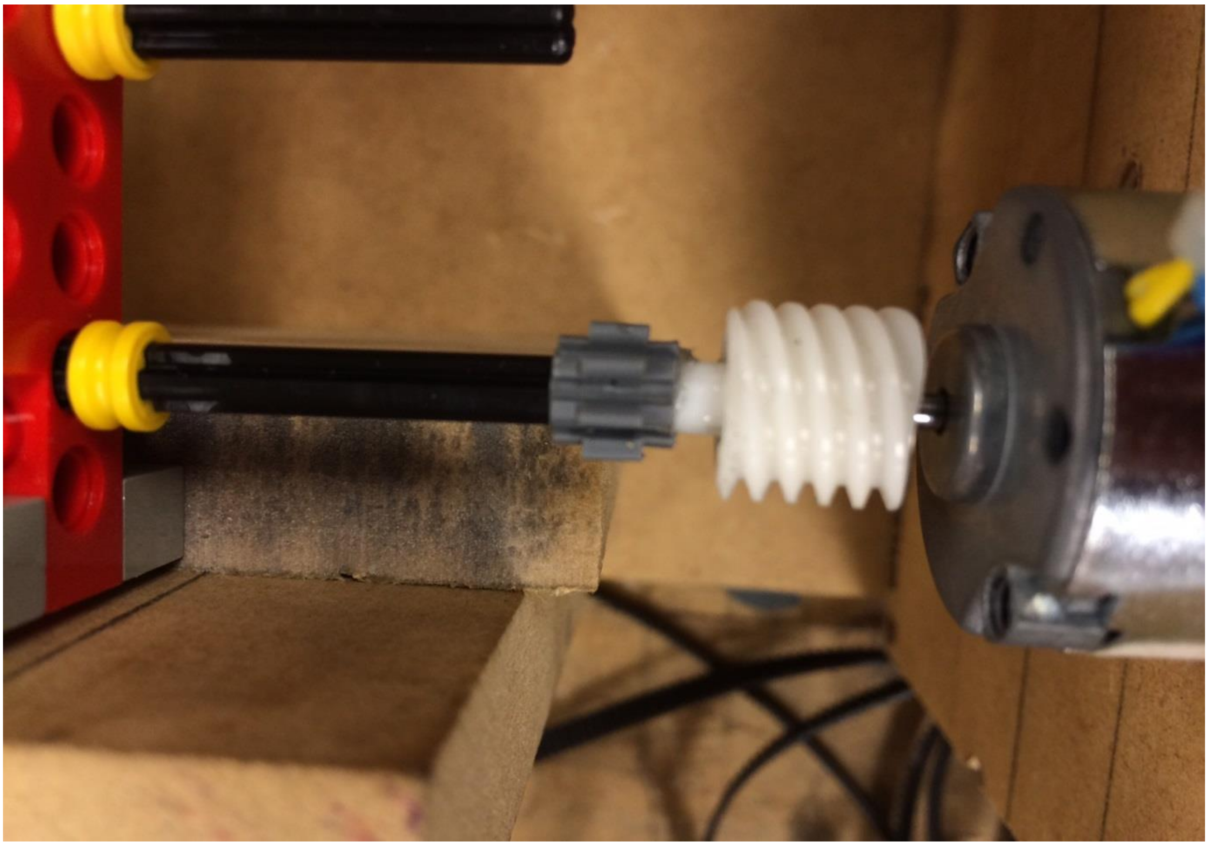


Figure 30: Detail of Modified LEGO Gear and Motor Shaft

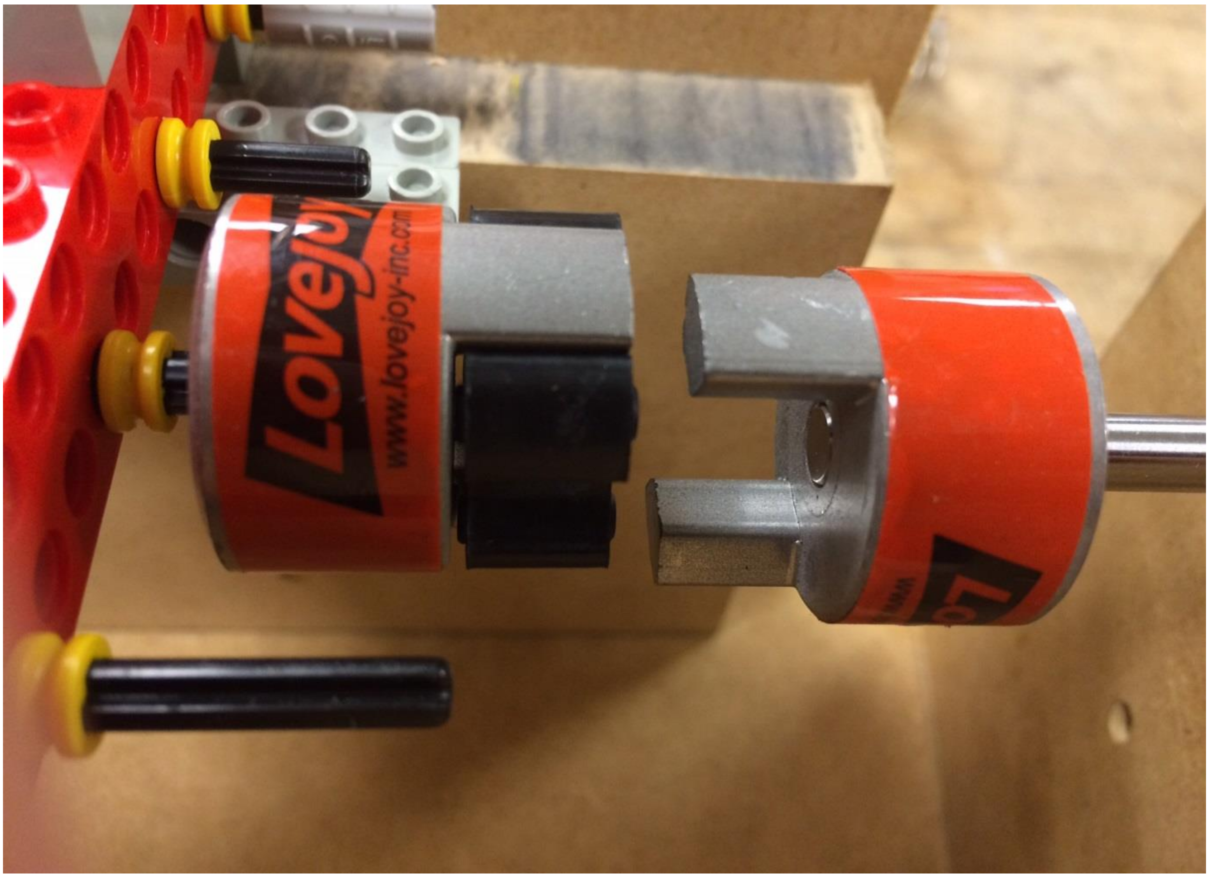


Figure 31: Coupling (uncoupled)

