Automated Sample Dispenser Final Design Proposal

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All work in this report is by the listed authors with the exception of properly cited materials.

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Executive Summary

The primary aim is to engineer a system capable of dispensing five different concentrations of solutions within 120 seconds while staying within the dimensions of 200mm by 200mm by 210mm, it also has a limited amount of 3D printing and laser-cut acrylic all while requiring minimal human intervention to operate. All these parameters are met using four different subsystems including a liquid dispenser and a powder dispenser, a gearbox attached to a turntable and a mast with cross beams. This report will emphasize the problem that needs to be solved by creating unique methods and designs for each subsection in an attempt to solve the proposed problem.

A lot of ideas and trial and error were necessary in order to find a working design. During the first stages of making a design, many unrealistic ideas were made that proved unfeasible upon further investigation. For example, the prototype was planned to be fully enclosed, but there were not enough resources to accommodate that idea. Making a weight-based powder dispenser seemed to also a good idea but it also proved to be unrealistic due to the limitations of the electronics received. As more efficient and reasonable ideas were made, the final design slowly came together.

The model comprises four key functional subsystems: the powder dispenser, liquid dispenser, mast and supports, and the gearbox turntable system. These components were integrated to achieve a seamless and efficient automated fluid dispensing system. In order to accurately dispense the desired amount of powder and liquid into the test tubes, it is very important to have a constant rate of flow so that dispensing it can be time-based. The powder dispenser is made up of a small 3D-printed reservoir on top of a vertical gear that dispenses powder into each test tube. As the gear moves, the teeth collect small amounts of powder and consistently dispense a measurable amount of powder. The liquid dispenser consists of a waterproof reservoir; which is a small water bottle that can hold 150 mL of water, and a peristaltic pump; which can pump the water out of the reservoir and deposit it into the test tubes at a consistent rate of flow. The gearbox and turn table system are equally important as the dispensers as it is needed to rotate the turntable. It is composed of three gear stages; that produce a gear ratio of 1000 to 1, a large ball bearing; which is necessary to hold the weight of the turntable, and a turntable; which holds five test tubes. Finally, the entire model is held together by a mast which consists of two supports on either side of the model with a hollow crossbeam to hold all the necessary parts.

The final product resulted in a complete and theoretically fully functional automated fluid dispenser, meeting all the specified requirements, and operating within the designated time frame without spillage or potential harm. With the calculated speed of the turntable, as well as a logical analysis of the fluid and solid dispensers, testing the automated sample dispenser should fall easily within time constraints. Along with testing, there are no foreseeable problems with concentration.

In conclusion, the project culminated in the creation of a theoretically fully functional automated sample dispenser. Overcoming challenges and refining designs with new and better ideas, the model integrated four key subsystems that met the specifications of the problem. This includes the powder and liquid dispensing, a gearbox turntable system, and a sturdy mast support.

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1. Problem Definition

1.1 Project Goal

The aim of this project is to create a fully functional and sustainable automatic sample dispenser that will be able to produce five different samples of solutions with different concentrations of Naloxone hydrochloride dihydrate [1], the active pharmaceutical ingredient (API) used to block or reverse the effects of opioid drugs mixed with water. This project, which is supported by HumanEng Inc., will attempt to help reduce the number of deaths worldwide caused by overdoses from drug use. For it to be used for pharmaceutical purposes, the automatic sample dispenser must consistently produce the exact concentration inputted so that it can reliably and accurately dispense medications. The engineering team will attempt to create an effective automatic sample dispenser collectively by integrating innovative technologies, employing precision engineering methodologies, and conducting thorough testing protocols. To test the dispenser, Kool-Aid powder will be used as the solute instead of the API to avoid any chemical risk that could impact the health of the team creating the dispenser. The design and function of the automatic sample dispenser will be separated into four different sub-sections including the mast, which holds the structure together, the powder dispenser, the liquid dispenser, and the gearbox and turntable. The design will also be heavily influenced by the stakeholders that are interested in the project. Specifically, the project must align with the Health Canada protocols, which includes the requirement for clinical trials, the requirements of the Food and Drug Administration, and the United Nation sustainable development goals where the project can ensure healthy lives for all audiences experiencing the effects of opioid drugs [2] [3]. The inclusion of stakeholders will not only enhance the performance of the dispenser but will also contribute to the overarching goal of mitigating opioid-related overdoses on a global scale. Furthermore, the goal is to make a safe and sustainable model of the automatic sample dispenser by considering Engineers Canada's sustainability guidelines that can be easily accessed by all audiences.

1.2 Product Function

This automated sample dispenser must be able to autonomously prepare five solutions containing Naloxone hydrochloride dihydrate, an active pharmaceutical ingredient (API), and water in a rotating test tube rack. The automatic sample dispenser has a lot of components and is spread out into four sub-functions. The powder dispenser is one of the sub-functions that dispenses powder using a flap that can open via the servomotor. The powder reservoir is just on top of the flap so that once the flap opens, gravity allows the powder to pour into the test tube. Using this strategy, dispensing the powder can be time-based as it will be dispensed at a relatively constant rate. The rate was calculated to be about 0.4 grams per second meaning that placing the amount of solute needed was as only calculating the time for it to dispense was needed. The liquid dispenser, another sub-function that works similarly to the powder dispenser, contains a peristaltic pump that allows the dispensing of water using pressure at a very consistent rate of 1.3 millilitres of water per second. This means that, unlike the powder dispenser, the liquid reservoir does not need to be directly on top of the test tubes, instead, the reservoir can be placed anywhere. The third sub-function consists of the turntable, which will hold the test tubes, and a gearbox, which will determine the speed at which the turntable rotates. For the automatic sample dispenser to work, the turn table must be able to spin at an appropriate speed so that every test tube can be filled with different concentrations. The team was able to calculate that having a gear ratio of 1000:1 is an appropriate ratio to have the desired speed. Finally, the mast will be able to hold everything together with minimal shaking using two acrylic stands and a shelf in the middle to hold both dispensers.

There are also a lot of electronics and code that are needed in order to have the automated sample dispenser work. Figure 1 below shows the process that occurs as the mechanism fills all 5 test tubes. To begin, there must be an input force which is activated by the press of a button. Once activated, the gearbox starts rotating the turntable until it makes contact with a limit switch. Once it makes contact, the Arduino receives the signal and allows the liquid and powder dispensers to pour for a desired time . After time passes, the Arduino allows the gearbox to rotate the turn table again. The process repeats 5 times as all the test tubes fill up with the desired concentration before stopping.

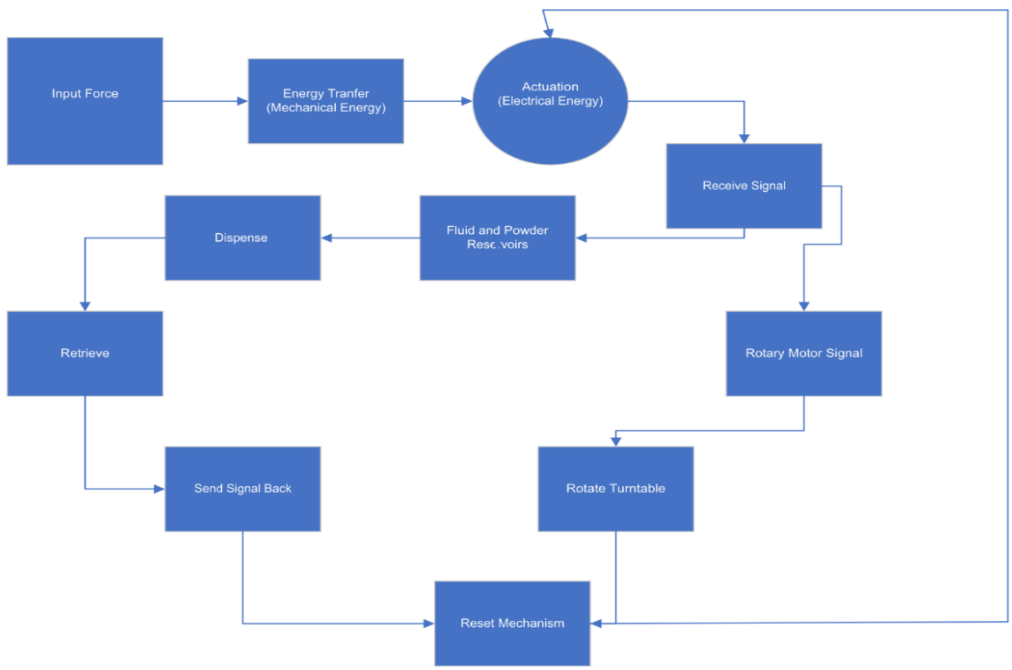

Figure 1: Diagram that displays the order that the automated sample dispenser will work. It requires an initial input force so that it can be activated, all the other processes including the rotation of the turntable and the dispensing of the liquid and powder will run autonomously.

