Fall 2015

Plate Pouring III

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This project, Plate Pouring III, is an automated device that fills petri dishes with a liquid solution called Agar. This is done in a sterile environment, not needing any human interaction for the mechanism to function. It safely removes the lid individually from petri dishes, injects the solution, reinserts the lid, and stacks the filled petri dishes.
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1 Introduction

1.1 Project problem statement

This project aims to streamline the testing process in biology labs through simultaneously increasing the time efficiency, maximizing the sterility, and lowering the cost of preparing Petri dishes for testing. Through automating the Petri dish preparation, time will be saved both by removing the need to purchase agar filled plates, and by providing biologists with significantly more time to be productive elsewhere in their labs. While there are other products currently on the market, they are severely cost-prohibited. This product will aim to have a production cost no higher than $400, making it the perfect tool for smaller-scale biology labs that may have limited funding. Furthermore, the accessibility of the project is a key component, through the development of a lightweight design that may be easily transported and may fit inside of a laboratory fume hood.

1.2 List of team members

Plate Pouring - III: Dagmawi Gebreselasse, Adam Cooperberg, Zachary Rouse

2 Background Information Study

2.1 A short design brief description that defines and describes the design problem

A biologist working at the STLCC Biobench CRO requires an automated Petri dish pouring device. It must be able to pour agar medium from a reservoir, have a flow regulating valve, and have a feature that times the process and moves the filled Petri dishes. The system also must be controlled by a laptop, fit inside of a fume hood, be sterile, easily cleanable, and pour a minimum of 120 Petri dishes in one hour.

2.2 Summary of relevant background information (such as similar existing devices or patents, patent numbers, URL’s, et cetera)
### Table 1: Relevant Patents

<table>
<thead>
<tr>
<th>Patent #</th>
<th>Publication date</th>
<th>Inventors</th>
<th>Title</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>US 4331262 A</td>
<td>5/25/82</td>
<td>P Snyder, D. Freedman</td>
<td>Calibrate Automatic Fluid Dispenser</td>
<td>automatic fluid dispenser</td>
</tr>
<tr>
<td>WO 2012015365 A1</td>
<td>2/02/12</td>
<td>K. Supanwong</td>
<td>Semi-automatic Machine For The Preparation of Drop Plates</td>
<td>automatic drop plates</td>
</tr>
<tr>
<td>US 4468914 A</td>
<td>9/04/84</td>
<td>A. Pestes</td>
<td>Apparatus For Filling Petri Dishes</td>
<td>filling petri dishes</td>
</tr>
<tr>
<td>US 4170861 A</td>
<td>10/16/79</td>
<td>P Snyder, D. Freedman</td>
<td>Method And Apparatus For Filling Petri Dishes</td>
<td>filling petri dishes</td>
</tr>
<tr>
<td>WO 2008049756 A1</td>
<td>5/02/08</td>
<td>A. Q. Gomez, <em>et al</em></td>
<td>Method For Providing Storable Plates Filled With Biological Culture Medium</td>
<td>biological culture</td>
</tr>
<tr>
<td>US 4684045</td>
<td>8/04/87</td>
<td>P. Su</td>
<td>Container With Adjustable Controlled Volume Liquid Pouring Element</td>
<td>liquid pouring</td>
</tr>
<tr>
<td>US 4601651</td>
<td>7/22/86</td>
<td>H. Vongeheur</td>
<td>Apparatus For Pouring Confectionery Solution</td>
<td>pouring solution</td>
</tr>
</tbody>
</table>

Other relevant URLs:

1. Systec Mediafill:
   

2. PetriSwiss PS900:
   


4. MediaJet:

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3 Concept Design and Specification

User needs, metrics, and quantified needs equations. This will include three main parts:

3.1.1 Record of the user needs interview

<table>
<thead>
<tr>
<th>Question</th>
<th>Customer Statement</th>
<th>Interpreted Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is 120 plates per hour a minimum</td>
<td>Yes, and more than 120 would be ideal.</td>
<td>Poured plate per hour is at least 120.</td>
<td>5</td>
</tr>
<tr>
<td>How large can the system be made?</td>
<td>It should be small enough that it fit in the work area.</td>
<td>PP should fit in 7500 square cm of area.</td>
<td>5</td>
</tr>
<tr>
<td>How long should the PP run without interruption?</td>
<td>It should run for an hour pouring 120 plates.</td>
<td>PP should run for at least an hour non-stop.</td>
<td>5</td>
</tr>
<tr>
<td>Does the system need to be sterile?</td>
<td>Yes, to make the solution sterile.</td>
<td>PP should be made out of parts that are autoclavable.</td>
<td>5</td>
</tr>
<tr>
<td>Does the PP need to be portable?</td>
<td>Yes, it needs to be portable between work spaces.</td>
<td>PP is easily dismantled.</td>
<td>3</td>
</tr>
<tr>
<td>Do the parts need to be autoclavable?</td>
<td>Yes, to make the system contamination free.</td>
<td>Find parts that are autoclavable as much as possible.</td>
<td>5</td>
</tr>
</tbody>
</table>
Does the PP need to engage the system in smooth fashion? | Yes, to avoid shaking of poured solution. | Find actuators with smooth movement and less vibration. | 4 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Is slow cooling of solution a requirement?</td>
<td>Yes, to avoid cloud on petri dish lid.</td>
<td>Stack poured plates on top of each other for slow cooling of solution.</td>
<td>5</td>
</tr>
<tr>
<td>What temperature does the solution need to be poured at?</td>
<td>At 70 degree Celsius and stir to avoid coagulation.</td>
<td>Put the agar flask on a heater and use a magnetic stirring device.</td>
<td>5</td>
</tr>
<tr>
<td>How simple does the PP control need to be?</td>
<td>As simple as just an on/off button.</td>
<td>Employ at most two control switches to operate PP.</td>
<td>2</td>
</tr>
</tbody>
</table>

