The Engineering Method (EGR 110): Final Lab Report

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Clock Design and Testing

North Central College

Fall 2018 (Due: 11/13)

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Executive Summary:

After finishing the bridge assignment, our class was given another one. This assignment involved coming up with a functional clock. This clock could have been anything; for example, a mechanical clock, a sand clock, or a sundial. In addition, the constraints were ambiguous and vague. Basically, all the clock had to do was display the time; however, you had to build all of it from scratch.

Me and Chris believed building a mechanical clock would be too frustrating, so instead, we came up with the idea of a water clock. The process behind building the water clock was very complicated and confusing; therefore, I will not go into detail in this summary, but I will give you a broad overview. In total, our clock consists of 9 parts. The two main parts of the design are the funnel and reservoir. The funnel is a part that holds all the water and it has a hole at the bottom that slowly flows water outward. And obviously, the reservoir part collects all the water from the funnel. Another important part in our design is the float. This part floats on the water in the funnel. As the water level decreases, the float goes downward. There are minute markings on the float. When the mark has passed, it means it has been a minute. Our design can only last 10 minutes. Thus, in total, there are 10 markings for each minute. There are other components to our design; however, these components do not serve any major functions besides helping our clock run.

All the parts I went over above were created from scratch in Solid Works and I used a 3D printer to print these parts out. The design took about a week to come up with and print it out. We spent $66.26 in printing filament and electricity in order to get the clock produced. I will go into more detail about the printing cost in the report. Fortunately, all our parts were printed correctly and were able to fit together. In the end, our clock was able to function correctly without any problems; therefore, this report is a success analysis and not a failure analysis. In addition, we had to present our findings to the class and talk about the clock we came up with.

All the information mentioned above is in this lab report. This page isn't as detailed as the pages below. Use the table of contents to navigate around.

Safety Review:

i. Moving Parts: Whenever the printer is on and printing something, keep all body parts away from the machine and gears. Never stick your hands or anything near the moving parts. Make sure you avoid the "pinch points" on the printer. The printer doesn't care what is there and it will crush it.

ii. Nozzle: The printer's nozzle can get up to between 260 degrees Celsius and 280 degrees Celsius. This is extremely hot and dangerous. Never touch the nozzle when you are printing or when it's warming up because it has the potential to give you third degree burns.

iii. Hot Filament: Be wary of the hot filament the printers spits out. Make sure you never touch the filament coming out of the nozzle because this is when it's the hottest and it will burn you.

iv. Motor: The printer has a motor in it, and these parts move. Make sure you don't get it wet or put anything inside of it. You might break the printer or harm yourself.

v. Fan: The printer has a fan and this moving part is open. Make sure you never stick anything by this part. Anyone with long hair, make sure you avoid this moving part.

vi. Cord: Make sure the electric cord to the printer isn't damaged or wet. If it is, make sure you notify everyone about it and find help.

vii. Carrying Printer: You should never really have to carry the printer. However, if you do, make sure you are wary of its weight and it is unplugged. And obviously, never move it when it is printing!

viii. Clean Workstation: It is critical that you keep your workstation clean and you put everything away where it belongs. A dirty workplace will eventually lead to accidents and someone might get hurt.

ix. Crowded Workplace: Whenever the printers are crowded with people, make sure you avoid bumping into anyone or just move out of the way.

x. Stool: Whenever you need to use the stool, make sure it locks into place. You should be about to hear it. And move it back to where it belongs after you are done with it.

xi. Water & Food: Make sure you never eat in the lab and you keep the area clean. Whenever you see a puddle of water on the floor or anywhere in the lab, notify everyone and clean it up.

xii. Backpacks & School Work: Make sure your belongings are in a safe place and away from walk ways. Anyone can trip over your stuff and this could lead to an accident.