1.3 Constraints

There are many constraints that must be considered during the designing of the automatic fluid dispenser. All the specifics of the constraints can be found in }
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Appendix IV – Constraints List. Most importantly, the automated fluid and powder dispenser must be able to assemble and disassemble so that it can be easily transported. The device must also be the right size so that anyone can use it, more specifically, the device must fit within maximum dimensions of 200 by 200 by 210 millimeters. It is also important to note that the dispenser must be able to fill all test tubes within 120 seconds, this will greatly affect the team's decision to determine the rotational speed of the turntable. Furthermore, resources are also limited as only a total allowed 3D printed filament volume is 30000 mm^3, such that maximum total printing time is 90 minutes. This could be a tough limitation to overcome since there could be a lot of parts that need to be 3D printed, including the fluid and powder containers. Furthermore, there is a limitation on the amount of acrylic that can be used and will be used to make the housing of the dispenser and will also be used as a case for all the electronic components and gearbox. These limitations can be easily overcome by planning with the team and figuring out the best strategy to make the dispenser effectively work at the appropriate size whilst also remaining resource friendly.

Aside from this specific project's constraints, there are critical medical and pharmaceutical codes, standards, and regulations that must be met when designing automated dispensing devices. While not required for the first prototype, they should be considered in all future designs that may be produced on a large scale. Automated powder and fluid devices are very important in the medical field and therefore must meet very specific regulatory and quality requirements. Since the COVID-19 pandemic, these restrictions have been heightened as the medical and pharmaceutical industry further transition from manual to automated devices. These standards include repeatability, process control, traceability, volume throughput, cost efficiency and assembly [4]. Additionally, all automated medical devices must meet standards for patient safety such as having override access, safety checks and maintenance, access to electronic medical profiles, downtime procedures in case of malfunction, and specifically, safety features of unit-dose drug distribution [5]. As later discussed in section 3.1 Hypothetical Design, the design process for automated medical dispensing devices should also prioritize patient care over resource and cost efficiency.

1.4 Customer Needs and Stakeholders

This automated fluid dispenser is being designed for use and distribution in the pharmaceutical industry, specifically to block or reverse the effects of opioid drugs with the intention of reducing deaths by overdose. HumanEng Inc. is the supporting company in this design, development, and manufacturing process, and like any stakeholder, has certain expectations for this product. Primarily, the automated fluid dispenser must have the ability to operate autonomously, using only a start and stop button, to create a series of solutions by mixing given ratios of naloxone hydrochloride and water.

This product must also prove to work in the way advertised to maximize sales, profit, and ultimately, the customers' trust in the product. This aspect of product design and marketing introduces various other stakeholders such as regulatory bodies. For example, the device would be heavily regulated by the department of government responsible for national health policy, Health Canada [3]. Clinical trials would be used to assess whether the dispenser met pharmaceutical regulations. Otherwise, any required design revisions would have to be further funded by Queen's University to meet the requirements. Furthermore, the automated fluid dispenser must also meet the guidelines of the Food and Drug Administration for pharmaceutical production and the Current Good Manufacturing Process (cGMP) standards for approved distribution in a pharmaceutical setting. Therefore, the financial security of the stakeholders is dependent on a well-developed design that meets customer needs and ministry standards without major last-second revisions.

While not always obvious, the product should also be appealing and user-friendly. This includes accounting for design aspects such as neat body lines, and easy assembly and disassembly for cleaning and accessing components. This can be accomplished by having a large, transparent opening that allows for easy movement of test tubes and components while still maintaining structural rigidity and insulation. The placement of components is also crucial to avoid complications with exposed wiring and possible unnecessary repairs. Additionally, the interface must be simple and easy to set up and operate for new and less experienced users, which is why there will only be a start and stop button. The specific mixture ratios will be entered via an intuitive separate digital interface that will be connected to the Arduino. Substance transport tubes must also be placed away from contaminating agents such as lubricants to prevent any interference.

1.5 Safety Risks

The primary requirement of the AFD being autonomous eliminates the possibility of human contamination during the solution formation; however, there are many construction elements that can still result in safety risks. For example, all wires and transport tubes must be fastened and concealed in an orderly fashion to decrease the possibility of them being pulled or displaced when exchanging or cleaning components. Additionally, to prevent electrical failures, fires, and/or electrocution, all electronics must be in a water-resistant enclosure, away from liquids. This includes routing wires as far as possible from any fluids, including the water reservoir and transport tubes. Additionally, all electrical components near the entrance should be enclosed in case of spillage while assembling or using the product. To prevent internal failures, precautions must be taken in terms of voltage supply, as if the electronics are overloaded, it may result in electrocution or product malfunction.

During assembly and evaluation, it is important to note the mechanical hazards associated with the gearbox. It must be sealed so that there is no contamination from lubricants, fluids, or scraps as these could cause the gears to fail. If the test tube is not aligned properly, gearbox failure could occur which will result in dispensing fluid or powder into the mechanism. Contact or accidental consumption by the operator of any powders or fluids in concentrated amounts can be very dangerous and should be prevented. Additionally, any mechanical errors could alter the concentration of the solution and therefore is also a risk to the health of the patient.

2. Prototype and Testing

2.1 Design Process and Drawings

2.1.1 Mast Structure and Electronics Housings

The design process for the mast structure and electronics housings was conducted following a set of key criteria including rigidity, safety, and material/dimensional constraints. The specific requirements can be found in }
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Appendix IV – Constraints List.

The mast structure had to be able to support components such as the Arduino, powder dispenser, and liquid tubing all without exceeding 10mm of deflection when applied with a force of 5N. The original design for the mast was very large and enclosed most of the product with acrylic; however, it was quickly realized that this would have used far too much material. To achieve a similar function without using too much material, two acrylic walls were made with a 3D printed insert that spanned between the two walls, both increasing stability and modularity of the mast. The insert was printed with space hollowed out to allow for mounting of the powder and fluid dispensers above the test tubes. While this solution is not very enclosed, it provided the best compromise between functionality, stability, and material consumption (refer to Figure 2). To hold the walls to the pegboard, small 3D printed friction fit mounts were designed. These used little material and maintained the ability to use the pegboard instead of printing an entirely new platform. This design emphasized using the stronger material for the supporting walls and the weaker plastic with 10 percent infill for the accessory components.

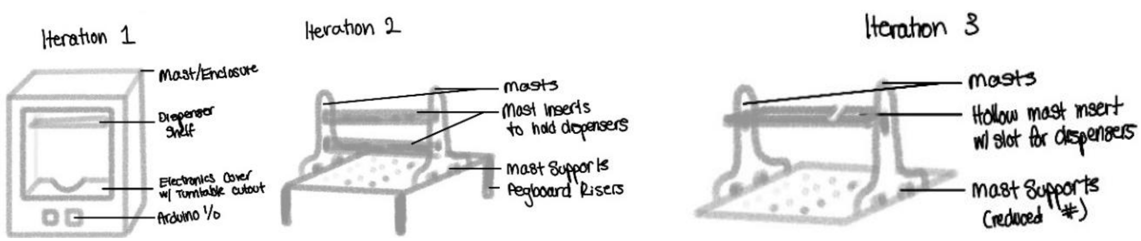

Figure 2: Major design iterations of mast assembly and product structure.