### 3.1.2 List of identified metrics

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PP pours at least 120 plates per hour</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>PP fits in the work space area</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>PP pours for at least an hour without interruption</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>PP avoids contamination of plates while pouring</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>PP is portable</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>PP parts are autoclavable</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>PP moves the plates (if at all) gently without shaking</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>PP allows for slow cooling of poured plates</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>PP keeps the agar solution container hot and stir it to avoid coagulation</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>PP has easy control (preferable just on/off button)</td>
<td>2</td>
</tr>
</tbody>
</table>
### 3.1.3 Table/list of quantified needs equations

*Table 4 - Quantified Needs Equations*

<table>
<thead>
<tr>
<th>Metrics Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Min Value</th>
<th>Max Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>Number of plates</td>
<td>Integer</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>Area</td>
<td>cm^2</td>
<td>6000</td>
<td>7500</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Time</td>
<td>minutes</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Percent plates contaminated</td>
<td>Percentage</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Weight</td>
<td>Kg</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>number of non-autoclavable parts</td>
<td>Integer</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>Acceleration of petri dishes</td>
<td>cm/s^2</td>
<td>0.25</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>Rate of temp. change</td>
<td>°C/min</td>
<td>0.2</td>
<td>0.5</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Agar container temp.</td>
<td>°C</td>
<td>69</td>
<td>71</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>number of controls</td>
<td>Integer</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

### 3.2 Four (4) concept drawings
Figure 1 - Concept Sketch #1

- Stack of Plates: ready to be poured
- Rack: holds empty plates and turns the stack.
- Rack Support: holds the motor that turns the rack.
- Lid Holder: traps the lid and plate near pump tip.
- Linear Actuator: pushes plate up to store it back in the rack.
- Flask
- Peristaltic Pump
Figure 2 - Concept Sketch #2

- Arm takes the lid off of the Petri dishes
- Drive Wheel
- Geneva Wheel
- Petri dish moves, turning 1/5 a rotation for every rotation of the driving wheel
- Filled Petri dishes are loaded onto a spring platform
- Agar reservoir
- Agar is poured into Petri dishes
Figure 3- Concept Sketch #3
Figure 4 - Concept Sketch #4
Figure 5- Concept Sketch #4 Breakdown

Concept Sketch #4

Rack:
Holds the stack of petri dishes and turns the stack to dispense the dishes.

Rack Support:
supports the rack and holds the motor that turns the rack.

Actuator with Suction Tip:
lifts the dish lid, turns and closes the lid once the plate is filled.

Spring Loaded Dish Receiver:
gently lowers the filled plates as they are mounted on it from the conveyor belt.

Stack of Petri Dishes:
empty plates ready to be filled.

Conveyor Belt:
transports the empty plates to the pump tip and then mounts them onto the receiver rack.

Peristaltic Pump:
Pumps agar from the flask to the plates.

Plate Lid:
lid held by suction tip

Flask:
Stores the agar to be poured.

Dish Receiver Support:
supports the receiver and holds the motor that turns the receiver.
### 3.3 A concept selection process. This will have three parts:

#### 3.3.1 Concept scoring (not screening)

**Table 5 - Concept Scoring for Design #1**

<table>
<thead>
<tr>
<th>Need#</th>
<th>Need</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Needs Happiness</th>
<th>Importance Weight</th>
<th>Total Happiness Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PP pours at least 120 plates per hour</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.113</td>
<td>0.086899791</td>
<td>0.0289376</td>
</tr>
<tr>
<td>2</td>
<td>PP fits in the work space area</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.933</td>
<td>0.243475992</td>
<td>0.2271631</td>
</tr>
<tr>
<td>3</td>
<td>PP pours for at least an hour without interruption</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.1304801067</td>
<td>0.0652401</td>
</tr>
<tr>
<td>4</td>
<td>PP avoids contamination of plates</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>5</td>
<td>PP is portable</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.817</td>
<td>0.238768267</td>
<td>0.1670146</td>
</tr>
<tr>
<td>6</td>
<td>PP parts are autoclavable</td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.333</td>
<td>0.086899791</td>
<td>0.0289376</td>
</tr>
<tr>
<td>7</td>
<td>PP moves the plates (if at all) gently without shaking</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>0.6</td>
<td>0.1565762</td>
<td>0.0939457</td>
</tr>
<tr>
<td>8</td>
<td>PP allows for slow cooling of poured plates</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.333</td>
<td>0.086899791</td>
<td>0.0289376</td>
</tr>
<tr>
<td>9</td>
<td>PP keeps the agar solution container hot and stir it to avoid coagulation</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>0.1304801067</td>
<td>0.0652401</td>
</tr>
<tr>
<td>10</td>
<td>PP has easy control (preferable just on/off button)</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>0.667</td>
<td>0.174060541</td>
<td>0.1160994</td>
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<th>Units</th>
<th>integer</th>
<th>cm²</th>
<th>minutes</th>
<th>Percentage</th>
<th>Kg</th>
<th>integer</th>
<th>cm/s</th>
<th>°C/min</th>
<th>°C</th>
<th>integer</th>
<th>Total Happiness</th>
<th>0.8215149</th>
</tr>
</thead>
<tbody>
<tr>
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-Page 19 of 78
### Table 7- Concept Scoring for Design #3

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-Page 20 of 78
Table 8- Concept Scoring for Design #4

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<td>PP allows for slow cooling of poured</td>
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3.4 Preliminary analysis of each concept’s physical feasibility

Concept 1: Self-Feeding Rack

Designing the self-feeding rack device poses a few challenges. The big challenge in building this concept is establishing a synced system, where the turning of the plate rack exactly aligns with the hole beneath to dispense the plates. The movement of the lid holder should also be in sync with the hole under the poured plate and the one above it for successful closing and storage of each petri dish. Another challenge in this design is the movement of the petri dishes for pouring and storage of the dishes. The movement needs to be smooth so that the solution in the dishes isn’t disturbed and spilled. In addition, as the design project requires sterile environment, it poses a challenge to make the system out of autoclavable materials. On the other hand the design is compact where the dispensed and poured dished are stored
back in the same rack. This conserves space. Moreover, the system has only three separate motions each with a single
degree of freedom, which reduces error and simplifies the system. This also makes it easier to troubleshoot when the
system goes wrong. Finally, this concept has few steps that it can easily pour the required amount of plates per unit
time.

Concept 2: Geneva Drive

Concept 2 centralizes around the use of a Geneva Drive. A Geneva Drive is a geared mechanism with a constantly
rotating wheel drive fastened by a pin. Connected to this drive wheel is a driven wheel, which is turned a partial rotation
for every full rotation of the drive wheel due to a pin on the rotating drive wheel which connects into a slot on the
driven wheel. This concept takes advantage of the drive system just explained, by using the arc-shaped slots as Petri Dish
holders, while turning, yet staying stationary at a point for an extended period of time. Remaining stationary for an
extended period of time allows for the ideal situation to insert Agar solution into the Petri dish. This concept would
prove to be extremely challenging to build, as a Geneva Drive needs to be extremely precise to function appropriately.
Similarly, the time required to fill a Petri dish with Agar solution would likely be longer than the time allotted by one
rotation of the driven wheel. Another significant issue with using a Geneva Drive is that the Petri dish would need to
have a fastener built into the semicircular slots to hold the Petri dishes. This would be highly unrealistic to build
something so precise. One of the greatest concerns would be that the arm which removes the Petri dish lids would
malfunction frequently and either fail to remove the lid or spill Agar solution. Finally, upon being filled and resealed with
Agar solution, the Petri dishes would likely spill out their contents if they were the first Petri dish dropped onto the
spring-loaded system, which although it is plausible on paper, the spring-loaded system will likely not work well in
practicality.

Concept Sketch #3: Central Grabber Arm

The largest physical problem to address with this concept sketch is coordinating the movement of all the moving parts in
tandem. The two motors, the “grabbing hand” and the peristaltic pump must all engage and disengage at different times
in order for the operation to function properly. As a result, there must be a fairly complex control system to regulate the
machine timing, possibly involving feedback sensors. Additionally, the motors must be very carefully chosen in order to
get the correct RPM or else motions will be too fast and jerky and will result in spilled agar. This could be somewhat
mitigated by clever use of a simple pulley system to adjust the RPM of one or both motors however. Also, the grabber
mechanism needs to be designed such that it does not bump into the petri dishes while it is in motion. This might
require a more complicated grabber design than shown in the current concept sketch. Finally, the agar tubing attached
to the peristaltic pump must be designed such that it does not get tangled as the grabber arm rotates about its central
axis. This could be solved by either adding extra slack in the tubing or through better positioning of the peristaltic pump
and tubing.