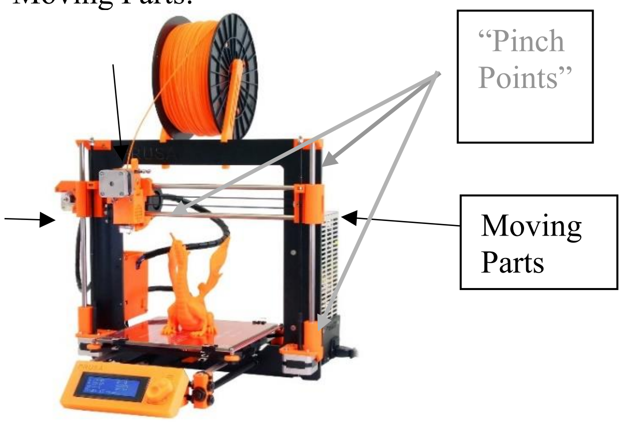
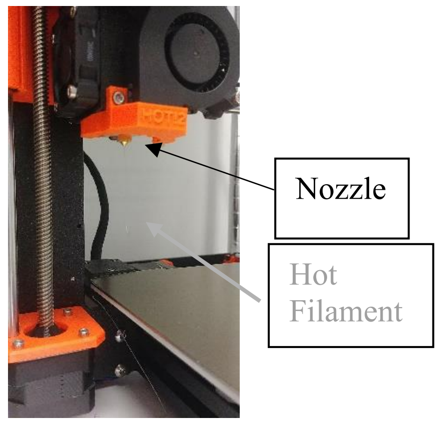
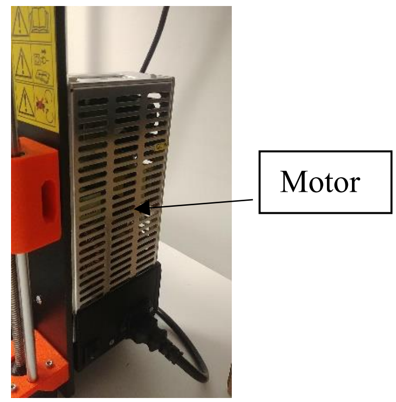
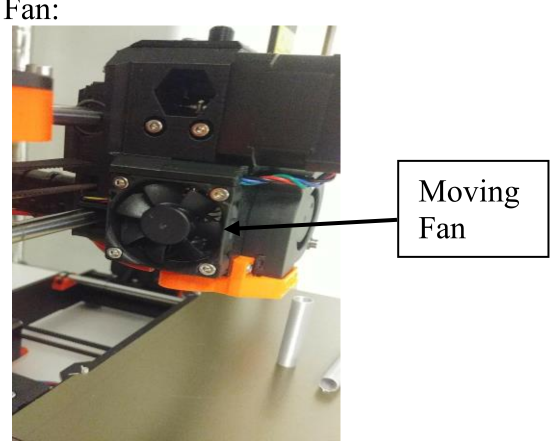
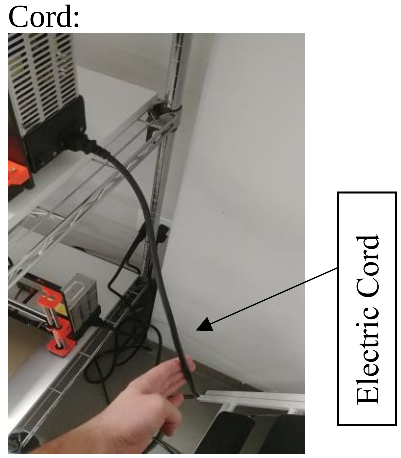
xiii. Horseplay & Running: Whenever you are in a lab like this one, all your attention should be on is your task and avoiding potential accidents. You should never run or goof-off in the lab because this will lead to accidents.

xiv. Lights: While there are people in the lab, you should never turn off the lights. This could lead to chaos and accidents.

xv. Outlets: Make sure you plug and unplug everything correctly into the outlets on the walls.

xvi. Communication: Whenever you have an issue or a problem in the lab, make sure you communicate it with everyone and you get help immediately.

Photos:

Moving Parts:	Nozzle:	Motor:
		
Fan: 	Cord: 	Outlet:  Stool: 

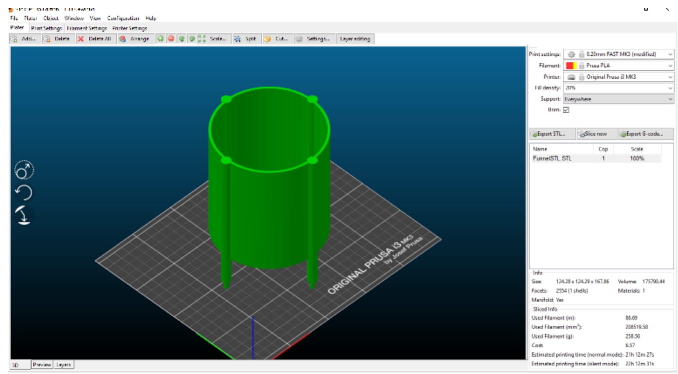
Cost Analysis:

The tables below show how expensive each part was to build and how much filament I used. Every one of these parts are included in my final clock design. In total, I used nine parts to build my design. All these parts are different; however, they all assemble in my design.

Parts:

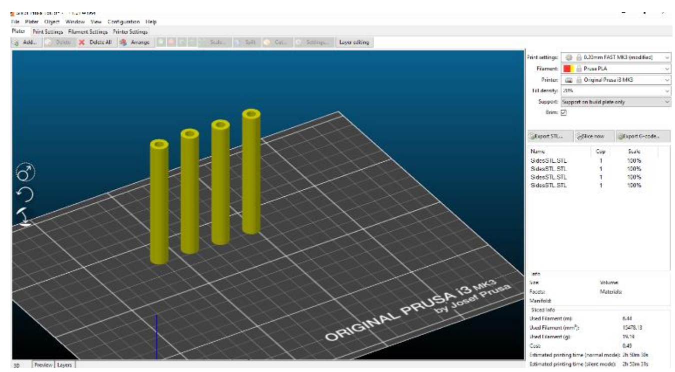
Funnel (Part 1):

Filament Measurement	Results:
Used Filament (m):	86.69
Used Filament (mm^3):	208519.58
Used Filament (g):	258.56
Time:	76347 s
Estimated Printing Time (Normal Mode):	21hr 12m 27s
Estimated Printing Time (Silent Mode):	22hr 12m 31s
Cost:	
Cost (US Dollars)	6.57



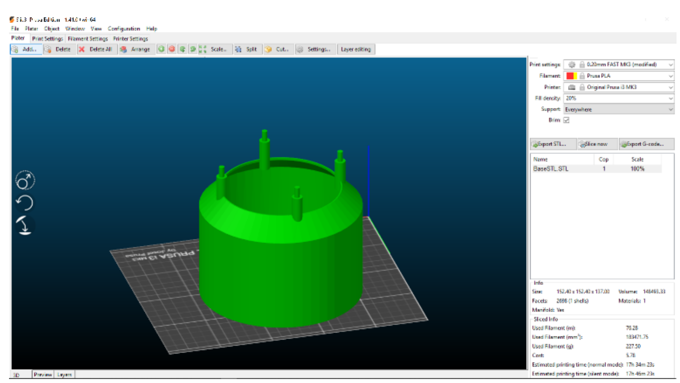
Sides (Part 2-5):