As for the electronics housings, there were not many design iterations. Initially, acrylic material was supposed to be used to enclose the Arduino, motor shield, and breadboard; however, after reconsideration, it was decided that because the acrylic was only available as 6mm thick, it would be too space consuming. Additionally, by 3D printing these parts, it would be easier to modify and make cutouts for the input and output ports (refer to Figure 3).

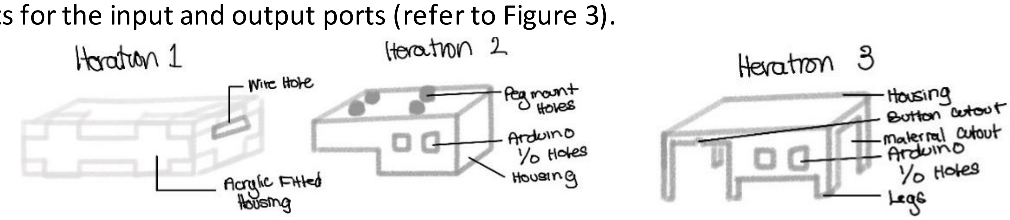

Figure 3: Major design iterations of electronics housings.

The limit switch holder was also 3D printed with a friction fit peg mount so that it could be moved around on the pegboard to find ideal positioning (refer to Figure 4). Having a modular design for the limit switch accommodates for future modifications during the building process in case revisions were be made.

Figure 4: Modular limit switch holder.

All the design choices for this subfunction and its accessories were also made with consideration for usability, reliability, sustainability, manufacturability, and testability. As mentioned above, more material would have allowed this product to be more enclosed and rigid, theoretically increasing its safety and longevity. This is because with this design, the test tube and powder reservoir are very exposed to the surrounding environment and could be easily contaminated. Additionally, by having a larger enclosure, the product would be easier to transport and store without worry of damaging any components. With that being said, products that require a lot of plastic are not very environmentally friendly due to their eventual disposal. Material usage was further reduced by using other items to replace components such as the pegboard stands that did not need to be acrylic cut or 3D printed.

2.1.2 Gearbox and Turntable

To design an appropriate and effective model of the gearbox, many constraints must be considered. To begin, the stakeholders suggest that the entire prototype must fit in a 200 x 200 x 210 mm area, which means that the gear box must be designed in such a way that other components can also fit in the prototype. The team decided to place the gearbox beneath the pegboard in the final design to maximize space for the water and powder reserves, the turntable, and the mast. Furthermore, putting the gearbox below the peg board implies that the rotating table will be at a lower height, allowing the masts to be at a lower height as well, making it less prone to bending. This means that the gearbox must meet the requirement of having a height of less than or equal to 50 mm. The first design of the gearbox, shown in Figure 5, presents a relatively lengthy model of the gearbox where it shows the three gear stages in a linear pattern.

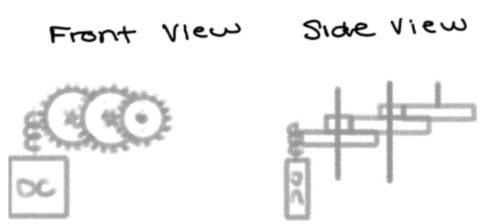

Figure 5: The front and side view of the gearbox in its linear form.

This initial model seemed to work very well, as it could fit under the pegboard since it had a height of less than 50 mm, but it was problematic because using this model forced the electronic housing to move to an unideal location. To solve this problem, the gearbox was compressed, as shown in Figure 6, so that the electronic housing could fit.

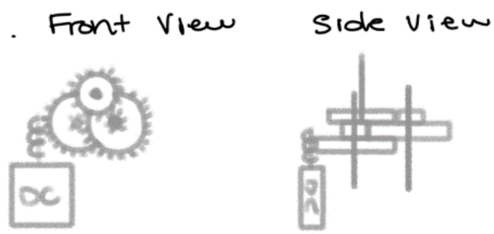

Figure 6: The front and side view of the gearbox in its compressed form.

Changing the gearbox design to a more compressed model worked very well as it could still fit under the pegboard, the gears could still rotate smoothly, and it could also have the electronic housing in its ideal spot on the automatic sample dispenser. The final product of the gearbox is shown in Figure 7.

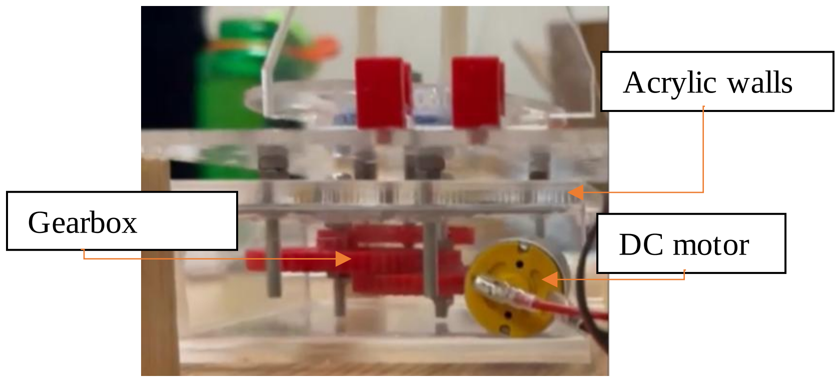

Figure 7: The side view of the built model of the gearbox in the automated sample dispenser.

The gearbox also must be in an enclosed space to avoid any risk of injury or damage that could occur while testing the automatic sample dispenser. To do this, the gearbox was placed in a case made of acrylic as shown in Figure 7Figure 7. The case is separated into a front and a side wall, a side wall with a hole in it so that the DC motor can fit, which is also presented in Figure 7, and a ceiling and floor. The open side of the case points towards the inside of the dispenser where there is a very low risk of damage.

When making the design for the gearbox and turn table, there seemed to be a lot of weight on the last gear of the gearbox from the turntable and its test tubes. This extra weight would make it much harder, if not, impossible for the DC motor to move the gears. Because of this, the team decided to come up with an effective solution to 3D-print bearings just below the rotating table to effectively remove the pressure on the last gear as shown in Figure 8.

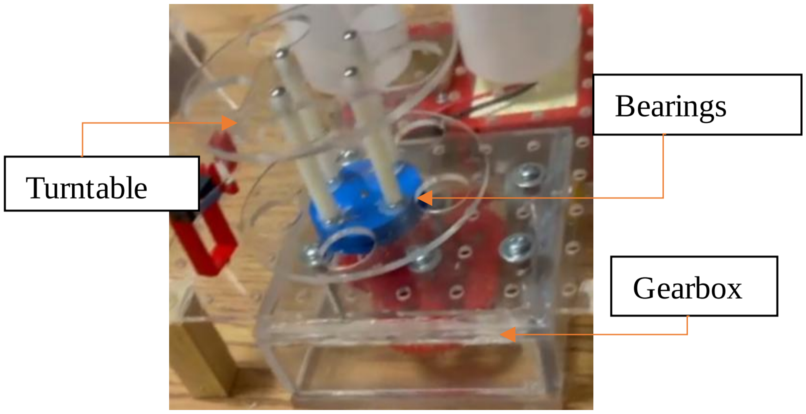

Figure 8: The top view of the built model of the gearbox in the automated fluid dispenser.

2.1.3 Powder Dispensing

The powder dispensing system had specific requirements. It had to dispense powder with just the push of a button press, delivering a precise amount of powder to create an arbitrary concentration in each test tube. To begin, the group brainstormed various methods of powder dispensing.

The first model design was conceptually simple since it makes use of a flap that can be configured by the servomotor to open and close vertically. But with that being said, it was a challenge to position the servomotor to open and close in such a manner given the mast the group built. Moreover, the powder may be dispensed inaccurately due to the inaccurate orientation of the slant.

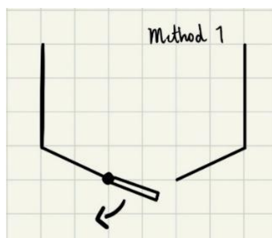

Figure 9: First method of dispensing which makes use of a single flap to dispense powder.