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Concept 4: Conveyer Belt System

This design poses some difficulty in petri dish transportation from the dispenser to the storage rack. The fact that this is done by a conveyer belt is likely to result in sliding and misalignment of the petri dishes. This concept also has the challenge of finding autoclavable materials to build it with. Moreover, delivery of dishes from the conveyer belt to the storage rack would most likely cause shaking that would disturb the poured solution. In a worst case scenario, this may even cause spilling of the poured solution. Another possible problem is that the actuator that opens and closes the petri dish lids has two degrees of freedom which may very well lead to positioning and timing errors. On a positive note, this design encompasses relatively independent movements which makes the system to work easily. This also allows for the construction of separate systems which would eventually be integrated together to form the final product. However, having independently working design results in a system that could take up significantly more space than would be allotted given the design constraints. The combination of so many different independently working designs allows creating a challenge in syncing up all of the different designs as they will have to work perfectly in tandem.

3.4.1 Final summary

WINNER: Concept 1 – Self-Feeding Rack

Concept 1 is the simplest and most feasible design. Compared to Concept 2, the Self-Feeding Rack is a much more refined idea which better addresses the opening and resealing of the petri dishes, and is relatively much gentler on the filled agar plates. While Concept 3 is likely more gentle on the filled agar plates than Concept 1, the complex actuation and rotation involved in the process will likely make it very expensive and prone to failure. Concept 4 is very complicated. Managing the “conveyor belt” system and keeping the spring loading system functioning would be near impossible. Concept 1 is a straightforward design which minimizes the number of different moving parts, while not being too harsh on the filled plates. One of the chief design problems with the plate pourer is how to open and close the lid of the petri dish, and Concept 1 uses the best method of using gravity to “sieve” the lid off the base. Additionally, from the happiness equations, Concept 1 scores significantly higher, making it the winner.
3.5 Proposed performance measures for the design

- PP pours 120 plates per hour.
- PP must not contaminate more than 10 plates during the process.
- PP must not disturb more than 1% of filled plates
- PP must fit in a standard fume hood of 17 in deep, 6 ft. wide and 18 in high.
- PP must be fully automated once started.
- PP should not allow agar to coagulate in the tubing.
- PP should be portable enough for one person to carry (< 40 lbs.).
- PP should allow for easy filling and unloading of petri dishes.
- PP should not spill agar outside of the petri dishes.
- PP should be sterile and autoclavable.

3.6 Design constraints (include at least one example of each of the following)

3.6.1 Functional

In terms of functionality the plate pouring system was required to be made of autoclavable materials to make the process of sterilization easy. For this reason we chose to make out system out of aluminum and autoclavable plastic. In addition, the pump used to pour the agar solution was required to have adjustable speed so as to control the speed of the pouring process. This was accomplished by choosing a peristaltic pump that uses a DC motor to pour the solution. The speed of the DC motor was used to control the speed of the pouring process.

3.6.2 Safety

The design must be sterile, as it is to be performed within a laboratory and sterilization is mandatory for successful experimentation. To this end used a peristaltic pump that allows the poured solution to be self-contained in the pouring tube and not be in contact with any part of the pump. We also used a low torque stepper motor to avoid damage to system of parts in case of any malfunction. The pouring area is also located in a partially enclosed space which prevents accidental spillage of solution on users.
3.6.3 Quality

The quality of our design is aimed at the reliability of the system. Our system is made of four independent simple processes. We had two rotational movements used in conveying the empty and poured plates, one linear motion used in loading poured plates back to the storage rack and one pumping process powered by a simple high speed rotation of a dc motor. The simplicity of each of these processes made the general operation of the system more reliable.

3.6.4 Manufacturing

In terms of manufacturing, we had quite limited ways of fabrication given the degree of precision and limited building material option. Given the highest degree of precision required for the rack and lid stages we used CNC milling. For the rest of the parts we used manual milling and lathing. We also used 3-D printing for non-critical, and non-load bearing parts such as the guiding lid and plate cones. Sing 2D printing also allowed us to make parts which would otherwise have difficult shapes to make in a conventional way.

3.6.5 Timing

Timing constraint for designing, building and testing is given by the Gantt chart in section 4.5.

3.6.6 Economic

Our design must be constructed within the modest budget granted to us by the Mechanical Engineering Department, requiring the design to be built within a budget of $400. All of the budget spent went towards buying parts. For the manufacturing stage of the project we used different campus resources such as the architecture shop and the mechanical engineering department to do CNC and 3-D printing. These services were given for free and thus lowered the overall cost of the project. Design, development, and testing also didn’t incur any cost as the prototyping was done using materials found in the machine shop and the tests done were non-destructive in nature.