Filament Measurement	Results:
Used Filament (m):	6.44
Used Filament (mm^3):	15478.13
Used Filament (g):	19.19
Time:	10230 s
Estimated Printing Time (Normal Mode):	2hr 50m 30s
Estimated Printing Time (Silent Mode):	2hr 53m 31s
Cost:	
Cost (US Dollars)	.49



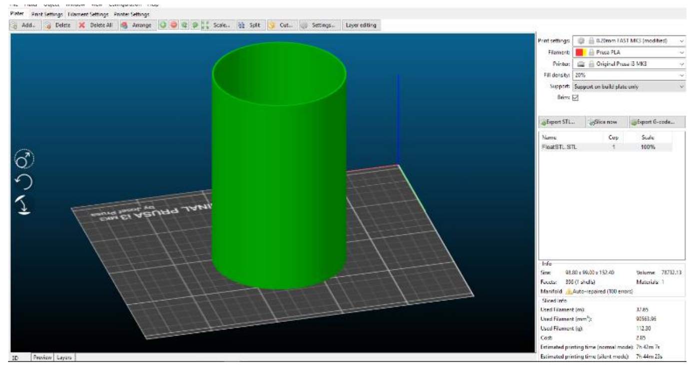
Base (Part 6):

Filament Measurement	Results:
Used Filament (m):	76.28
Used Filament (mm^3):	183471.75
Used Filament (g):	227.50
Time:	63263 s
Estimated Printing Time (Normal Mode):	17hr 34m 23s
Estimated Printing Time (Silent Mode):	17hr 46m 23s
Cost:	
Cost (US Dollars)	5.78



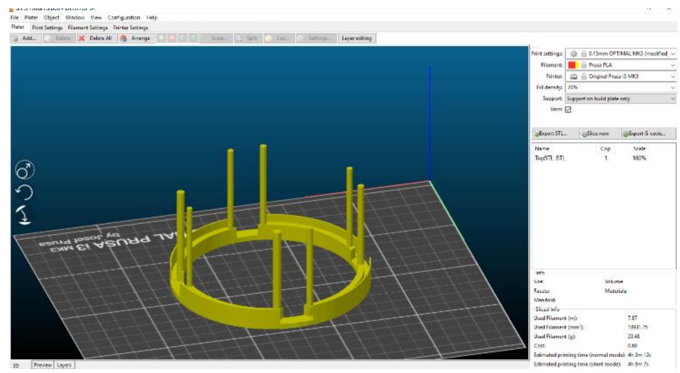
<u>Float</u> (Part 7):

Filament Measurement	Results:
Used Filament (m):	37.65
Used Filament (mm^3):	90563.96
Used Filament (g):	112.30
Time:	27727 s
Estimated Printing Time (Normal Mode):	7hr 42m 7s
Estimated Printing Time (Silent Mode):	7hr 44m 23s
Cost:	
Cost (US Dollars)	2.85



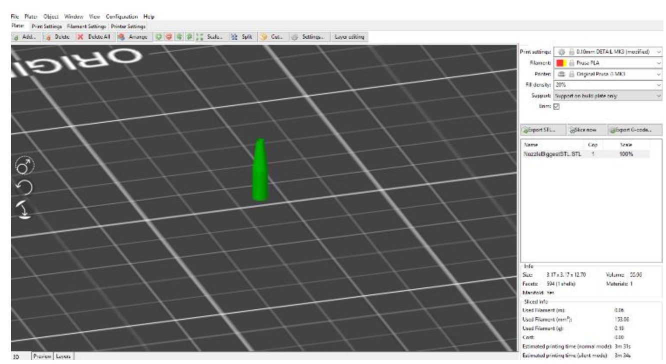
<u>Top</u> (Part 8):

Filament Measurement	Results:
Used Filament (m):	7.87
Used Filament (mm^3):	18931.75
Used Filament (g):	23.48
Time:	14592 s
Estimated Printing Time (Normal Mode):	4hr 3m 12s
Estimated Printing Time (Silent Mode):	4hr 8m 7s
Cost:	
Cost (US Dollars)	.60



<u>Nozzle</u> (Part 9):

Filament Measurement	Results:
Used Filament (m):	.06
Used Filament (mm^3):	153.06
Used Filament (g):	.19
Time:	211 s
Estimated Printing Time (Normal Mode):	3m 31s
Estimated Printing Time (Silent Mode):	3m 34s
Cost:	
Cost (US Dollars)	0.00



Although I have supplied the cost of printing, I still must show the overall cost, this is called the "build cost." The build cost involves how much electricity I used plus the cost of the filament, which I have already supplied. The next page has a table of the build cost.

Cost Parameters:

- Machine Time = $1 / hour
- Material Cost = $20.00 / kg

Equation: (Est Printing Time (Normal) sec/ 3600 sec)($1.00) + (Used Filament g / 1000 g)($20.00) = Cost

Item:	Calculations:		Cost:
Funnel	(76347 sec/ 3600 sec)($1.00) + (258.56 g / 1000 g)($20.00)	=	$26.38
Sides	(10230 sec/ 3600 sec)($1.00) + (19.19 g / 1000 g)($20.00)	=	$3.23
Base	(63263 sec/ 3600 sec)($1.00) + (227.50 g / 1000 g)($20.00)	=	$22.12
Float	(27727 sec/ 3600 sec)($1.00) + (112.30 g / 1000 g)($20.00)	=	$9.95
Top	(14592 sec/ 3600 sec)($1.00) + (23.48 g / 1000 g)($20.00)	=	$4.52
Nozzle	(211 sec/ 3600 sec)($1.00) + (.19 g / 1000 g)($20.00)	=	$.06
Total:	26.38 + 3.23 + 22.12 + 9.95 + 4.52 + .06	=	$66.26

"Build Cost"

Build Cost:

Overall, all my designs cost a grand total of $66.26, and this includes the printing filament and the electricity the printer used. This project was a lot more expensive compared to the bridge because I had to print out multiple parts and each one took a while to print out. In addition, I was not limited to only using less than 20 g, so I probably used a lot more filament than I should have. These calculations aren't included above, but I used 125.95 g in scrap filament in order to produce the two main components of the design, the funnel and base. I didn't include the other components because their scrap use was minuscule compared to these components. This means I spend about $14.52 dollars on scrap, including the electricity too. Overall, I am happy with the cost because all the parts printed correctly, and I didn't waste any extra money on failed prints.