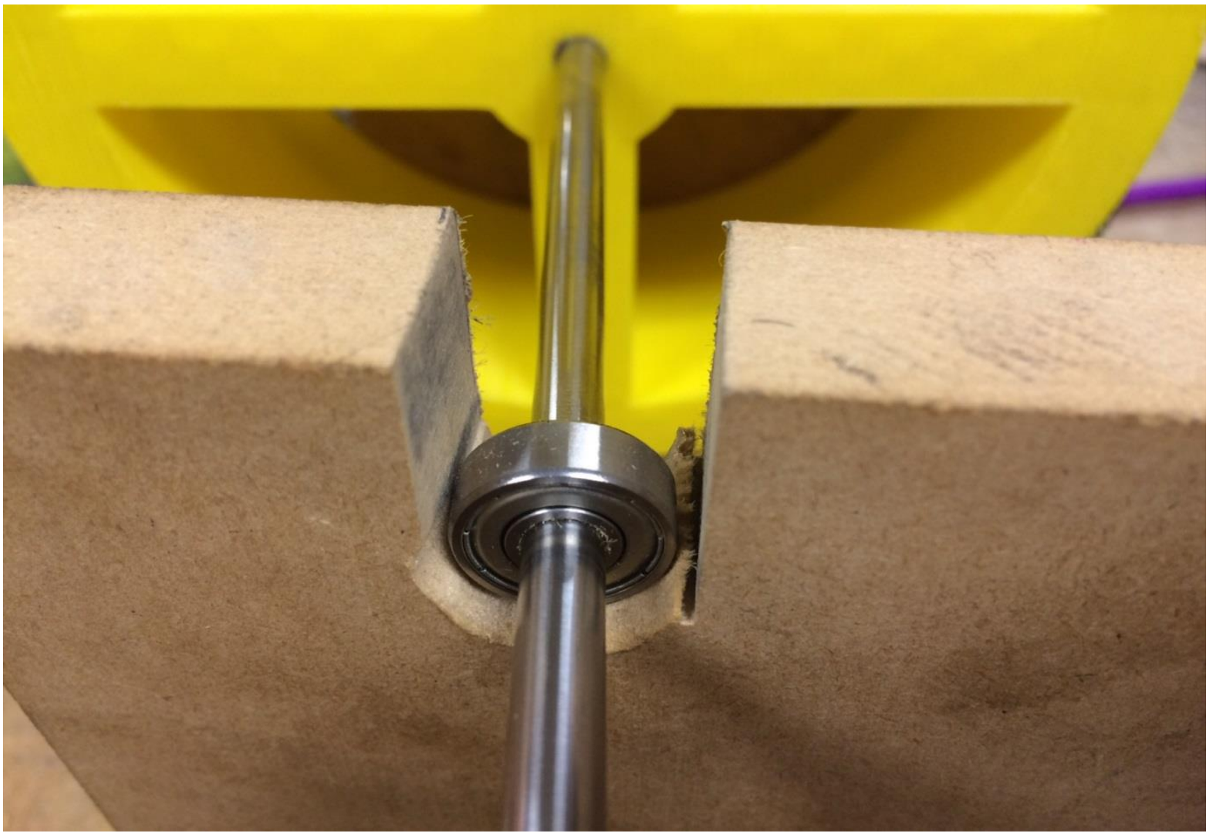


Figure 32: Cylinder shaft and Bearing

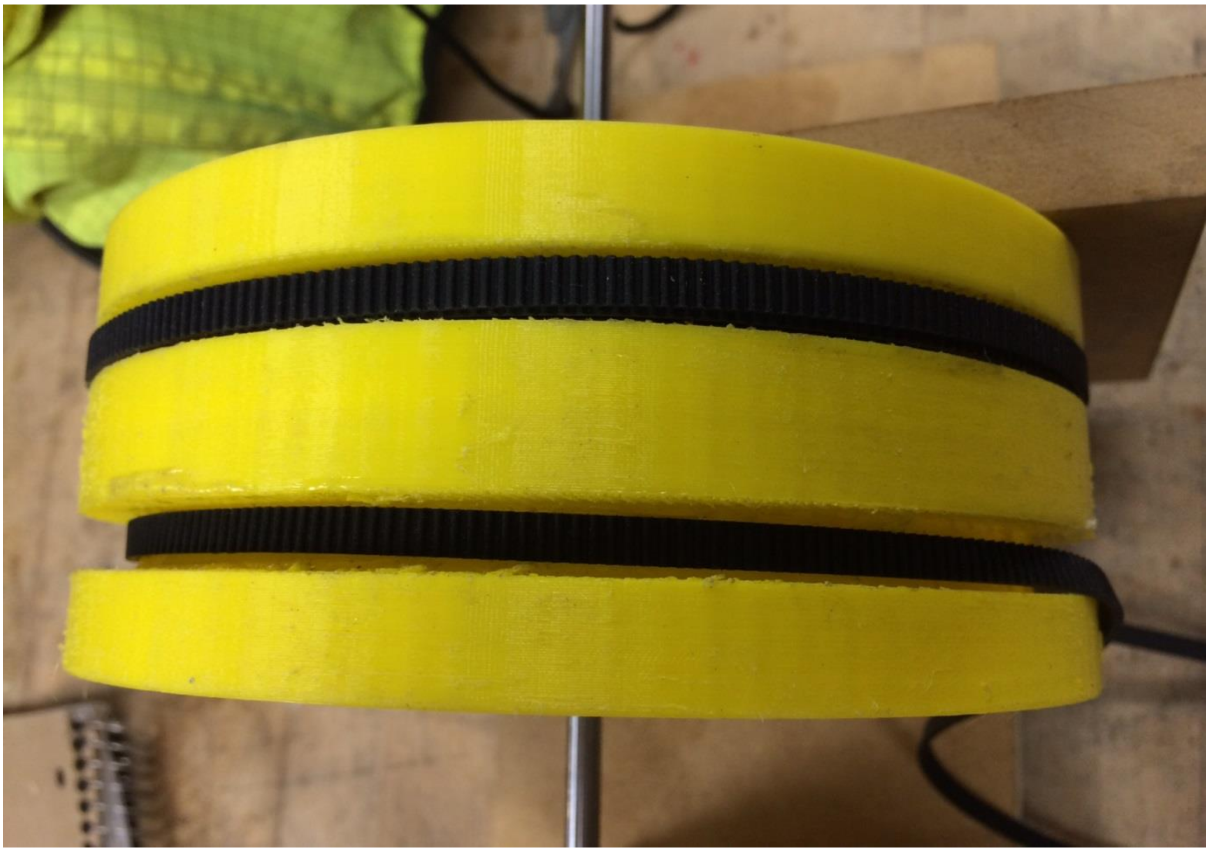


Figure 33: Cylinder (top view) and Belt

Figure 34: 3D Printed Cylinder (side view)