3.6.7 Ergonomic

In terms of user operation and comfort, our design was made to have programmable microcontroller that would allow users to vary the number of plates being poured as well as the change the amount of solution poured on each plate. This would be accomplished by taking into account the number of plates stored in each column and by adjusting the delay time of the dc motor driving the peristaltic pump. Moreover, to make the storage and replacement of plates easy the
scheme of stacking poured plates was chosen. The plate pouring system is also assembled in such a way that a malfunction in one sub system (pouring system for example) would be easily fixed without disrupting the rest of the system. This helps users lower maintenance cost.

3.6.8 Ecological

The plate pouring system is made of readily available materials such as all-purpose aluminum and thermoplastic, which are readily available in the market. This would help in the sustainability of our product. In addition, the solution being poured onto the plates is contained within durable plastic tube that can withstand temperatures up to 100 degrees Fahrenheit. This would ensure the containment of the solution within the system to avoid any leaks that would create toxic environment.

3.6.9 Aesthetic

Our design is compact that encompasses both the loading and storing area which take up less than 3 feet squared of area in total. The assembly is also built so that the whole process would be visible to users which adds to the attractiveness of the design. In addition, the metal parts are made to have aesthetically pleasing surface finishes and regular shapes for appeal. The activation of the system also gives mechanical movements that catches anyone's attention.

3.6.10 Life cycle

Most of the parts of the system are made of materials that would last for at least five years without wear. The limiting part of the whole system in terms of endurance is the life cycle of the stepper motors which is affected by the life cycle of the bearings inside. These bearings last for 10,000 hours of operation. Therefore assuming that the system would be used for 10 hours a day it would last for 2.7 years.

3.6.11 Legal

Our device must be sterile, requiring us to meet laboratory sterilization standards. The parts used in building our system are easy to disassemble and clean in order to avoid contamination of poured plates. In addition the poured plates can easily be removed from the storage rack without any issue of spillage and danger to the user.
4 Embodiment and fabrication plan

4.1 Embodiment drawing
## 4.2 Parts List

*Table 9- Parts List*

<table>
<thead>
<tr>
<th>Part</th>
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<th>Unit price ($)</th>
<th>Total Price ($)</th>
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4.3 Draft detail drawings for each manufactured part

Figure 7- Actuator and Rod Detail Drawing

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Figure 8: Base Stage Detail Drawing
Figure 9- Drive Geneva Wheel Detail Drawing
Figure 10- Driven Geneva Wheel Detail Drawing
Figure 11- Holding Rack Detail Drawing
Figure 12- Lid Stage Detail Drawing
Figure 15- Geneva Wheel Shaft Detail Drawing
4.4 Description of the design rationale for the choice/size/shape of each part

Holding Rack

The Holding Rack is designed to hold six stacks of plates while having one empty slot for loading the poured plates. Once the slot is empty the slot that just became empty after pouring a stack of plates would serve as a loading slot. This is done by turning the holding rack until the now empty slot is aligned with the loading axis. For this reason the rack stacks are aligned in a circular pattern. In addition, the holding rack would have threaded holes to install rods that support the stacked plates from toppling.

Prep Stage

The prep stage is a stationary disk mounted directly onto the frame of the mechanism. The prep stage is designed to support the petri dishes and allow them to slide across its top surface when the holding rack rotates. The two large holes in the stage allow petri dishes to fall down to and be loaded up from the lid/base stages. The hole directly above the actuator has three latches (not pictured) which allow the agar filled petri dishes to be loaded up into the holding rack by the actuator, but not fall back down onto the lid/base stages. In the center of the prep stage there is a circular hole which allows the rack axle to pass through freely. There are four tapped holes in the prep stage for where it is screwed onto the frame of the device.

Lid Stage

The lid stage is designed to separate the petri dish lids from their bases and then to facilitate their recombination once the agar filling is complete. The four holes in the stage are just large enough to allow the petri dish bases to fall through, but not quite wide enough for the lids to slip through. The geometry of the holes centers the petri lids so that they remain lined up with the bases, and also so that the top surface of the lids is flush with the top surface of the lid stage. The latter makes the rotation of the lid stage jostle the petri dish stack less. In the center of the lid stage is a keyway which interfaces with the top of the driven axle in order to get torque from the axle.

Base Stage

The Base Stage is a circular flat plate with four holes for holding the plate while being poured and transporting the plating back to the loading point. The holes are chamfered to allow for the plate to be centered while being poured and is wide enough to allow the actuator go through it in the loading process. The number of holes were chosen to be four because more holes would make plates to be open for longer period of time after being poured and less holes would geometrically interfere with the rack storage system.
Actuator

The Actuator is used to push the poured plates up and back into the storage rack. It is a simple part made of a shaft with a circular disk at its end. The disk is wide enough to bass in between the holding latches on the storage rack but large enough to keep the plates level in order to avoid shaking and imbalance of plate containing liquid agar. At the end of the actuator shaft is a miniature ball transfer that helps to avoid friction between the actuator and actuation loader.