The second model was the chosen design. Designed through SolidWorks, it made use of a gear mechanism to dispense the powder. A 20-tooth gear would rotate through the servomotor which could be coded and controlled. Even though a 0.5mm clearance fit was used, the 3D printed material was inconsistent and thus, the gear was the perfect width, yet the length was of inaccurate size. Because of this, the gear had to be sanded and clipped down so that it would fit its component. Although it eventually came down to its correct size, the coarse powder would not dispense and led to the component being constantly jammed with no way for the servomotor to overcome it.

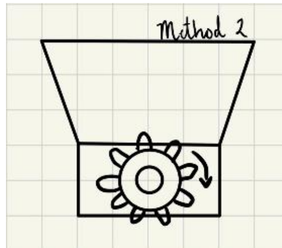

Figure 10: Second method of powder dispensing which utilizes a rotating gear.

The last model makes use of a piece of paper attached to the flap of the servomotor to act as the cover for the opening of the dispenser. This was the improvised Method 2 (refer to Figure 10). Because this method is based on gravity, the group calculated the rate of the amount of powder dispensed at a constant time, since gravity is the only external force acting on it. The group found the rate at which the powder is dispensed by mathematically solving the correct amount of time to dispense a specific amount of powder. For 1 gram of powder to fall, the flap had to stay open for 2.35 seconds. This equates to 4.7 seconds if 2 grams of powder were to be dispensed.

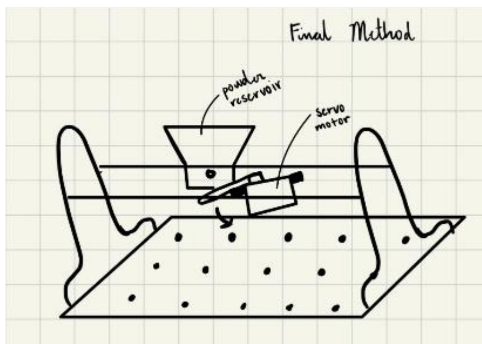

Figure 11: Final method for dispensing. Shows improvised method.

2.1.4 Liquid Dispensing

The fluid dispensing system had minor constraints. It had to dispense 20mL of fluid into test tubes 1 and 4, and 15mL into test tubes 2, 3, and 5, in a timely manner to not exceed the overall time constraint of 120 seconds. While also fitting in the requirements of 3D printing material, acrylic cut material, and overall dimensions. The lack of constraints made it a very easy part to change and was therefore a last priority for use of material. The original design involved a 3D printed reservoir capable of holding 100mL of water, therefore having a 100cm3 rectangular volume. This design had a large hole at the top for easy refilling with a perpendicular ring on the side. This acted as a peristaltic pump holder. This part was compact; however, due to the dimensions of the other parts, there wasn’t space on the 200mm-by-200mm pegboard for the part. The second iteration avoids the problem of fitting by being separated into two separate parts, the reservoir, and a separate holder for the peristaltic pump. Also, by changing to a cylindrical reservoir, it took advantage of the excess vertical space while keeping the large hole for refilling. The pump holder now used triangular supports attached to a tube the length of the body of the pump. At the base, there were small pegs that fit into the board. However, when it came time to print out the parts, there wasn’t enough 3D filament in the parameters of the project to print out the liquid dispensing system. This meant all previous designs had to be completely scrapped. There was a space of

100mm by 200mm on one side of the pegboard to build the fluid dispensing system. Instead, two plastic bottles were used, one as a reservoir and another next to it to hold the peristaltic pump and other wiring inside as a waterproof container. Initially, there was a small 3D printed piece to attach to the mast to hold the tubing that came from the pump to dispense. Using a smaller version of the pump holder, the tubing could easily be slid through to accurately dispense into the test tube. This design was also scrapped due to the lack of 3D material. The solution was to use the gap between the two bars in the mast to hold the tubing in place; no other piece was needed. (See Appendix VI for image)

2.2 Testing and Modeling Evaluation

2.2.1 Mast Structure and Electronics Housings

For testing, the mast structure was required to experience less than 10mm of deflection when applied with a force of 5N. The modeling equations predicted that the mast should have been able to withstand this easily; however, it was also noted that during testing it would likely experience greater deflection than the calculated value of $6.25x10^{-4}mm$. The modeling calculations can be found for this below [4].

$$\delta_{max} = \frac{FL^3}{3EI} \qquad [1]$$

$$\delta_{max} = \frac{(5N)(155mm)^3}{3(3.2x10^3MPa)(\frac{(10mm)(155mm)^3}{12})}$$

$$\delta_{max} = 6.25x10^{-4}mm$$

During testing, the mast did withstand the 5N force without deflecting greater than 10mm; however, as predicted, it experienced a greater maximum deflection than calculated. This rigidity of the mast remained consistent and reliable throughout the entire building and testing period. Additionally, the limit switch holder and electronics box kept the parts stable and protected from potential spillage during product operation. Section 3.1 Hypothetical Design describes a hypothetical physical system that should experience less maximum deflection.

2.2.2 Gearbox and turntable

For testing, the gearbox was required to rotate the gearbox 360 degrees so that every test tube could be filled by the dispenser. By using the gear ratio of 1000:1, which was calculated by the team, the gearbox would be able to rotate the turntable at a relatively fast speed. However, during the testing, the worm gear could not make close contact with the 50-tooth gear. Because of this, the speed was drastically decreased as the gears would not move consistently and would even stop moving in some cases. Having the DC motor closer to the 50-tooth gear by adjusting the location of the hole on the acrylic wall could allow for more contact between both gears. Furthermore, a support made of acrylic could be used to slightly adjust the angle that the DC motor is facing so that the worm gear can have more contact with the 50-tooth gear.

2.2.3 Powder Dispensing

Method 2, shown in figure 10, shows a gear inside the reservoir which rotates to dispense powder. During testing, the gear was constantly jammed, and the motor was not powerful enough to overcome this. To fix this issue, the reservoir opening might have needed to be bigger in width and length. This is hard to model because powder cannot fall through involuntarily and due to the inconsistencies of the 3-

d printing materials. For testing, the powder dispenser was required to dispense 1 gram of powder into test tubes 1, 3, 4, and 5 and 2 grams of powder in test tube 2. Method 3, shown in figure 11, was used instead as a way of improvising the already printed reservoir from method 2.

2.2.4 Liquid Dispensing

Testing of the fluid dispensing system required it to dispense 20mL of fluid into test tubes 1 and 4, and 15mL into test tubes 2,3 and 5. Initially the rate of flow from the peristaltic pump needed to be found. Using the known volume of the test tube and running the pump until it was empty the rate was found to be 0.756mL/s. During the testing there was some error in time of dispensing however once that was fixed in the code the liquid was dispensed nearly exactly at 20mL for the first test tube.

2.3 Prototype Outcome

2.3.1 Mast Structure and Electronics Housings (Ethan Solnik)

After completing the design for the first prototype, several small changes were made in the actual construction process due to unaccounted for errors and restricted printing materials. These include using wooden posts instead of 3D printed, as well as only using two mast support pegs per wall instead of four. Additionally, hot glue was used to secure loose fitting pegs to the pegboard to increase the rigidity. On the other hand, the mast insert fit perfectly after some sanding and maintained a rigid support structure for the dispensers. Similarly, the limit switch holder and electronics box remained the same as in the initial design and met the requirements mentioned in the problem definition.

The requirements states in the problem definition were that the mast had to withstand 5N of force with less than 10mm of deflection and that the electronics must be enclosed so that the electronics were not at risk of damage or failure from water or powder spillage. These functional requirements and goals were met.

2.3.2 Gearbox and Turntable

After completing the initial design of the gearbox, not many changes were made in the building process as everything fit together nicely. As the gears rotated, it was noticed that the M40 nuts that held the gears were slowly unscrewing. To eliminate this problem, hot glue was used to secure the nuts in their place so that the gears would not become loose and potentially lose contact with the other gears.