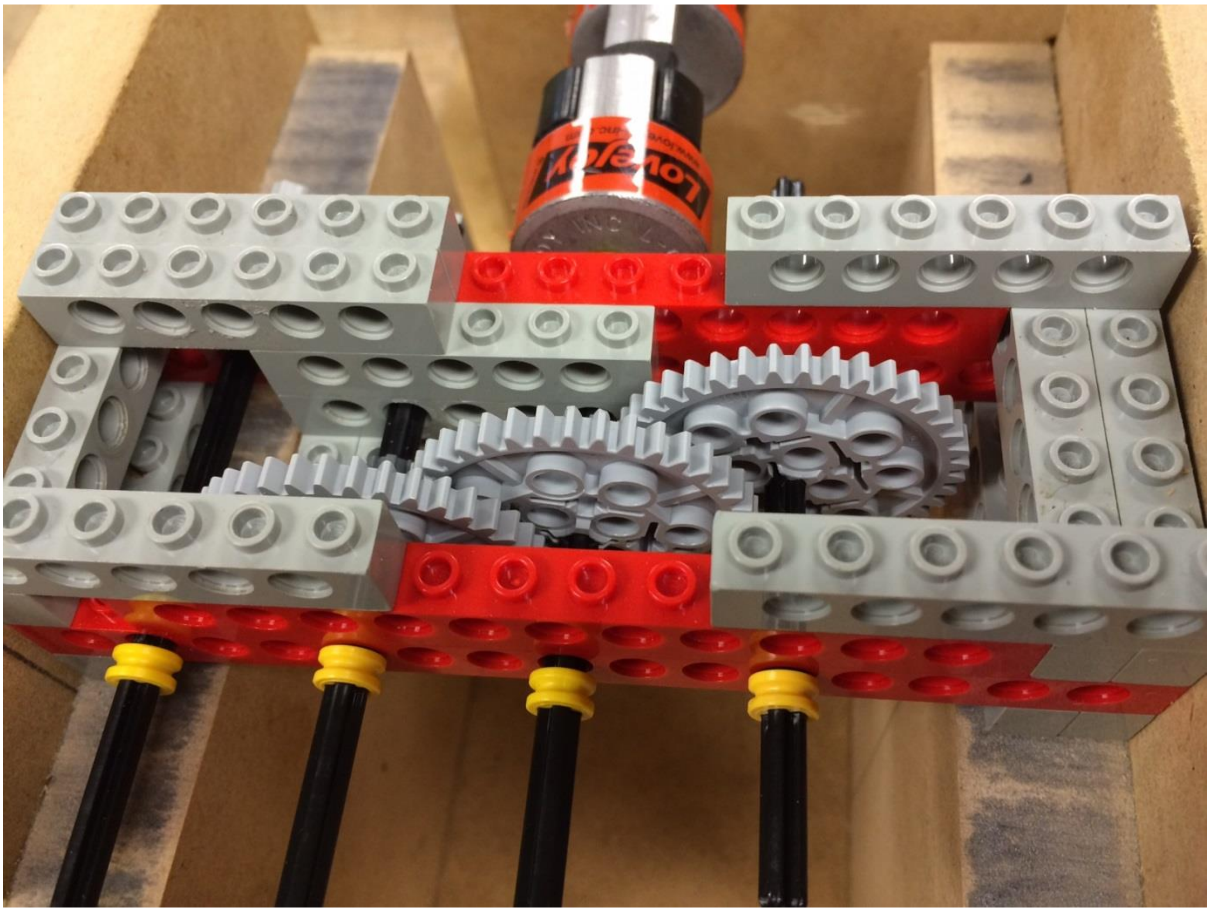


Figure 35: LEGO Gear Train

9 DESIGN DOCUMENTATION

9.1 FINAL DRAWINGS AND DOCUMENTATION

9.1.1 A set of engineering drawings that includes all CAD model files

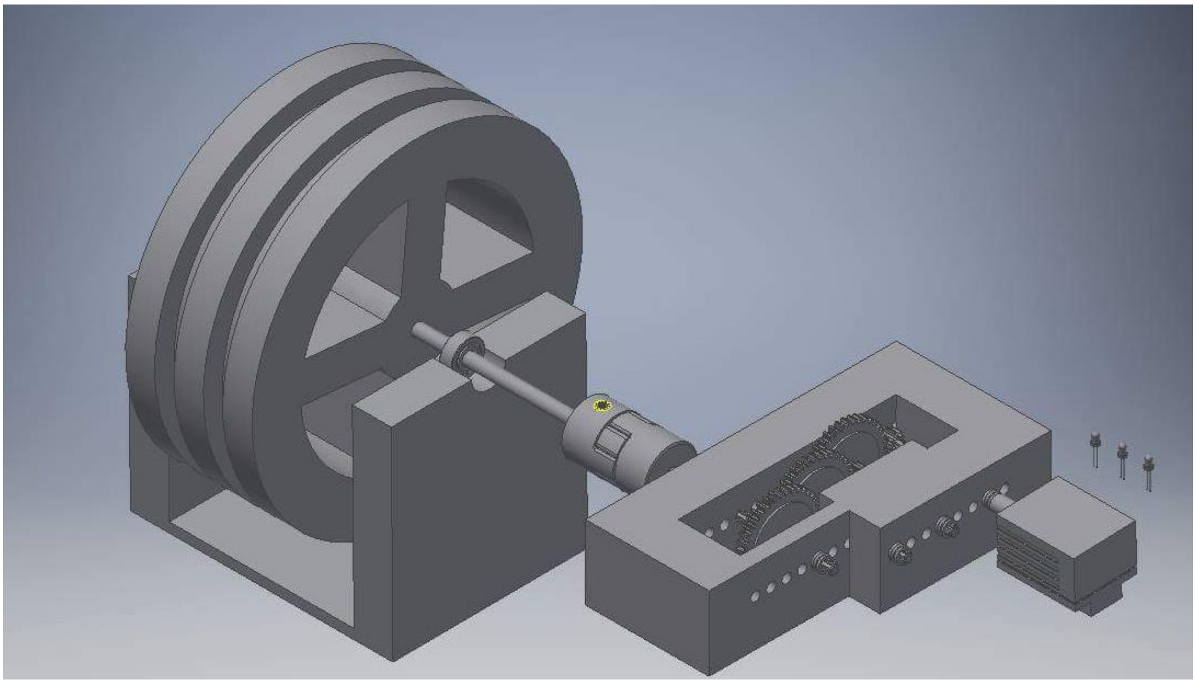


Figure 36: Final Design Assembly

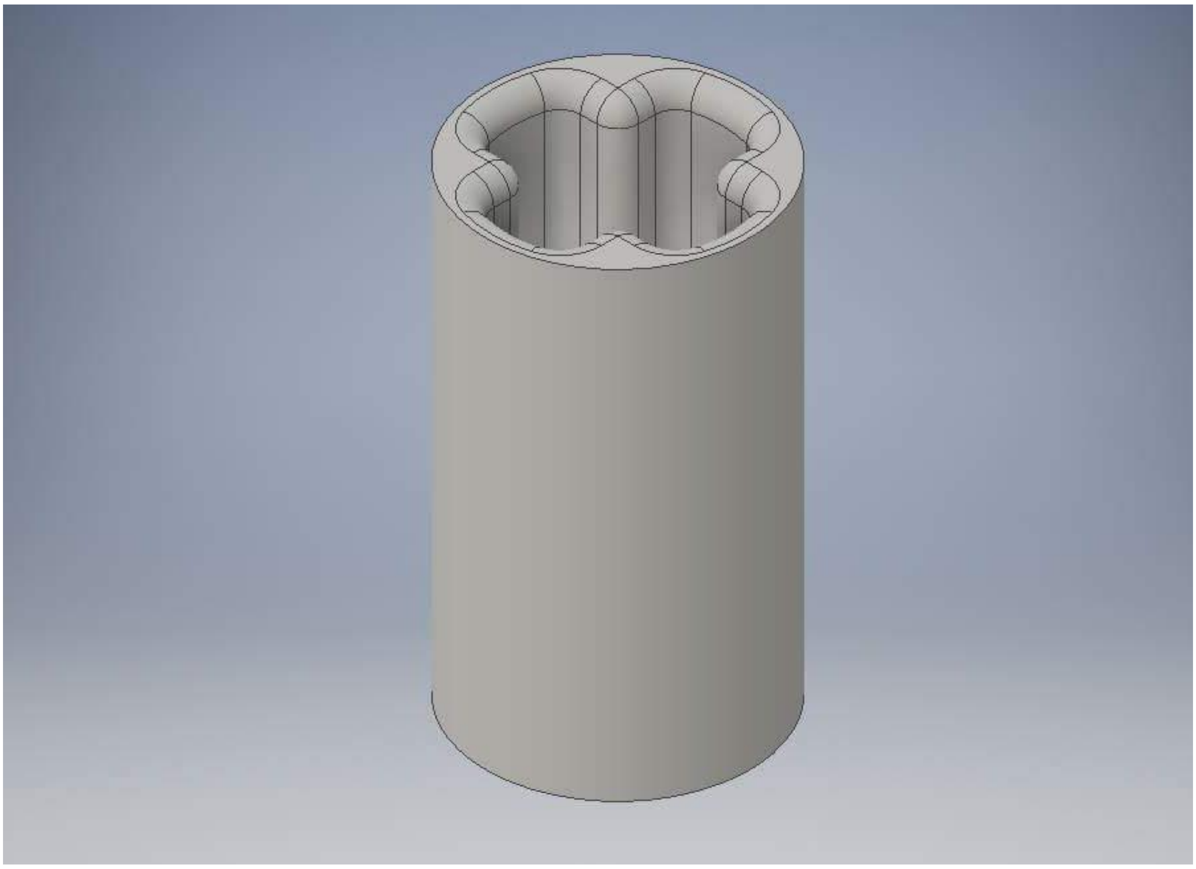


Figure 37: Final 3D Printed LEGO Shaft Adapter Drawing

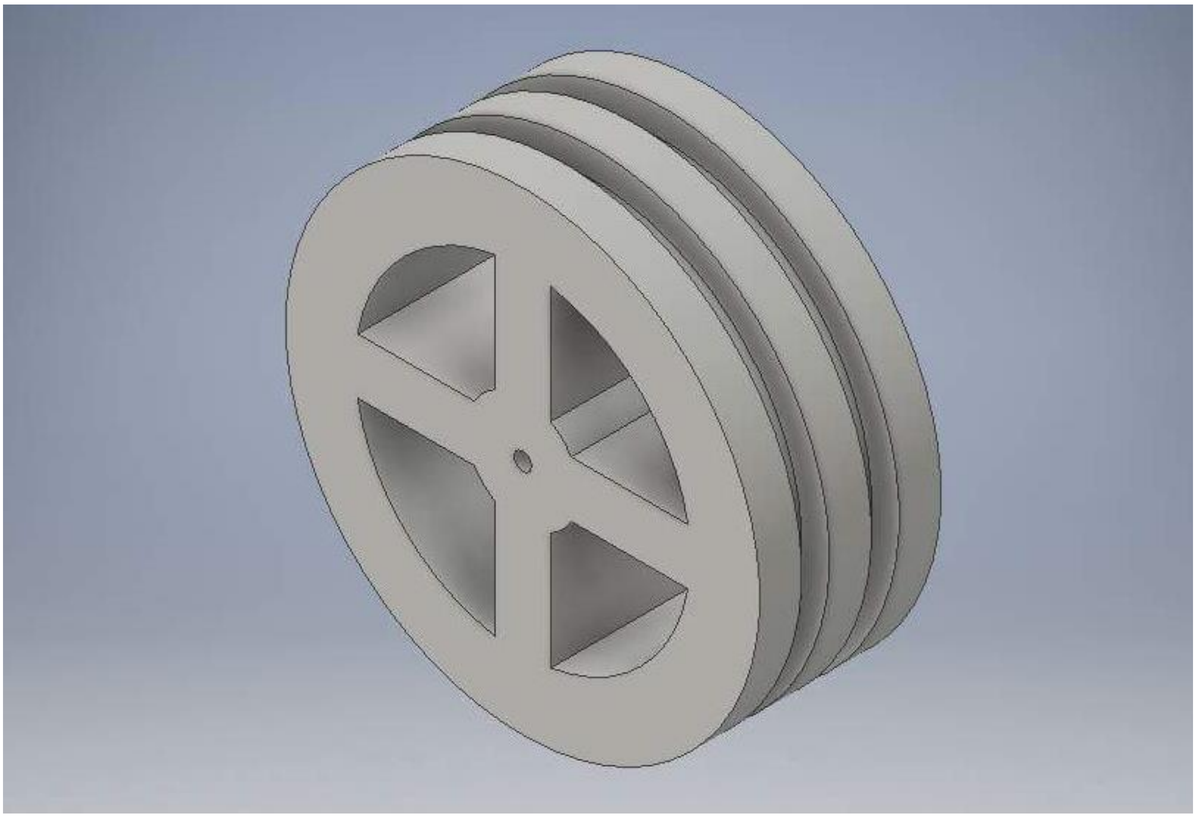


Figure 38: Final 3D Printed Cylinder Drawing

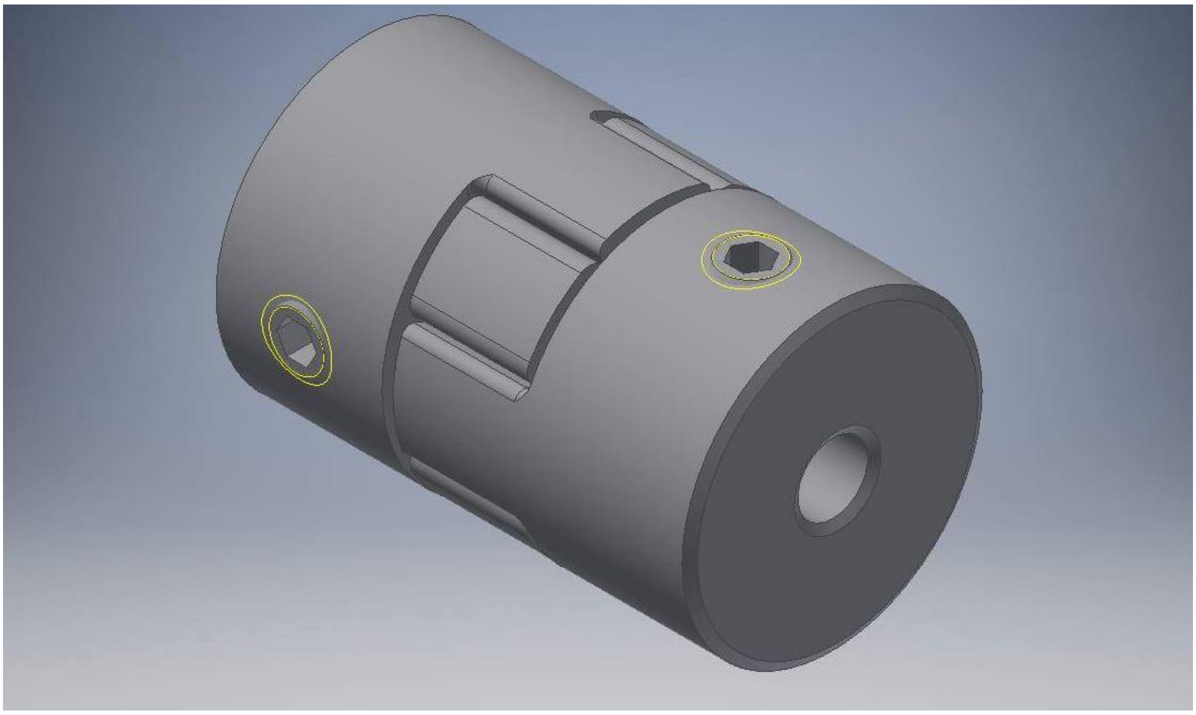


Figure 39: Final Coupling Drawing

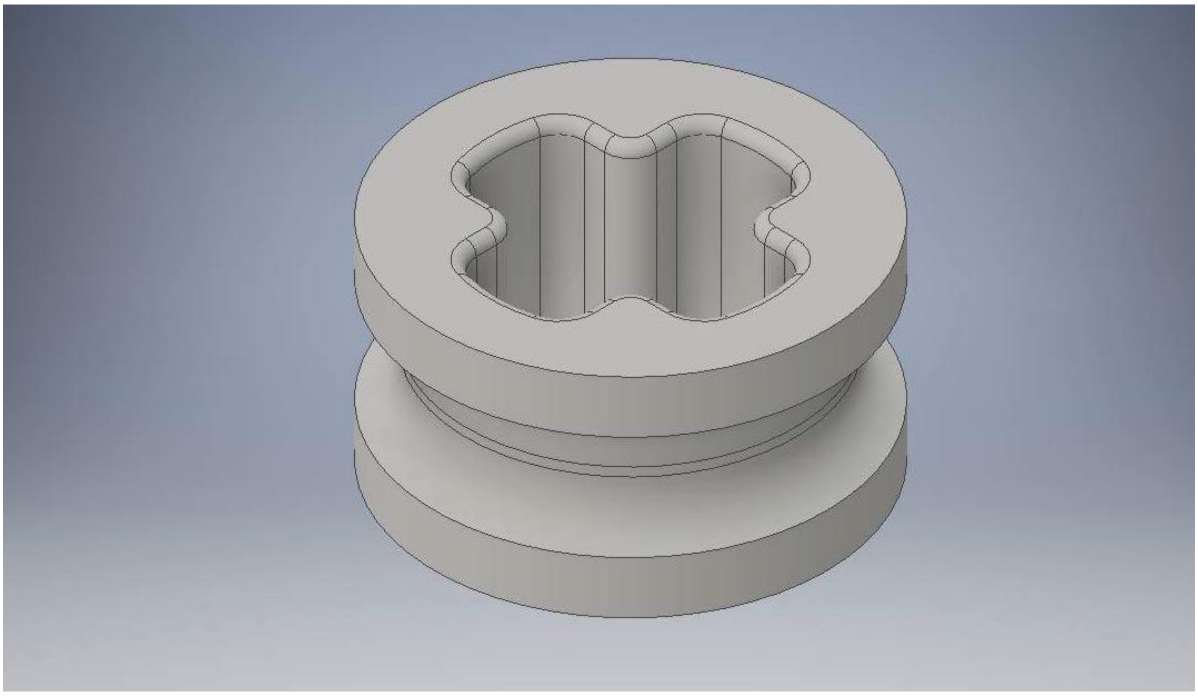


Figure 40: Final LEGO Shaft Holder Drawing

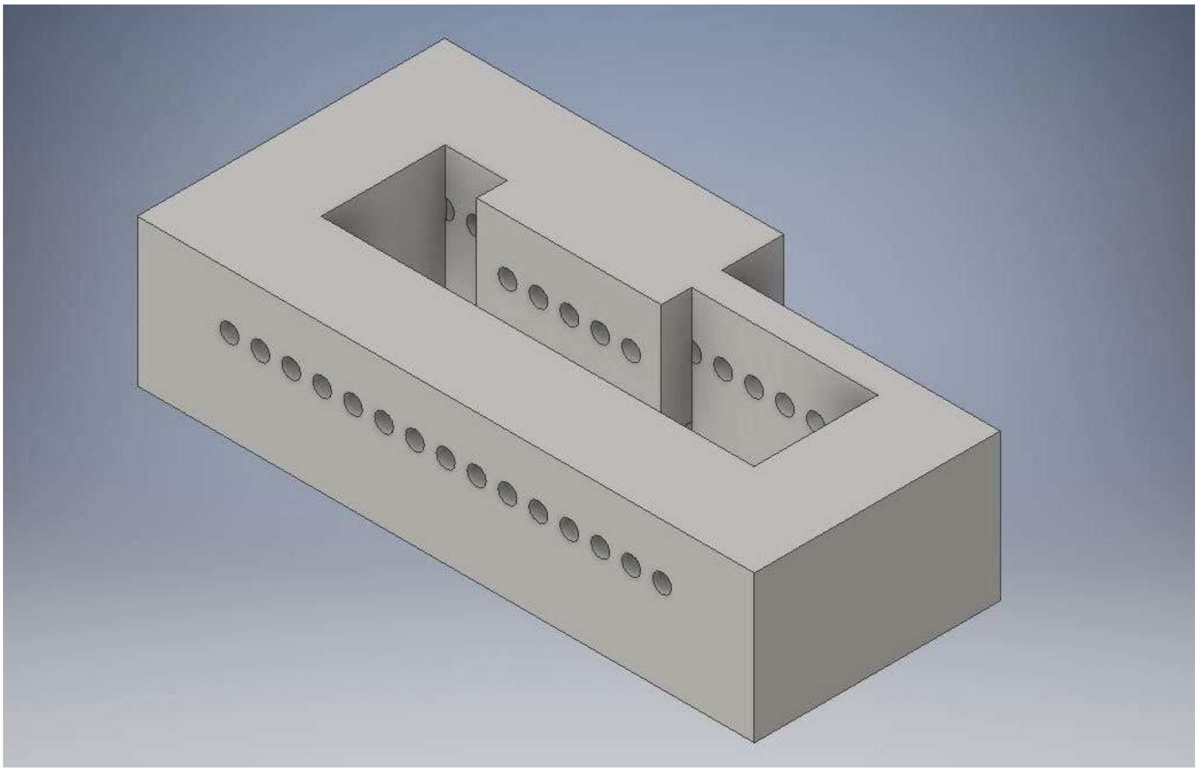


Figure 41: Final LEGO Shaft Support Design

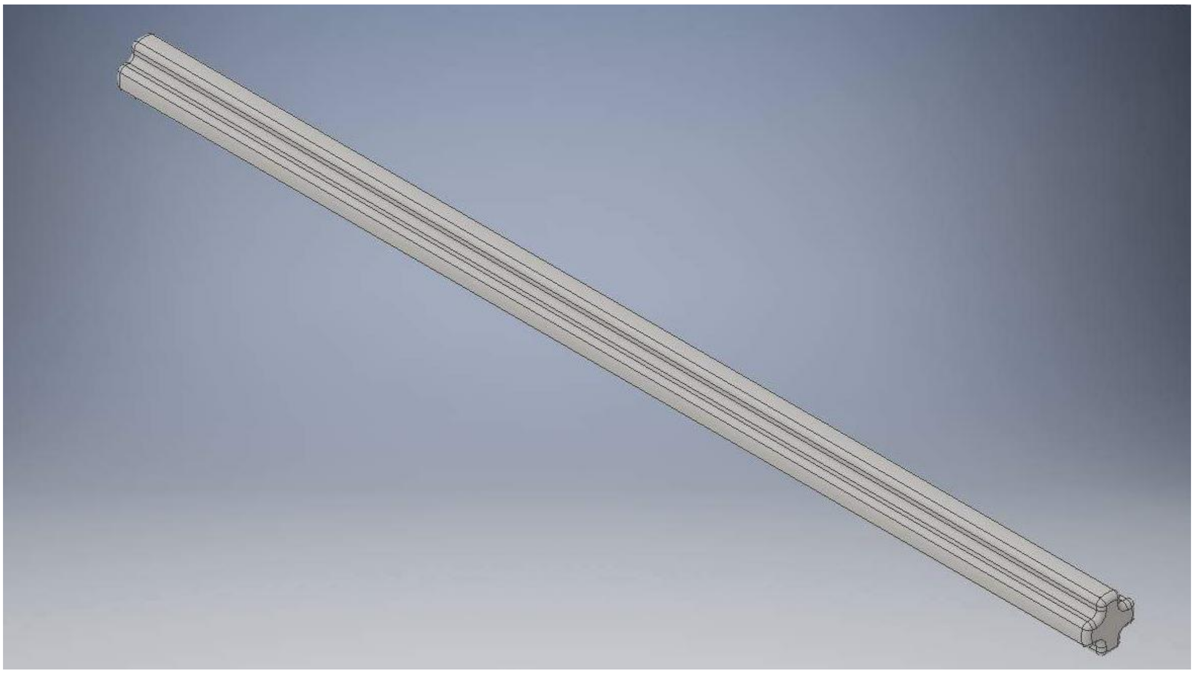


Figure 42: Final LEGO Shaft Drawing

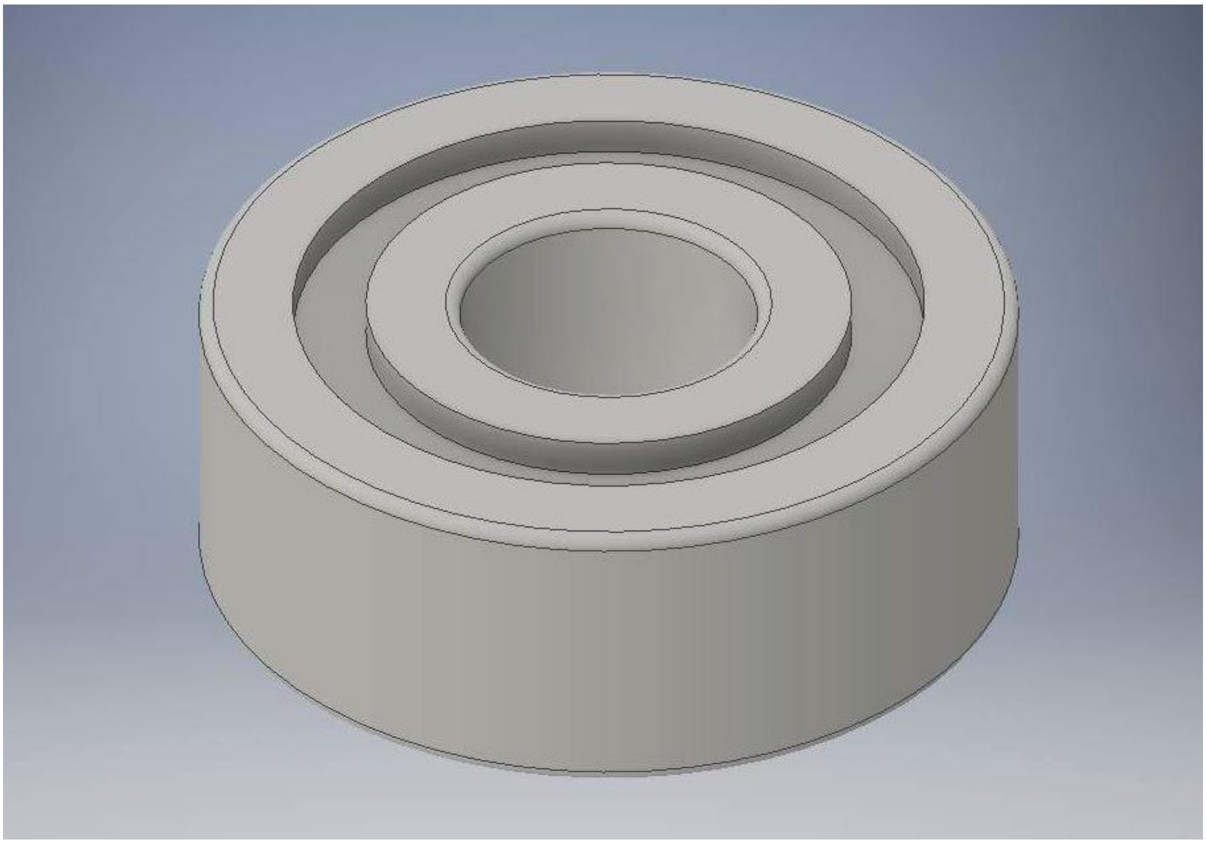


Figure 43: Final Bearing Drawing

9.1.2 Final Design Rational of Parts

1 – LEGO Motor