Lid Stage and Base Stage Cones

The initial designs of the lid and base stage were modified to not include the chamfered parts due to manufacturability constraint. Instead the chamfered structures were made separately as cones that were later attached to the lid and base stages to serve as guiding structures in dispensing the plates.

Short Axle

This axle is coupled to a stepper motor at its base and to the lid and base stage at its top. It is machined from a ½” aluminum rod, but has a 1-¾” long section with ¾-16 threading. This top section allows the base stage to be forced onto the shoulder of the ¾” to ½” step in the axle using a nut. The middle section of the axle slides through a sleeve bearing mounted to the baseboard of the assembly to keep it level. The surface of the axle is sanded down with 400 grit sandpaper to reduce friction.

Long Axle

This axle is coupled to a second stepper motor at the bottom and to the holding rack at the top. The bottom half is firmly attached to the stepper motor using a shaft coupler. The top 1-½” of the axle is given ¾-16 threading and slides freely through the prep stage, thrust bearing, and holding rack. A nut and washer is then tightened on the very top of the threads until the holding rack is forced tightly onto the thrust bearing.

Obsolete Parts from Earlier Prototype:

Geneva Drive/Driven Wheel

These parts were part of an initial prototype assembly and were eventually removed from the final product. The Geneva wheel was chosen to allow for the coupling of loading and transportation of plates. This coupling could me made electronically but that would most probably creating the problem of being out of sync over the lifetime of the system. The Geneva Wheel has a four to one ratio to allow for four loading of plates per each revolution of the Lid/Base Stage.
Actuation Loader

The loader is designed to manage the vertical displacement of the actuator while maintaining a mechanical relationship with the rest of the moving parts. The loader is on the driven axle, but is loosely fit, so it rotates independently. The loader is screwed into the holes tapped into the driven sprocket, so its rotation is locked to the rotation of the sprocket system, and thus the rotation of the motor. Because each rotation of the actuator loader causes one activation of the actuator, the system will be perfectly in sync in terms of actuation / rotation of lid-base stages.
4.5 Gantt chart

![Gantt chart image]

*Figure 16- Gantt Chart*
5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 A form, signed by your section instructor

The following engineering analysis tasks will be performed by the group members indicated:

Before Prototype is built:
- Assembly interference test (ZR)

The assembly interference test is vital to the assembly of the different components which comprise the final assembled product. This test will be performed in CAD software using the CAD file created to create accurate results. It allows for the determination of whether or not components should be used to assemble various components together in the assembly, such as a press fit or friction fit, determining the exact tightness a fit should have.

- Manufacturing feasibility analysis (OG, AC, ZR)

The manufacturing feasibility analysis allows for the determination of whether or not parts that have been scheduled to be machined by team members can realistically be built due to limitations in equipment available and difficulty of manufacturing. This is to be performed based on the CAD file and a discussion with a knowledge machining expert, Pat Harkins.

- Maximum torque estimation on the rack axle (ZR)

The rack axle will be tested to estimate the maximum torque it can withstand to ensure it will function properly without being damaged. This will be done through using the CAD file with a moment placed on the rack axle. It is extremely important that a high factor of safety exists, so that the maximum torque is significantly higher than what the realistic torque on the rack axle may be.

- Stress test on a drive gear case (AC)

The drive gear case will be tested to ensure that it will be able to withstand the possible stresses it would face during operation. This stress test will occur on the CAD file under the stress simulation. It should permit for much higher allowable stress than the part would ever experience to ensure a high factor of safety and proper functioning.

- Bending test of rack rods (AC, ZR)

Bending test on the rack rods allows for the determination as to whether or not the rack rods will be able to hold the force that will be placed upon them during actual testing. The rods will be tested using their CAD file with a simulation stress load that resembles the force and direction the rods would face in real testing conditions. The rods must be able to not only withstand the force, but also be able to have a significant factor of safety to ensure success.

After prototype is built:
- Peristaltic pump actuation test (AC)

To test the peristaltic pump, an actuation test will be performed. This test will feature the peristaltic pump undergoing performance testing at levels similar to what would be required during the functioning of the plate pouring assembly. This is to ensure that the peristaltic pump functions without considerable deviation on a reliable basis as it is required to be used 120 times in the span of 8 hours.

- Electronic control test (DG)

The electronic control test will be utilized to ensure that all of the electronic components utilized to make the functioning assembly will work as expected. A physical test of the electronics used during the assembly will be performed. This will involve a simple circuit to verify that all components that are electronically used in the control will function as intended.

- Motor drive test (ZC)

This test will be done upon the motor to ensure that it functions properly and as expected, up to the specifications promised. It will be done using a simple current which will allow the motor to reach performance levels that it would likely experience during testing, as well as those significantly higher than it may be expected to perform at.