The problem definition states that the gearbox must be kept in a safe enclosure, and that the gears must have contact with each other for the gearbox to function. There was no secured contact between the worm gear and spur gear as they were too separated for them to rotate together. All the other functional requirements and goals from the problem definition were met.

2.3.3 Powder Dispensing

After receiving the 3-D printed powder reservoir, many changes were made due to factors like inconsistency in 3-D printing, gear not rotating when powder was poured through, etc. Initially, the 20-tooth gear would not fit lengthwise inside the reservoir even though its width could fit through. The team ended up sanding and clipping the gear down. Eventually, the gear did fit through, and the gear mechanism would work together to rotate. However, when the group tested powder through the dispenser, it was constantly jammed and stuck. There was no way around this so the team decided to just remove the gear inside as a whole. To improvise, a piece of paper was glued to the flap of the servomotor which acted as the cover for the reservoir.

For testing, the powder dispenser was required to dispense 1 gram of powder into test tubes 1, 3, 4, and 5 and 2 grams of powder in test tube 2. Using the calculated rate at which the powder was dispensed, the powder dispenser would have been able to dispense the right amount of powder into the corresponding test tubes. It would dispense 1 gram of powder in 2.35 seconds and 2 grams of powder in 4.7 seconds. Since the gearbox failed to spin at the supposed rate, it was a challenge to test the powder dispenser as it did not properly align with the test tubes. The Teaching Assistant (TA) in charge of the group's testing allowed the group to test the powder dispensing component. The right amount of powder was dispensed; therefore, the component met the individual sub function requirements, but it failed to work alongside the system when tested as whole. As a requirement, the powder dispenser has to dispense 1 to 2 grams (depending on the test tube.) With that being said, the group's dispenser met these requirements.

2.3.4 Liquid Dispensing

The final prototype for the liquid dispensing system was assembled quickly. A small hole was cut into the screw-on cap of one of the bottles, the same diameter of the tubing. This eliminated leakage from the bottle since there were no holes below the water level. The cap could still be removed to enable easy refilling. The second bottle had a large hole in the bottom to allow wiring to enter when connected to the peristaltic pump, which was resting in the open top of the bottle. The diameter of the pump and open lid was the same, making it an effective holder. Both bottles were then hot glued onto the pegboard to secure them in place.

As testing began, the first step was to dispense 20mL into one of the test tubes. Due to some error in the recorded value of liquid dispense time, there was an overpour. However, with some quick tweaks to the value in the code, the liquid dispensing system was able to dispense nearly exactly 20mL of water into the test tube.

3. Final Design

3.1 Hypothetical Design

After the completion and testing of the initial prototype, various flaws and places for improvement were identified, primarily regarding the gears, powder dispenser, and mounting the pump. During testing, appropriate amounts of water and powder were dispensed, and the mast met the strength requirements; however, the turn table was unable to complete a full cycle, and the electronics had to be accessed from outside of the enclosure. While these issues could be resolved with minimal changes, there several design components that would be revised if a second prototype were to be developed with fewer constraints.

The first major design flaw with the first prototype was the stability and power of the DC motor as well as its ability to maintain good contact between the worm gear and the 50-tooth gear. This led to frequent slippage at this interface, preventing the gearbox from functioning and subsequently, preventing the test tube rack to turn in time with all the other functions. If a second prototype were to be made with fewer restrictions, a screw in mount for the motor would be 3D printed to secure it in place (refer to Figure 12). A mount like this was unable to be printed for the first prototype due to 3D printing material restrictions.

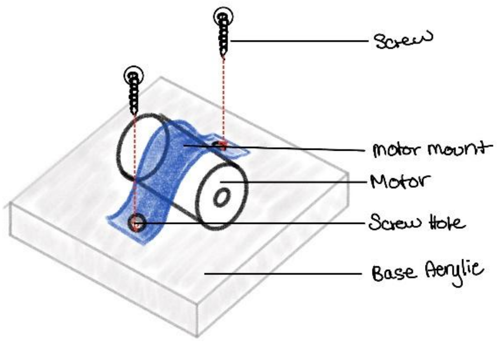

Figure 12: Potential design for a screw in motor mount into acrylic.

In addition to a stronger motor mount, the gearbox would greatly benefit from a stronger motor, as unless placed perfectly, the DC motor did not provide enough torque to spin the gears. Using gears made of a stronger material such as steel-alloy with a more defined tooth profile would also decrease slippage at the interface of each gear. Lubricating the gears would allow more greater efficiency as well as it decreases the net friction in the box.

Another design revision would be to use more acrylic material to enclose and support the machine. In the first prototype, pegboard mounts were 3D printed to secure structural components such as the mast. Ideally, the pegboard would not be used and instead, acrylic would be cut to accommodate only the parts being used. By fitting larger sheets of acrylic together via screws and friction fit slots, a much more rigid and enclosed volume would be achieved (refer to Figure 13).

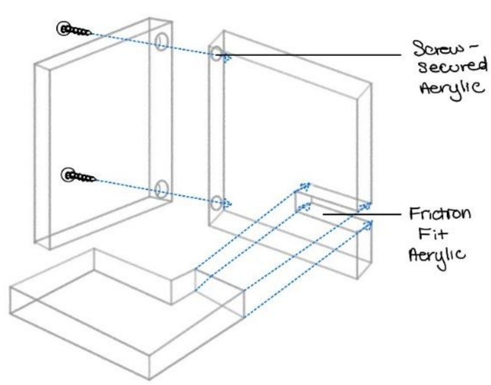

Figure 13: Diagram for how acrylic sheets would be joined by screws and by friction fit to form a more rigid structure for the second product prototype.

Using this method to join acrylic pieces allows for a much more rigid structure that encloses more volume while still being modular. The use of friction fitting, and screws removes the need for glue and tape which prevent disassembly and do not look professional. A general model of this product housing can be seen below in Figure 14.

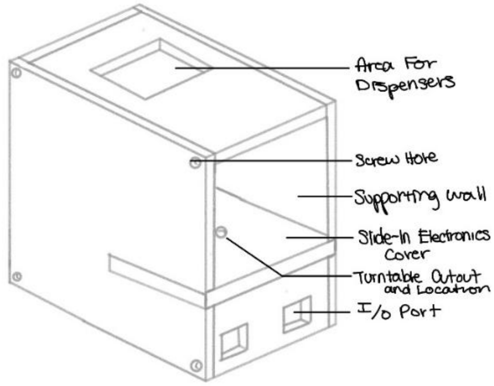

Figure 14: Example of possible acrylic product enclosure showing where accessory components would be located and how friction fitting, and screws would be implemented to assemble.

This design would replace the original mast structure found in Figure 2. The accessory subfunctions such as the liquid and powder dispensing systems would stay primarily the same as in the first prototype. The fluid dispenser uses a small plastic screw-top bottle as a reservoir with a hole in the cap for the tubing. This tubing is then fed to the peristatic pump which would sit in a newly 3D printed holder inside of the enclosure (refer to Figure 15 below).

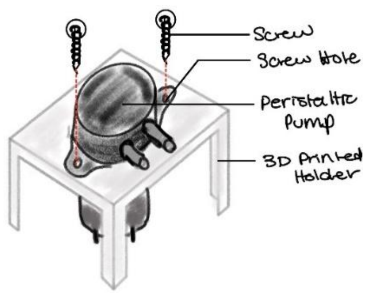

Figure 15: Example of 3D printed peristaltic pump mount for second prototype with screw holes for secure fit. To be placed inside of housing found in Figure 14.

In the original prototype, there was not enough material to print a mount like this, so it was placed in a plastic screw top container identical to the fluid reservoir. This can be seen in Figure 16 below.

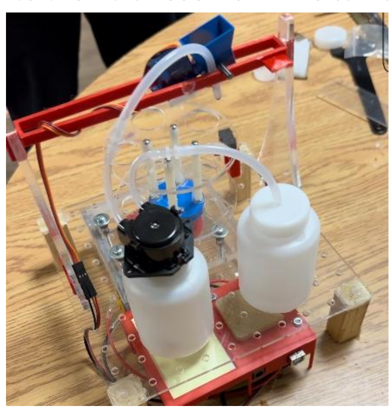

Figure 16: Peristaltic pump holder and fluid reservoir used in prototype one.