This LEGO motor is rated for 9V and 35mA at 4100rpm. We chose this motor because we needed a motor that would provide the needed voltage and current at a relatively low rpm without a large required torque to get the motor shaft turning. We also chose a LEGO motor because the motor shaft easily connects to the gear shaft with a LEGO coupling.

2 – LED
We originally chose a Lumiled high power LED, but because it was too small to use we switched to a regular high efficiency LED. To resolve the brightness lost from switching LEDs, we hooked three of the high efficiency LEDs up in parallel to our motor to get a much higher light output.

3 – Cord
The cord is a piece of a timing belt from a 3D printer. It is made of fiberglass reinforced neoprene. We wanted to find a high strength cord that would be able to hold the tension of the falling weight. We also wanted to find a cord we could repurpose instead of somehow making one ourselves. The timing belt we chose is lightweight but can still withstand all the stress that is put on it.

4 – Coupling
The coupling is a standard ¼" bore Lovejoy coupling made of sintered Iron. This is the smallest size of coupling readily available and is used to detach the cylinder from the gear train and motor during the reset of the weight. We didn't want to turn the motor the opposite way while we rewind the cord back up or make it more difficult to rewind than needed because of the extra resistance from the motor, so we added the coupling to the design.

5 – Coupling Spider
The coupling spider is also a standard Lovejoy solid jaw type elastomer spider used to keep the coupling in place while connected.

6 – Cylinder Shaft
The cylinder shaft is a ¼" diameter carbon steel shaft from Thompson. It was originally 12" long, but we cut it to be able to decouple the design. We chose the size to ensure it would not bend or shear from the load and so it would fit with the coupling and the bearings.