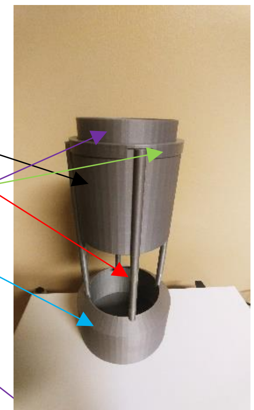
Saving Money:

From designing and printing my clock, I have found some great ways of saving money while printing. The best way to save money is to design your project in a way that uses the least amount of filament. Thus, you save on filament obviously; however, you will also save a huge amount of money on electricity. Another way of saving money is using the least amount of filament for support. Although this is risky and hazardous, you will save a lot of money on scrap and it will also decrease the printing time. You can do this a couple of ways. For example, you can manually adjust the filament settings on Slic3r or you can lay it on the printing platform in a way the uses less support. These techniques will drastically save you money because you will be using less filament and electricity, thus decreasing the build cost for your design.

Specification:

Below I will discuss the constraints I had to follow for my clock design. In addition, I will show how my clock followed all these constraints.

Clock Constraints:

<table>
<tr>
<td>Constraints Consist of the following:
1.) Must be assembly of at least 3 printed parts that you have designed from scratch.
2.) The clock must have an easily visible means of evaluating its function.
3.) You can incorporate other, inexpensive materials into the clock, such as water ball bearings, sand, cylindrical shafts, etc.
4.) You are not allowed to use imported files (files from the internet) to make any of your parts.
5.) You must be able to provide either data showing the performance of your clock, or a detailed failure analysis explaining why it did not work as intended.</td>
<td>Clock & Features:
1.) Printed Parts Include:
- Funnel
- Sides (4 Parts)
- Base
- Top
- Float
2.) Easily readable clock:
- The float has minute markings on it
3.) Incorporating materials include:
- Water
4.) All the parts were built by me: ✓
5.) Data will be provided below showing the performance of the clock.

</td>
</tr>
</table>

Scenario:

Let’s say you were living in the Middle Ages, which was between 476-1453 A.D., and you needed a clock in order to time exams. You are a professor and you must have a device that times the exams you give out. Instead of buying an inaccurate mechanical clock, you decide to use my water clock. One of your exams should only take your students 10 minutes to finish. You use my clock because you can easily see when it has been 10 minutes. The only thing my clock requires is some water, so you must have water accessible to you.

Below is a visual demonstration on how my clock can be used by you in order to time your exams:

Demonstration:
With my clock design, you can pay attention to the time and your student simultaneously without worrying about the clock failing on you.

In addition, your students can also check on their timing to see if they need to slow down or speed up.

Clock Design:

After being given the instructions and the constraints the clock had to follow, me and Chris, my lab partner, immediately started coming up with some ideas about different clocks. We thought about building a mechanical clock; however, the process behind it seemed complicated, so we decided to fold on that idea and build a water clock. Our original idea for the water clock consisted of two parts in Solid Works. The first part was a tank with a hole in it, and the second part was a reservoir to catch the water. With this rudimentary idea, we slowly started to build the clock and adjust it to the following constraints. The next page goes into detail about the process we took in creating the clock.

Process of Creating our Design:

i. The first part I designed was the tank or funnel because it was the most important part in the design. In Solid Works, I designed a 2D shape that looked like half of an upside-down home, and then I revolved it 360 degrees. In addition, I put 4 columns going through it. These columns served the main purpose of holding up the tank.

ii. Next, I created the sides. I created a circle in Solid Works and then I extruded it 3 inches. In total, there are 4 of these and they fit together with the columns on the tank. These parts give the tank more of a height. So as a result, you can see the water going through the nozzle.

iii. The reservoir or base was the next part I had to build. Building this part in Solid Works was very similar to building the tank. I used the same steps and features. But this part was a little bit bigger because I wanted it to hold more water than the tank. This part serves two major purposes in the design, it collects the water from the tank and it holds the clock upward in a standing position.

iv. After creating all these parts, we had to build something that could float on top of the water and give you a reading of the time. In Solid Works, I started with a circle that was about 99 mm in diameter and I extruded it 6 inches. Then I extruded cut part of the way through the cylinder. The design looked something like a large cup. The float was lightweight and had a lot of buoyancy. We expected this part would be able to float above the water and give an accurate reading of the time