- Actuation loader test (AC)

The actuation loader test will be used to determine the functionality of the actuation loader. This will be performed using the actuation loader constructed for the prototype to ensure reliability and consistency. It is vital that the actuation loader is tested to high standards to ensure that it will never fail.

- System compatibility test (AC, OG, ZR)

A system compatibility test will be performed to ensure that all of the various components in the assembly function together with proper timing to accurately and effectively perform the plate pouring with reliable results. This will involve testing the physical prototype for an extended period of time to test that it would be able to meet the standards and expectations set for the amount of time poured in the span of 8 hours.

Figure 17- Analysis Tasks Agreement

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5.2 Engineering analysis results

5.2.1 Motivation. Describe why/how the before analysis is the most important thing to study at this time. How does it facilitate carrying the project forward?

The motivation behind our before engineering analysis was to test the most challenging components involved in our design. Due to the results of the engineering analysis, the design that was originally conceived has been significantly changed. These optimizations further prove that the engineering analysis is the most important part of the process that has yet been performed on the design. Carrying the project forward, certain aspects have been streamlined, eliminating unnecessary complexities and moving parts in favor of a simpler, more straight-forward design that more effectively accomplishes the required goals.

5.2.2 Summary statement of analysis done. Summarize, with some type of readable graphic, the engineering analysis done and the relevant engineering equations

There was initially some concern that the pin on the Geneva drive would undergo significant stresses while turning the driven wheel. While it was constructed of fairly thick aluminum, the sharp angle at its base introduced a significant stress concentration factor. As a result, it was necessary to perform finite element analysis on the pin to ensure that it had a sufficient factor of safety to never snap off of the Geneva drive. Pictured below is the finite element analysis, showing how the force was applied to the pin in order to yield it.
5.2.3 Methodology. How, exactly, did you get the analysis done? Was any experimentation required? Did you have to build any type of test rig? Was computation used?

The analysis was completed through a variety of means, each requiring a different method. The stress analysis testing, for example, was done through CAD software. Our models in CAD follow the exact dimensions that our prototype is being built to. By using a stress analysis testing of a load being placed on various parts, overestimating the loads and accounting for a significant factor of safety, we were able to effectively analyze our design.

5.2.4 Results. What are the results of your analysis study? Do the results make sense?

The results of our analysis study were extremely positive overall. They proved to emphasize that the design that had previously been developed was plausible, and that the dimensions for various parts that will be experiencing significant load will be able to easily withstand their load with a comfortable factor of safety. It is highly important to note that the tests revealed that the design that was being studied would prove to be much more difficult to construct, assemble, and operate than initially intended. The design appeared to be over-engineered, and through the analysis it was determined that certain aspects of the design were not necessary. Many of these parts were able to simply be removed from the
assembly without requiring replacements, emphasizing their redundancy. This reduction of moving parts and complexity in machinery will significantly reduce manufacturing costs and assembly time. The results do make sense and are integral to our design moving forward.

5.2.5 Significance. How will the results influence the final prototype? What dimensions and material choices will be affected? This should be shown with some type of revised embodiment drawing. Ideally, you would show a “before/after” analysis pair of embodiment drawings.

Unfortunately, these results did not have a significant effect on our final design. While the Geneva drive was shown to be more than strong enough for our purposes, the Geneva drive concept itself was not reliable enough to be included in the final design. It was ultimately scrapped and the driven axle was attached directly to the stepper motor. The analysis was helpful in showing that the generated stresses in our assembly are much lower than the stresses required to yield aluminum parts however, as it is unlikely that our newer design would have fifteen times the stress of the earlier design. Shown below are the two assembly drawings: the older, Geneva drive based one, and the newer one respectively.
Figure 19- Version 1 of Full Assembly
5.2.6 Summary of code and standards and their influence. Similarly, summarize the relevant codes and standards identified and how they influence revision of the design.
ISO 17769-1:2012 standard code was referred in picking a pump appropriate for laboratory equipment. It describes the different allowable flow rates and pump heads applicable in laboratory settings.

5.3 Risk Assessment

5.3.1 Risk Identification

There are a number of extremely serious and important risks that were taken into account throughout the development of the project. As the product is intended to be used in a laboratory setting under the strict codes and practices established therein, it is highly important that the product is sterilized to standards, at a minimum. Health and safety concerns are extremely important in this regard. Operational risks are necessary to keep in mind, as agar is the medium being worked with, it has the potential to envelop into unwanted locations. The mechanism itself is a delicate instrument that should be handled with care. Although it is lightweight, it should be handled with care and may easily be damaged. Particularly, the placement of the device inside of a fume-hood is a key point of concern. Removal and insertion of Petri dishes should also be noted as a potential risk for safety of spilling agar as well as damaging the mechanism or injuring the lab technician. In addition, since the pouring system deals with fluid the risk of the solution coming in contact with the electrical wiring should be taken into account to avoid any kind of shorting or electrical shock.