7 – Bearings
The bearings are UXCELL deep groove ball bearings. We needed bearings in this design so the shaft with the cylinder and gear can rotate freely. These bearings had the inner diameter measurement we needed to fit the shaft.

8 – Carabiner
Carabiners are inexpensive and easy to use. They also are able to hold well over the amount of force we put it under. We used a carabiner we previously had, but one could easily be found online or even in most convenience stores.

9 – Alligator Clips
We needed a way to transfer the electric energy from the motor to the LED and alligator clips are a very easy and simple way to do that.

10 – Shaft Converter
The shaft converter is 3D printed out of PLA filament. We needed to couple our cylinder shaft with a ¼” inner diameter to the LEGO gear shafts to transfer the rotational energy from the cylinder shaft to the LEGO gear train. Because of that, we had to design our own shaft converter that connected to the LEGO gears but still fit in the shaft. Our converter had an outer diameter of ¼” and was made to fit the splined LEGO shafts.

11 – Large LEGO Gears
These gears have 40 teeth and are 40 mm in diameter. All LEGOs are made out of acrylonitrile butadiene styrene (ABS). We chose to use LEGO gears because they are stronger than many other types of gears of the same size and because they have a splined shaft and thus turn the entire shaft instead of just the gear. This reduces the possibility of the gears meshing at an angle and reducing our torque. It also reduces the possibility of the gears translating on the shafts and getting out of alignment.

12 – Small LEGO Gears
These gears are 8 mm in diameter and have 8 teeth. We use these gears in front of the larger gears on the same shaft to create a pseudo double gear type arrangement. This makes it possible to get the gear ratio we need to spin the motor shaft fast enough to light the LED.