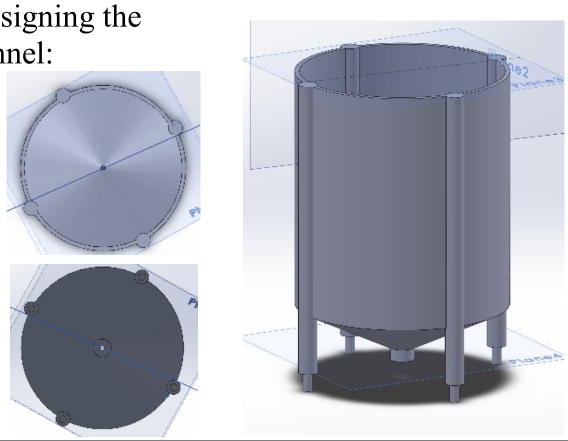
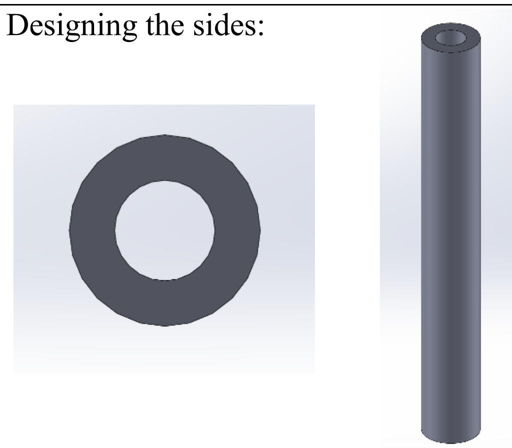
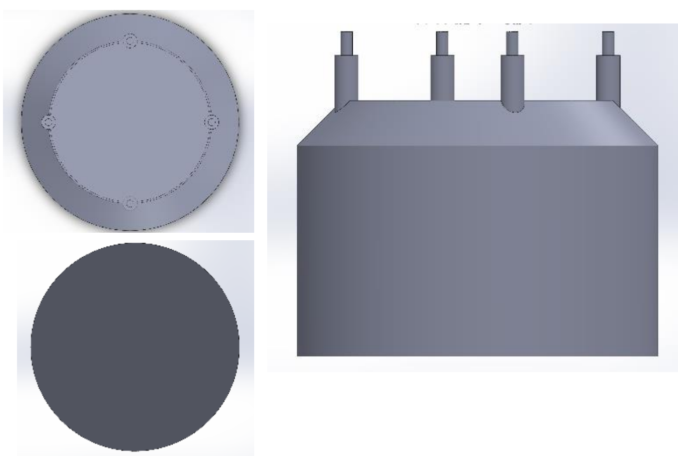
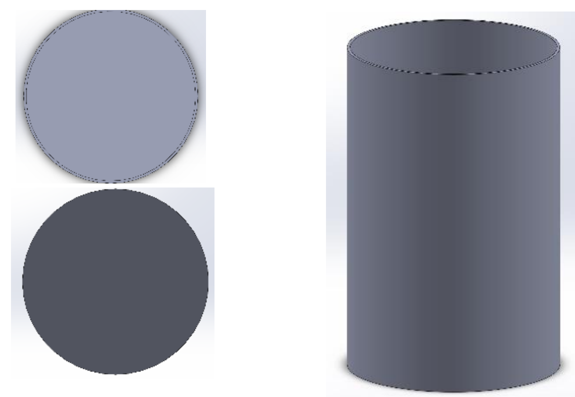
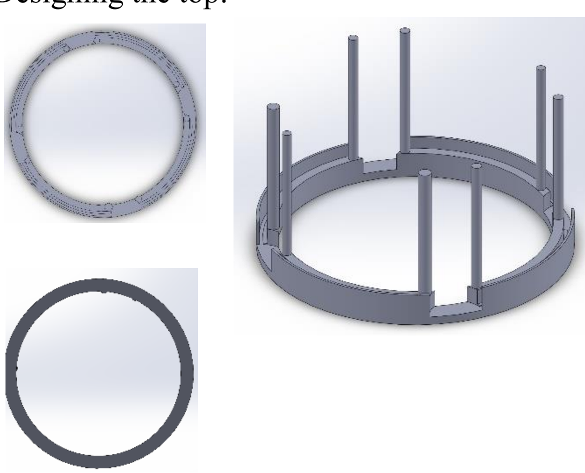
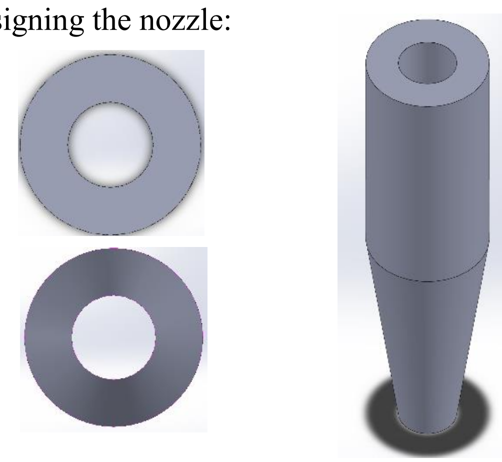
v. While testing our clock, we noticed the float part was unstable and was tilting around. To fix this issue, I created another part called top. The process behind this part on Solid Works is kind of confusing, so I won't explain how I built it. However, the only purpose this part has it to stabilize the float part while the clock is running. This part significantly decreases the amount of tilt with the float part.

vi. The last part we created was the nozzle or orifice. This part was designed with extreme detail because of its size. This part was able to fit inside the hole (1/8in in diameter) in the tank and slow down the speed of the water. Instead of having a 3-minute clock, we were able to get this clock to go to ten minutes because of this part.

vii. Finished design! – Followed All Constraints!

For more clarity, please look at all the pictures below. These pictures will help you understand the process I took in designing the clock.