As for the powder dispenser, a very similar model would be used; however, it would also integrate a way to route the fluid tube so that both dispense into the same test tube, and it would be secured in the area indicated as "area for dispensers" in Figure 14 (refer to Figure 17 below). In the first prototype, the powder dispenser and servomotor were attached with hot glue to the mast insert which and the tubing was friction fit in between (refer to Figure 14). This solution was to get the product to function for testing but is not an ideal final solution and this revision should both increase the functionality and presentability of the product.

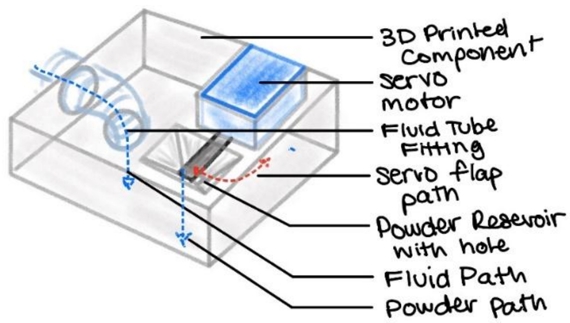

Figure 17: Potential design for second prototype for fluid and powder dispensing interface. Servomotor directly mounts to the part and rotates a flap underneath the powder reservoir to release powder into the test tube. Tube routing allows fluid to be dispensed accurately into the test tubes.

All wiring would be routed along the back corners of the enclosure using 3M wire clips to keep the wires organized and away from liquids. The breadboard, Arduino, and motor shield would all be located beneath the friction fitted acrylic insert shown in Figure 14 where the wire ports and start/stop button are accessible via cutouts in the acrylic. Additionally, to prevent any liquid or powder from interfering with the gearbox or electronics, there would only be cutouts for the rod spinning the turn table, in the corners for the wires, and underneath the test tubes for the limit switch. By covering the rest of the area underneath the turn table, the insert encloses the electronics and gearbox. A more detailed model of this can be found in Figure 18 below.

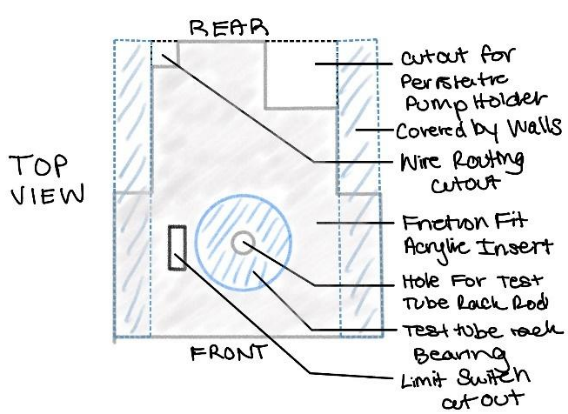

Figure 18: Top view of the acrylic insert found in Figure 14 showing all holes and cutouts for components. Insert covers majority of surface to prevent any spillage from interfering with electrical components and gearbox.

By implementing these design revisions, the second prototype should eliminate any inconsistency with the rotation of the turntable, improve presentability of the powder dispenser, better enclose both the electronics and gearbox, as well as increase the overall structural stability of the product. While this second prototype demands greater use of acrylic, it should not require much more 3D printed material. Additionally, the use of more material allows for a safer product as there is less risk of spillage causing the gearbox to malfunction or for electronic failure. Similarly, a full enclosure of the product greatly reduces the possibility of contamination from the surrounding environment. Lastly, using screws to secure the outer acrylic structure allows for the product to be more easily assembled, disassembled, and modified.

3.2 Sustainability and Safety

The dispensing system's safety considerations encompass a thorough evaluation of potential risks, including electrical shock, chemical exposure, and physical harm from moving components. To reduce the probability of these dangers occurring, strict precautions were taken in both design and operation phases, such as enclosing the gearbox and housing the electrical components. A computer-controlled start and stop feature was also implemented as a precautionary measure. Aligning with stakeholders' primary concern for employee safety, the design minimizes human interaction and sticks to industry safety standards. The use of fail-safe mechanisms and adherence to Good Manufacturing Practices (GMP) ensure a secure operational environment, meeting regulatory requirements.

Furthermore, sustainability was integrated into the design through materials selection and ease of disassembly. While considering Engineers Canada's sustainability guidelines, the system minimized 3D printed components, utilized wood as stands for the system, and focused on sustainability. Addressing hazards like potential water exposure to electronics, the final design strategically placed the electronics in enclosed components, secured the fluid container, and incorporated an emergency stop button for immediate halting of operations, ensuring a safer operational environment overall.

3.3 Device Operation and Regulations

The AFD (Automated Fluid Dispenser) has various restrictions. All general restrictions are listed in Appendix 5, which will be referenced for the more pertinent parameters. The group-specific regulations for operation involve dispensing the correct amounts. In the case of group 150, that was 20mL of fluid into test tubes 1 and 4, and 15mL into test tubes 2, 3, and 5. Other regulations pertain to the production of the prototype, which includes a restricted amount of 3D filament, 6mm thick acrylic, filling all 5 test tubes within 120 seconds, and fitting in a volume of 200mm by 200mm by 210mm. The device operation is split up into three separate parts, all of which are interconnected by the electronics and coding. These three subsystems are liquid dispensing, solid dispensing, and turntable rotation. The device begins operation at a standstill with the initial liquid dispensed into test tube 1. In immediate sequence, the solid is dispensed into test tube 1 as well. Then, the turntable rotates until hitting the limit switch, causing it to stop in the position of the next test tube under the dispensers. This theoretical operation of the device was not achieved during testing; however, most subsystems did function.

Liquid dispensing was powered by a peristaltic pump with a rate of 0.756 milliliters per second. The start of the pumping was dependent on multiple variables in the code: the start button having been pushed, zero to four previous test tubes having been filled, the pump counter being less than the pump time, and the emergency stop button not having been pushed. If all these requirements were met, it would check how many previous test tubes had been filled based on a counter and start a loop to pump for 20 milliseconds before checking again. Each time the loop was run, it would add to the pump counter until the required time had run. After the liquid has been dispensed, the next step is solid dispensing. This is controlled by a servo motor attached to a reservoir and funnel for the solid. The funnel led into a small rectangular opening at the bottom. This was quickly blocked off and opened by the servo motor rotating 25 degrees. This action was only dependent on the number of test tubes filled to select which amount to use and the emergency stop button. Once met, the servo motor would open for a set time to release a specific amount of solid at a rate of 0.426 grams per second. The final step is rotating the turntable using a DC motor. The DC motor is attached to a system of gears which turns a vertical shaft. The shaft leads into a ball bearing to reduce friction while turning the turntable. Once the solid dispensing is completed, a constant positive while loop runs to check the state of the stop button, limit switch, and run the DC motor. If the limit switch is hit, it will stop the motor and break out of the loop. This completes one cycle and adds to the total test tube counter. This can then be repeated with a new test tube value to produce different amounts.

The emergency stop button is constantly being checked with the "EmergencyStopState=digitalRead(EmergencyStop);" command. Every loop is ran at a low increment time so that the state can be checked as often as possible for optimal response time. Since everything is dependent on the stop button not being pressed, all subsystems stop as soon as it is pressed.

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. [Accessed 2 12 2023].