13 – LEGO Gear Shafts
The LEGO gear shafts are splined so they don’t allow for slippage of the gear rotating around the shaft. The shafts we are using are 40 mm in length and 4.9 mm at max cross sectional width.

14 – Screws
We used screws we found in the machine shop to secure the wood parts and make the loop in the timing belt for the carabiner.

15 – Motor Coupling
The motor coupling is a LEGO coupling that connects the LEGO motor shaft to the LEGO gear shaft to rotate the motor shaft.

16 – Wood Supports
The base of the design and the supports holding up the shafts are made out of wood found in the machine shop. We decided to use wood because it is easy to handle and machine and sturdy enough for our purposes with this project.

17 – LEGO Technic Brick
These LEGO bricks have holes to put the shafts through. The holes allow the shafts to freely rotate and the bricks are stackable so they can be reinforced with other bricks to provide the stability we need without breaking.

18 – LEGO Bushing
The bushings are on the ends of the axles to prevent any translation of the axles in the gear train. The bushings keep the gears in place to make sure they are fully meshed.

9.1.3 Sourcing instructions

All CAD models can be found on the Washington University Open Scholarship page in a .zip file.

A Bill of Materials can be found in Appendix B.

9.2 FINAL PRESENTATION

9.2.1 Link to the video presentation

YouTube link: https://youtu.be/t8K0xN7A3PE

10 TEARDOWN

From: "Jakiela, Mark" <mjj@wustl.edu>
Date: August 3, 2016 at 4:48:21 PM CDT
To: "Herman, Austin R. (UMSL-Student)" <arh5tb@mail.umsl.edu>
Subject: Re: Teardown contract

Please consider this response as my approval and signature.

Thanks!

Mark Jakiela

From: Herman, Austin R. (UMSL-Student) <arh5tb@mail.umsl.edu>
Sent: Monday, August 1, 2016 6:17:41 PM
To: Jakiela, Mark
Subject: Teardown contract

For weight drop LED group:

Return all borrowed Legos to MEMS classroom.

Disassemble the remainder of the machine.

All cleanup from the time in machine shop and basement has already been accomplished.

Figure 44: Teardown Contract

11 APPENDIX A - PARTS LIST

Table 7: Final Parts List

#	Name	Manufacturer	Supplier	Part #	Quantity	Unit Price	Total Price
1	LEGO Motor	LEGO	Machine Shop	74569	1	$0.00	$0.00
2	LED	Unknown	Gateway Electronics	N/A	1	$1.95	$1.95
3	Cord	Fasmov	Amazon	TimingBelt-Black	3	$1.49	$4.47
4	Coupling	Lovejoy Inc.	Amazon	68514410206	2	$3.63	$7.26
5	Coupling Spider	Lovejoy Inc.	Amazon	68514410194	1	$1.22	$1.22
6	Cylinder Shaft	Thomson	Amazon	QS 1/4 L 12	1	$7.22	$7.22
7	Bearings	UXCELL	Amazon	1602-ZZ	3	$1.44	$4.32
8	Carabiner	Unknown	Previously owned	N/A	1	$0.00	$0.00
9	Alligator Clips		Gateway Electronics		2	$0.35	$0.70
10	Converter Gear	3D Printed	3D Printed	N/A	1	$0.00	$0.00
11	Large Lego Gears	LEGO	Amazon	3649	3	$0.26	$0.78
12	Small Lego Gears	LEGO	Amazon	3647	3	$0.26	$0.78
13	Lego Gear Shafts	LEGO	Amazon	3708	3	$0.26	$0.78
14	Screws	Unknown	Machine Shop	N/A	10	$0.00	$0.00
15	Motor Coupling	LEGO	Machine Shop	N/A	1	$0.00	$0.00
16	Wood Supports	N/A	Machine Shop	N/A	1	$0.00	$0.00
17	LEGO Technic Brick	LEGO	Machine Shop	3702	12	$0.00	$0.00
18	LEGO Bushing	LEGO	Machine Shop	3713	6	$0.00	$0.00
						Total Price	$29.48

12 APPENDIX B - BILL OF MATERIALS

Table 8: Bill of Materials

#	Name	Manufacturer	Supplier	Part #	Quantity	Unit Price	Total Price
1	Motor 1	Toshiba	Gateway Electronics	N/A	1	$3.40	$3.40
2	LED Type 1	Lumiled	Amazon	L128-4080CA3500001	5	$0.30	$1.50
3	LED Type 2	Unknown	Gateway Electronics	N/A	6	$1.95	$11.70
4	Cord	Fasmov	Amazon	TimingBelt-Black	10	$1.49	$14.90
5	Coupling	Lovejoy Inc.	Amazon	68514410206	2	$3.63	$7.26
6	Coupling Spider	Lovejoy Inc.	Amazon	68514410194	1	$1.22	$1.22
7	Cylinder Shaft	Thomson	Amazon	QS 1/4 L 12	1	$7.22	$7.22
8	Bearings	UXCELL	Amazon	1602-ZZ	10	$1.44	$14.40
9	Carabiner	Unknown	Previously Owned	N/A	1	$0.00	$0.00
10	Alligator Clips	N/A	Gateway Electronics	N/A	10	$0.35	$3.50
11	Shaft Converter	3D Printed	3D Printed	N/A	1	$0.00	$0.00
12	LEGO Pack 1	LEGO	Amazon	3649	1	$15.99	$15.99
13	LEGO Pack 2	LEGO	Amazon	3647	1	$15.49	$15.49
14	Lego Gear Shafts	LEGO	Amazon	3708	1	$6.95	$6.95
15	Screws	Unknown	Machine Shop	N/A	10	$0.00	$0.00
16	Motor Coupling	LEGO	Machine Shop	6538	1	$0.00	$0.00
17	Small Gear Shafts	UXCELL	Amazon	a13090200ux0053	10	$0.66	$6.58
18	Small Gear Pack 1	Lucksender	Amazon	Elec-A52-138	1	$6.84	$6.84
19	Small Gear Pack 2	UXCELL	Amazon	56102B	1	$6.08	$6.08
20	Epoxy	Great Planes	Amazon	GPMR6043	1	$8.99	$8.99
21	Wood Supports	N/A	Machine Shop	N/A	1	$0.00	$0.00
22	LEGO Motor	LEGO	Machine Shop	74569	1	$0.00	$0.00
23	LEGO Shaft Supports	LEGO	Machine Shop	N/A	12	$0.00	$0.00
24	Cylinder	3D Printed	3D Printed	N/A	1	$35.00	$35.00
						Total	$167.02