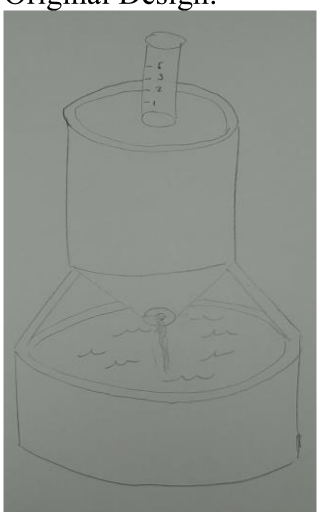
Pictures:

1.) Designing the funnel: 	2.) Designing the sides: 
3.) Designing the base: 	4.) Designing the float: 
5.) Designing the top: 	6.) Designing the nozzle: 

Concept:

Like what I said above, me and Chris's original idea was having to main components, a tank with a hole in the bottom and a reservoir to catch the falling water. And through the process of building the clock, we would fulfill all the constraints that were addressed. On the day we got the assignment, we came up with some sketches on how it would look and its function. Below are the drawings:

Original vs. Final Design:

Original Design:	Final Design:	Summary:
		As you can see, our original design looks very similar to the final design. However, there are some parts missing; for example, the original doesn't have the sides and the top part. And the floating part is a lot bigger on the final design compared to the original. But both of these designs share the same function we anticipated them to fulfill.

Project Plan:

Below is a timeline of the project, which shows what we got done every week and our productivity.

Week 6	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Develop Specification	Complete Design	Component Build	Final Testing	Team Presentation
Initial Concept	Engineering Analysis	Measurements	Assembly	Final Report
	Risk Mitigation		De-Bug	

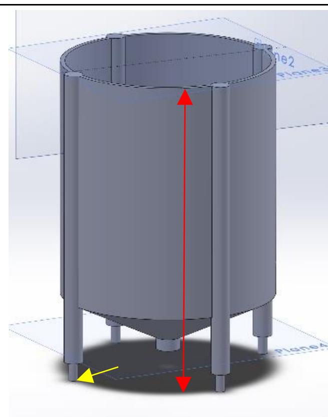
Design:

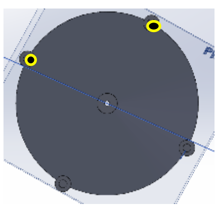
For this part of the report, I will be going through all the measurements of my final clock design. In addition, I will also go through the tolerance and design analysis. Below are all the measurements for each part in my design.

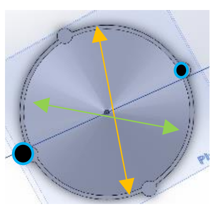
Measurements:

1.) Funnel:

Height (←→): 167.86 mm
Outer-Diameter (←→): 114.3 mm
Inner-Diameter (←→): 109.5mm
Thickness: 4.8 mm
Column Diameter (O): 10 mm
Column End Diameter (O): 5 mm

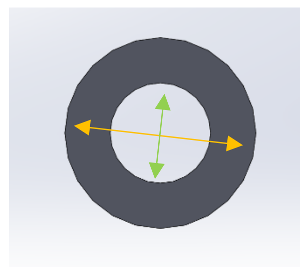


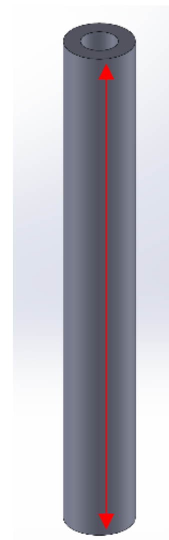




2.) Sides:

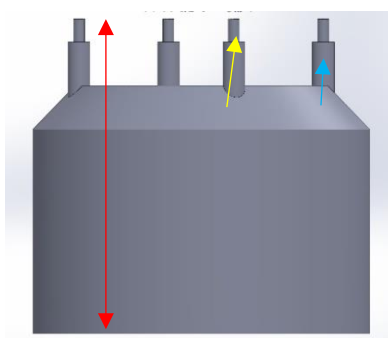
Height (←→): 76.2 mm
Outer-Diameter (←→): 10mm
Inner-Diameter (←→): 5.25mm

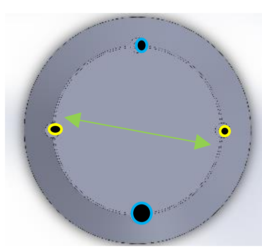




3.) Base:

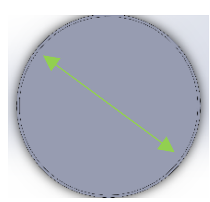
Height (←→):152.4 mm
Outer-Diameter (←→): 152.4 mm
Inner-Diameter (←→): 114.3 mm
Thickness: 2.75 mm
Column Diameter (O): 10 mm
Column End Diameter (O): 5 mm

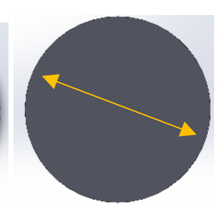




4.) Float:

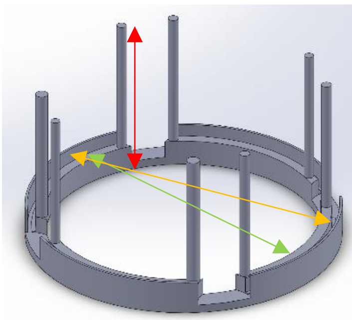
Height (←→): 152.4 mm
Outer-Diameter (←→): 99 mm
Inner-Diameter (←→): 96.25 mm
Thickness: 2.75 mm

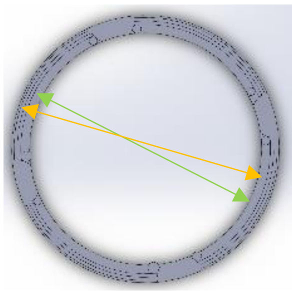


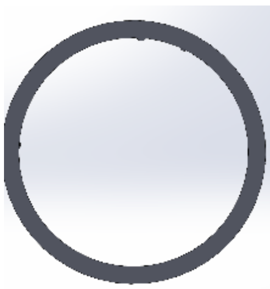


5.) Top:

Height (←→): 60.325 mm
Outer-Diameter (←→): 114.56 mm
Inner-Diameter (←→): 108.56 mm

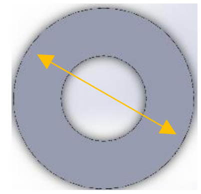


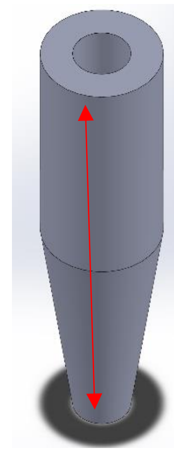




6.) Nozzle:

Height (←→): 12.7 mm
Top Diameter (←→): 3.175 mm
Bottom Diameter (←→): 1.5 mm
Thickness: 1.675 mm





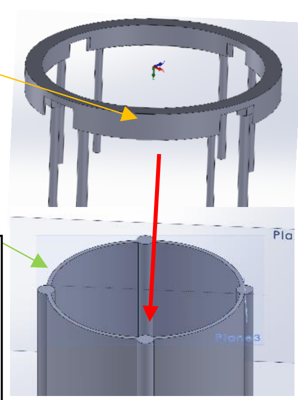
Tolerance Analysis:

For my design, I examined the tolerance for two different points. The first one is between the top and the funnel. And the other one is between the sides and the columns. The table below shows my calculations and results.

Tolerance Analysis Between Top and Funnel:

4.8 mm ± t_2
d_2 = 4.8 mm

6.0 mm ± t_1
d_1 = 6.0 mm



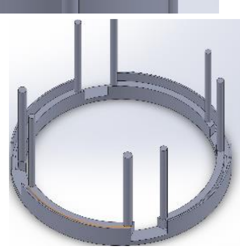
5.9 mm ≤ d_1 ≤ 6.1 mm
4.7 mm ≤ d_2 ≤ 4.9 mm

MMC: 6.1 mm Gap → 4.7 mm edge

Slip Fit: OK

MMC (Maximum Material Condition):

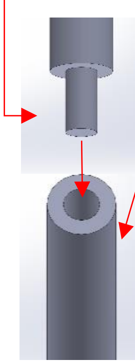
- Definition: Size of symbol that describes the condition of the feature.



Tolerance Analysis Between Sides & Columns:

5.0 mm ± t_1
d_1 = 5.0 mm

5.25 mm ± t_2
d_2 = 5.25 mm



4.9 mm ≤ d_1 ≤ 5.1mm
5.15 mm ≤ d_2 ≤ 5.35 mm

MMC: 5.1 mm Peg → 5.15 Hole

Slip Fit: OK

How I got the tolerance:

- From the last lab report, I figured out that the tolerance between two points is about .1 mm

Design Analysis:

For this section of the lab report, I will be going through exactly how we anticipated our clock to work and the calculations behind it. I will be talking about the rate of water flow through the orifice and how it works to show the time. Below is a table about the water flow through orifice.

Calculations for rate of water flow:

- To calculate the flow of water through an orifice, you must have three input values, primary pressure, secondary pressure, and the diameter of the orifice.

Three Inputs:
1.) Primary Pressure: 3.875 mmHgG
2.) Secondary Pressure: None
3.) Orifice Diameter: 1.5 mm

Height of funnel is about 3.875 in

Mercury was the closest unit to water

Equation(s):

$p_1 - p_2 < FL^2 * (p_1 - FF * P) \rightarrow$

$Q_w = 60 * C * (d_o / 0.183)^2 * (p_1 - p_2 / SG)^{1/2}$

$p_1 - p_2 \geq FL^2 * (p_1 - FF * P) \rightarrow$

$Q_w = 60 * C * (d_o / 0.183)^2 * FL * (p_1 - FF * P / SG)^{1/2}$

Symbol Meanings:
p1: Primary Pressure (psia)
p2: Secondary Pressure (psia)
do: Diameter of Orifice (in)
C: Discharge Coefficient
Q: Water Flow Rate (gal/h)
FL: Pressure Recovery factor (= 0.9)
FF: Critical Pressure Ratio Factor
P: Absolute Vapor Pressure of the Water at Inlet Temperature (psia)
SG: Specific Gravity

Results:
Water Flow Rate (WFR) = 1.19443 gal/hour

Conversion to mL:
(1.19443 gal / y mL) = (1 gal / 3785.41 mL)
y = 1.1993 * 3785.41
y = 4521.41 mL
WFR = 4521.41 mL/hour

Conversion to Minute:
(4521.41 mL/60) = (x mL/1)
x = 4521.41/60
x = 75.36 mL/minute

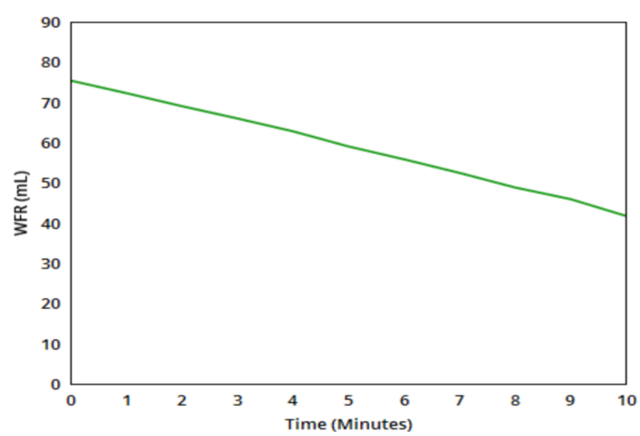
Evaluating time:

- As you can see to the left, I am able to calculate the amount of water that comes out of the funnel for each minute. Therefore, below is a small table of points that are calculated using the left side.