Appendices

Appendix I – Work Distribution

Table 1: Work Distribution and Time Investment Log

Task	Description of Activity	Activity Duration	Member Responsible
Appendices	Creating appendices, filling them out with roles, responsibilities, timelines, descriptions, and rubric.	1-2 hours	Ethan Solnik
Document Formatting	Organizing entire document including tables, figures, appendices, headers, labels, fonts, and spacing.	30 min	
Role Assignment	Assigning team members their responsibilities, informing deadline goes for project components, trying to ensure that everyone is on task and reviewing all content for cohesiveness and quality.	1hr	
Content Writing	1.3-1.5, 2.2.1, and 3.1	3-4 hr	Ethan Solnik
	Re-writing the executive summary, revising and adding onto the project goal (1.1), revising and adding onto the product function (1.2), writing the design process and drawings, testing and modeling evaluation and prototype outcome for the gearbox and turntable (2.1.2, 2.2.2, 2.3.2).	5-6 hr	Javier Otero
	Testing and modeling evaluation, prototype outcome, and sketching models used for powder dispensing. (2.1.3, 2.2.3, 2.3.3). Evaluating safety and sustainability of the whole system.	6-7 hr	Vaughn Soriano
	Design Process and Drawings (2.1.4), Testing and Modeling Evaluation (2.2.4), Prototype and Outcome (2.3.4), for liquid dispensing. Device Operations and Regulations. *If applicable Coding	6hr *6hr	Kieran Taylor

To improve the team's performance for this evaluation, the team collectively went through all the comments left on previous task submissions and identified what should be revised and restructured to better meet the rubric criteria. After building and testing the product, flaws were identified from the first prototype and used to inspire a second prototype that met these criteria. Specifically for this submission, more research was performed to back up the content and reference codes and regulations pertinent to this product in the medical and pharmaceutical industry. The criteria was updated to the most recent expectations of the product as well.

Due to inconsistencies in team contribution, the team met on several occasions with the project manager and the course coordinators to discuss strategies to improve communication, time effectiveness, and ultimately, quality of work. By doing so, the work was more evenly distributed amongst the team and therefore promoted greater team performance and subsequently, a higher quality submission.

Appendix II – Arduino Code

```
#include <AFMotor.h>
#include <Servo.h>

//Define what port on the arduino each electronic is connecting to
AF_DCMotor motor(1);
AF_DCMotor pump(4);
Servo Servo1;
#define StartButton A1
#define EmergencyStop A2
#define limitSwitch A3
//set servo position
int servo_pos = 0;

// Define variables to store the states of the push buttons as true or false
bool StartButtonState = HIGH;
bool EmergencyStopState = HIGH;
bool limitSwitchState = HIGH;

//setup the arduino, serial begin, and servo port
void setup() {
 Serial.begin(9600);

 motor.setSpeed(140);
 motor.run(RELEASE);

 Servo1.attach(9);

 // Configure the pins to to be input pins
```

```
 pinMode(StartButton, INPUT_PULLUP);
 pinMode(EmergencyStop,  INPUT_PULLUP);
 pinMode(limitSwitch,  INPUT_PULLUP);
}

void loop() {
 // Read the value of the pin as either HIGH or LOW/true or false
 StartButtonState=digitalRead(StartButton);
 EmergencyStopState=digitalRead(EmergencyStop);
 limitSwitchState=digitalRead(limitSwitch);

 //Input variables
 //set variables equal to run time for each trial
 int PumpTime1 = 756; //set a time 20ml (756*20) 15.12 seconds of pumping
 int ServoTime1 = 2350; //set a time 1g  2.35 seconds open
 int PumpTime2 = 567; //set a time 15ml  (567*20) 11.34 seconds of pumping
 int ServoTime2 = 4700; //set a time 2g  4.7 seconds open
 int PumpTime3 = 567; //set a time 15ml  (567*20) 11.34 seconds of pumping
 int ServoTime3 = 2350; //set a time 1g  2.35 seconds open
 int PumpTime4 = 756; //set a time 20ml  (756*20) 15.12 seconds of pumping
 int ServoTime4 = 2350; //set a time 1g   2.35 seconds open
 int PumpTime5 = 567; //set a time 15ml  (567*20) 11.34 seconds of pumping
 int ServoTime5 = 2350; //set a time 1g  2.35 seconds open


//define counter variables
 uint8_t i;
 int TestTubeCounter = 0;
 int ServoCounter = 0;
 int PumpCounter = 0;
 int PumpCounter2 = 0;
 int PumpCounter3 = 0;
 int PumpCounter4 = 0;
 int PumpCounter5 = 0;
 int DCRun = 0;
 float Start;
 int ButtonPushed = 0;



//Check if the button is pressed and set it a started
if(digitalRead(StartButton) == LOW){
 ButtonPushed = 1;
}
//TEST TUBE 1
```

```
//Check is emergency button pressed, how many times the is has dispensed and if the start button is pushed
if(EmergencyStopState==HIGH && TestTubeCounter == 0 && ButtonPushed == 1)
{

while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
//Loop of 20 millisecond running until pump time is up
while(PumpCounter < PumpTime1 && EmergencyStopState==HIGH){
 EmergencyStopState=digitalRead(EmergencyStop);
 pump.run(FORWARD);          //Direction of motor
 pump.setSpeed(255);         //Speed of motor

 delay(20);                  //Lenght of delay

 PumpCounter ++;             //Add 1 to pump counter every 20 milliseconds
}
 pump.run(RELEASE);          //Stop pump
 break;                      //Break statement to break out of while(1) loop
}

while(1){                    //Loop to constantly check state of emergency button
 EmergencyStopState=digitalRead(EmergencyStop);
//While loop that checks state of emergency stop and how many times the servo has ran
   while(EmergencyStopState==HIGH && ServoCounter < 1){
//servo code
    for (servo_pos = 90; servo_pos <= 115; servo_pos += 1){       //move the servo motor to open the solid
resevoir
      Servo1.write(servo_pos);
      delay(1);

 }
      delay(ServoTime1);     //Length based on predefined variable
      for (servo_pos = 115; servo_pos >= 90; servo_pos -= 1){     //move the servo motor to close the solid
resevoir
      Servo1.write(servo_pos);
      delay(1);

 }
ServoCounter ++;

}
 TestTubeCounter ++;         //Add to test tube counter, how many test tubes have been filled
 break;
}
```

```
while(1){                    //Loop to constantly check state of emergency button and limit switch
 limitSwitchState=digitalRead(limitSwitch);
 EmergencyStopState=digitalRead(EmergencyStop);

 if(limitSwitchState==LOW || EmergencyStopState==LOW){   //if statement based on limit switch and
emergency state to stop turning

   break;
 }
 motor.run(FORWARD);                               //If the if statement is not fullfilled run motor
}

motor.run(RELEASE);                               //If the if statement is fullfilled stop motor
}

/*The code now repeats with different varibles for each of the five test tubes. The code is the same other
than number of loops variables and amount specific variables. All relevant information in the following code
can be found in the first loop*/

//TEST TUBE 2
//Check is emergency button pressed, how many times the is has dispensed and if the start button is pushed
if(EmergencyStopState==HIGH && TestTubeCounter == 1 && ButtonPushed == 1)
{
while(1){                     //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
//run pump initially must set time
while(PumpCounter2 < PumpTime2 && EmergencyStopState==HIGH){
 pump.run(FORWARD);
 pump.setSpeed(255);

 delay(20);

 PumpCounter2 ++;
}
 pump.run(RELEASE);          // Stop the pump
 break;
}

while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
   while(EmergencyStopState==HIGH && ServoCounter < 2){
//servo code
    for (servo_pos = 90; servo_pos <= 115; servo_pos += 1){
     Servo1.write(servo_pos);
     delay(1);
```

```
 }
      delay(ServoTime2);
      for (servo_pos = 115; servo_pos >= 90; servo_pos -= 1){
      Servo1.write(servo_pos);
      delay(1);

 }
ServoCounter ++;

}
 TestTubeCounter ++;
 break;
}
while(1){                    //Loop to constantly check emergency button and limit switch state
 limitSwitchState=digitalRead(limitSwitch);

 if(limitSwitchState==LOW){

   break;
 }
 motor.run(FORWARD);
}

motor.run(RELEASE);
}



//TESTTUBE 3
//Check is emergency button pressed, how many times the is has dispensed and if the start button is pushed
if(EmergencyStopState==HIGH && TestTubeCounter == 2 && ButtonPushed == 1)
{
while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
//run pump initially must set time
while(PumpCounter3 < PumpTime3 && EmergencyStopState==HIGH){
 pump.run(FORWARD);
 pump.setSpeed(255);

 delay(20);

 PumpCounter3 ++;
}
 pump.run(RELEASE);          // Stop the pump
```

```
 break;
}

while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
   while(EmergencyStopState==HIGH && ServoCounter < 3){
//servo code
    for (servo_pos = 90; servo_pos <= 115; servo_pos += 1){
     Servo1.write(servo_pos);
     delay(1);

 }
     delay(ServoTime3);
     for (servo_pos = 115; servo_pos >= 90; servo_pos -= 1){
     Servo1.write(servo_pos);
     delay(1);

 }
ServoCounter ++;

}
 TestTubeCounter ++;
 break;
}
while(1){                //Loop to constantly check emergency button and limit switch state
 limitSwitchState=digitalRead(limitSwitch);

 if(limitSwitchState==LOW){

   break;
 }
 motor.run(FORWARD);
}

motor.run(RELEASE);

}


//TESTTUBE 4
//Check is emergency button pressed, how many times the is has dispensed and if the start button is pushed
if(EmergencyStopState==HIGH && TestTubeCounter == 3 && ButtonPushed == 1)
{
while(1){                     //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
```

```
//run pump initially must set time
while(PumpCounter4 < PumpTime4 && EmergencyStopState==HIGH){
 pump.run(FORWARD);
 pump.setSpeed(255);

 delay(20);

 PumpCounter4 ++;
}
 pump.run(RELEASE);          // Stop the pump
 break;
}

while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
   while(EmergencyStopState==HIGH && ServoCounter < 4){
//servo code
    for (servo_pos = 90; servo_pos <= 115; servo_pos += 1){
     Servo1.write(servo_pos);
     delay(1);

 }
     delay(ServoTime4);
     for (servo_pos = 115; servo_pos >= 90; servo_pos -= 1){
     Servo1.write(servo_pos);
     delay(1);

 }
ServoCounter ++;

}
 TestTubeCounter ++;
 break;
}
while(1){                   //Loop to constantly check emergency button and limit switch state
 limitSwitchState=digitalRead(limitSwitch);

 if(limitSwitchState==LOW){

   break;
 }
 motor.run(FORWARD);
}

motor.run(RELEASE);
```

```
}


//TESTTUBE 5
//Check is emergency button pressed, how many times the is has dispensed and if the start button is pushed
if(EmergencyStopState==HIGH && TestTubeCounter == 4 && ButtonPushed == 1)
{
while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
//run pump initially must set time
while(PumpCounter5 < PumpTime5 && EmergencyStopState==HIGH){
 pump.run(FORWARD);
 pump.setSpeed(255);

 delay(20);

 PumpCounter5 ++;
}
 pump.run(RELEASE);          // Stop the pump
 break;
}

while(1){                    //Loop to constantly check emergency button state
 EmergencyStopState=digitalRead(EmergencyStop);
  while(EmergencyStopState==HIGH && ServoCounter < 5){
//servo code
   for (servo_pos = 90; servo_pos <= 115; servo_pos += 1){
    Servo1.write(servo_pos);
    delay(1);

 }
    delay(ServoTime5);
    for (servo_pos = 115; servo_pos >= 90; servo_pos -= 1){
    Servo1.write(servo_pos);
    delay(1);

 }
ServoCounter ++;

}
 TestTubeCounter ++;
 break;
}
while(1){                    //Loop to constantly check emergency button and limit switch state
```

```
 limitSwitchState=digitalRead(limitSwitch);

 if(limitSwitchState==LOW){

   break;
 }
 motor.run(FORWARD);
}

motor.run(RELEASE);
}
}
```