Time Table:

Minutes	WFR
0 min	75.36 mL
1 min	72.25 mL
2 min	69.01 mL
3 min	65.95 mL
4 min	62.76 mL
5 min	59.00 mL
6 min	55.80 mL
7 min	52.42 mL
8 min	48.80 mL
9 min	45.90 mL
10 min	41.72 mL

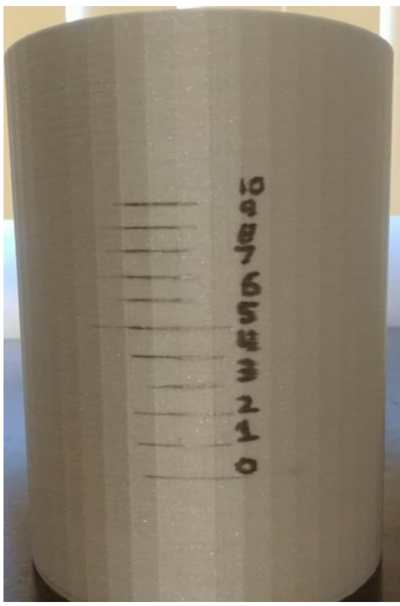
Time Graph:



Expected Results:

From doing the calculations above, I believe our clock will correspond to the following points that were in the table. And if not exactly, it will be close. I drew minute markings on the float part of my clock according to the calculations above. This is how we are going to evaluate the time. Every time the top part touches the minute mark, it means a minute has passed. Here is a picture of the float and its markings:

Front View of Float:



10 minutes

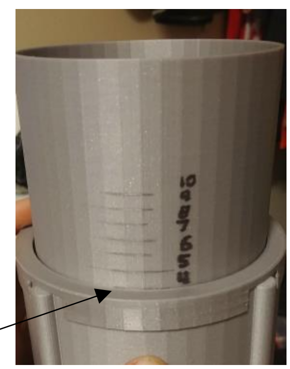
0 minutes

Viewing the Time:

- As you can see, it is very easy to view the time on the clock. It won't give you an exact time, but it will tell you whenever a minute has passed.

Example A:

Example B:



Examples of Readings:

- Example A: 1 minute
- Example B: 4 Minutes

Expected Conclusion:

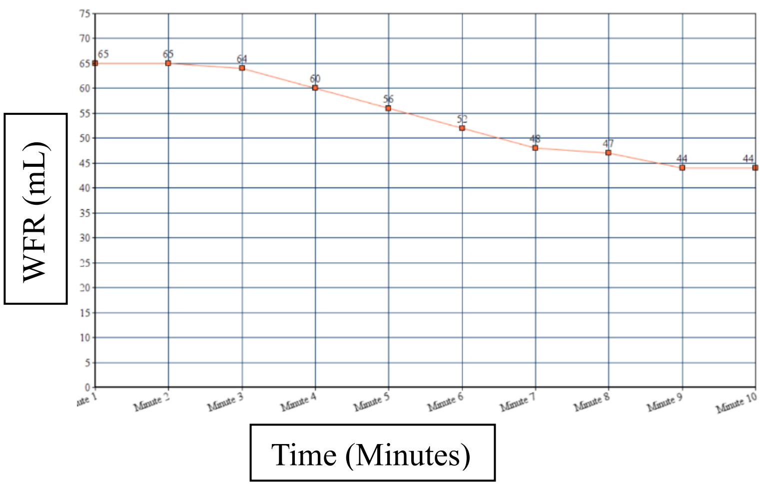
- I think I calculated everything well enough that the results will be very similar to the expected results. I will be going over my results on the next page for the verification section. In addition, I will discuss how my expected results differ from the actual results and maybe where I went wrong.

Verification:

A week before presenting our findings to the class, me and Chris tested our design to see how much water we loss for every minute. We recorded our results and plotted them in the graph below. As you can see, our data is very similar to the data above. Although our data was not exact, our clock was successfully able to keep track of time and follow all the constraints that were mentioned above.

Results:

Water Flow Rate Graph:



Water Flow Rate Table:

Time	WFR
1 min	65
2 min	65
3 min	64
4 min	60
5min	56
6 min	50
7 min	48
8 min	47
9 min	44
10 min	44

Experiment (Steps):

i. Filled the funnel with 975 mL of water. Put the float part inside the funnel and made sure it lined up with the zero marking. Placed a measuring cup underneath the orifice.
ii. For every minute, we would stop the clock and measure the amount of water that spilled out into the measuring cup. This is how we got the water flow rate for each minute.
iii. The maximum amount of time is 10 minutes, so we stopped the clock when we got to minute 10. The funnel had 432 mL of water left.
iv. Plotted and checked the data that we recorded.

Conclusion:

Looking at the water flow rate data, I think my results were close to the expected results, but they are far from being perfect. I think my results weren't perfect because there were a lot of factors that I didn't consider and count for. However, my clock was able to do its job and give an accurate reading of the time. Overall, I think I succeeded in designing a functional water clock because you can evaluate the time and use it without any problem.

In Class Presentation:

This link below will take you to our presentation slides we showed to the class:

- https://docs.google.com/presentation/d/1nDWRrxjG5pPnPgpgqZgvANqZlZWJj3BpMdfmiUj-_AM/edit#slide=id.p