Appendix IV – Constraints List

Table 2: Constraints list including all the limitations given to make the final design.

Overall Functional Requirements	**Prototype Requirements:**
☐ Dispense fluid and powder into a pre-loaded rack of 5 test tubes from user action. ☐ Dispense a software-specified volume of liquid from 5 to 20 mL (within the range of +/-1mL) into each test tube. ☐ Dispense a software-specified volume of powder in increments of 1 mL (about 1 g) into each test tube. ☐ Fill all test tubes within 120 s. ☐ Be possible to easily assemble and disassemble for transport. ☐ Any additional functional requirements identified by the team.	☐ Fit within maximum dimensions of 200 × 200 × 210 mm. ☐ Use the smallest possible material volume. ☐ Use the Arduino, motors, and some sensors ☐ Demonstrate structural rigidity of mast. ☐ Minimize sharp corners. ☐ Wires and tubes hidden fastened where possible. ☐ Product name visible on your design exterior. ☐ Loose fit holes for screws 4.2 mm in diameter.
3D Printed Part Requirements	**Acrylic laser cut Part Requirements**
☐ Total 3D printed filament volume < 30,000 mm^3 and print time < 90 min (predicted by Prusa Slicer using Speed mode with 10% infill). ☐ Team number on each part, extruded or indented 0.3 mm (depending on geometry) ☐ Feature sizes >1mm, wall thickness >1mm.	☐ Maximum acrylic area is 600 cm2 of 6.2 mm thick acrylic. ☐ All parts are 2D cutouts from 6.2 mm thick acrylic; no 3D structures can be fabricated by the laser cutter. ☐ Team number (e.g. “101”) on all parts as an etching ~1 mm depth.

☐ A part offset of 0.2 mm for press-fitted parts (tight) or 0.4 mm to slide freely. ☐ Holes intended to be self-tapping should be drawn with inner diameter ~ 0.2mm < screw diameter, with wall thickness at least the diameter of the screw. ☐ Hole diameter axel shaft to rotate freely in 3D part: 4.2mm ☐ Minimize overhangs > 5mm or < 35° (supports will need to be added). ☐ Parts oriented to minimize overhang and roughness on key surfaces. ☐ Tight friction fit for pegs into pegboard holes 4.95 mm. ☐ One SolidWorks part file (.SLDPRT) for each 3D printed part with "Nx" at the end of the filename, where x is the number of parts. ☐ Part material in SolidWorks should be PLA with a red color.	☐ One SolidWorks part file (.SLDPRT) for each acrylic part, with "Nx" in the filename, where x is the number of parts. ☐ Part material in SolidWorks should be acrylic (translucent) **Gearbox specific requirements** ☐ Centre distances between gearbox shaft holes are spaced as (in mm) (gear 1 tooth count + gear 2 tooth count)/2. ☐ Axel distance between worm gear and spur gear (in mm). (# spur gear teeth / 2) +3.5 ☐ Hole diameter axel shaft to rotate freely: 3.9 mm. ☐ Hole diameter to friction fit DC motor into gearbox wall: 23.8 mm.
Safety Requirements ☐ A water-resistant enclosure for electronics. ☐ Gears contained in a protective enclosure. ☐ A safety plan is provided that identifies potential safety risks during prototyping, assembly, and evaluation. This must specifically include keeping water away from all electronics and wall receptacles.	**Additional Hints and Instructions** ☐ Any parts you do not need printed should be colored blue in SolidWorks and NOPRINT included in the part name. ☐ If you use the BB's as ball bearings with 6mm diameter, plan for the race to have a diameter of ~6.2mm.

Appendix V – Extra Figures

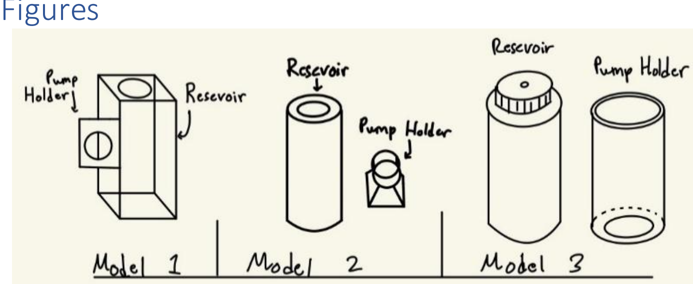

Figure 19: The three different iterations for the liquid dispensing sub system.