5.3.2 Risk Analysis

The spilling of the agar solution on parts of the system is one of the bigger risks. This could happen due to several reasons. If the pump is malfunctioning and operating at a higher pressure than needed the solution could shoot off the plate being pouring and contaminate the environment. Another reason could be an error in the programming of the microcontroller that could lead to pouring for extended period of that that would overfill the plates causing spillage. Yet another big cause of spillage could be the misalignment of the pump tube tip and the plate being poured into. This could be caused by the error in the stepper motors to correctly adjust its position based on the controller programming. This issues could be solved by rigorous testing of the pump, testing the reliability of the controller, testing the stepper motor in different conditions and possibly encompassing a position feedback system for the stepper motors to precisely drive the motors. To prevent any kind of spillage while removing the filled plates the storage system should be designed in such a way that it would easily detach and serve as a container for the plates. In order to avoid any risk of fluid coming in contact with the wiring, the electrical system should be sealed properly in a waterproof case.
5.3.3 Risk Prioritization

The number one risk associated with this design is electrical shock caused by spilled solution or by direct contact of the user to the electrical wiring. This is because user safety is should be given priority among other risks. The second most important risk is spillage of solution in the process of removing the poured plates. This is also risk associated with the users but less important one. Another less important risk is leaking o solution on to the system which would render the system unsterile. Therefore this risks should be addressed in the order of their importance to minimize the overall risk of the system as much as possible. After this is done the system should be checked whether or not it meets the national standard.

6 Working prototype

6.1 A preliminary demonstration of the working prototype (this section may be left blank).

Preliminary Prototype Video: https://www.youtube.com/watch?v=5SeX1FMzm3s

6.2 A final demonstration of the working prototype (this section may be left blank).

Final Demo: https://www.youtube.com/watch?v=_YwZw7cy4AQ
6.3 At least two digital photographs showing the prototype

Figure 21- Prototype Photograph

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Figure 22- Prototype Electronics
6.4 A short video clip that shows the final prototype performing

Final Prototype Video: https://www.youtube.com/watch?v=_YwZw7cy4AQ

6.5 At least four (4) additional digital photographs and their explanations

Figure 23- Lid and Base Stage assembly showing stepper motor and actuator setup
Figure 24- Early prototype Geneva drive setup

Figure 25- Microcontroller setup with power source and stepper motor
Figure 26- CNC milling of lid and base stage components
Figure 27- Early prep stage setup, showing C-channel frame setup

Figure 28- Early lid and base stage setup with first installed cone
7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 A set of engineering drawings that includes all CAD model files and all drawings derived from CAD models. Include units on all CAD drawings. See Appendix C for the CAD models.

Figure 29- Lid Stage Drawing

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Figure 30- Base Stage Drawing
Figure 31- Base Plate Cone Drawing
Figure 32 - Lid Cone Drawing
Figure 33 - Rod Drawing
Figure 34- Holding Rack Drawing
Figure 35- Prep Stage drawing
Figure 36- Short Axle drawing
Figure 37- Long Axle Drawing
Figure 38: Long C-Channel drawing
7.1.2 Sourcing instructions

All of the parts are listed in Appendix A can be sourced from online retailers.
The following is a description of parts and how they were made before final assembly:

Holding rack, prep stage, lid stage, plate stage: These parts were made using CNC, which helped guarantee the required low dimensional tolerance.

Short and long axle: these axles were made from the ½” aluminum axles purchased using lathing machine and tapping dies to make ⅜” 16 threads.

Lid and plate stage cones: these cones were made using 3-D which made fabrication easier given the shape and configuration of the cones.

Mounting Frames: the mounting frames were made from c channels cut to the appropriate height.

Motor mount: the motor mounts were made from wooden blocks.

Rods: The storage rack rods were made on lathing machine and tapped to 8-32 using a tapping die.

### 7.2 Final Presentation

#### 7.2.1 A live presentation in front of the entire class and the instructors (this section may be left blank)

Live Presentation Video: [https://www.youtube.com/watch?v=7WUgPixkfNo&feature=youtu.be](https://www.youtube.com/watch?v=7WUgPixkfNo&feature=youtu.be)

#### 7.2.2 A link to a video clip version of 1

Non-Live Presentation Video: [https://www.youtube.com/watch?v=Ce7wBwxhSS8](https://www.youtube.com/watch?v=Ce7wBwxhSS8)

### 7.3 Teardown

Teardown is not applicable for this project, as it is going to continue to be pursued in the coming months. The final prototype is being stored and improvements upon it will subsequently be made. For safety reasons, the electronics have been disconnected from the assembly for storage. The spare and scrap parts, particularly sheet metal, has been returned to the machine shop where the project was constructed.

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8 Discussion

8.2 Using the final prototype produced to obtain values for metrics, evaluate the quantified needs equations for the design. How well were the needs met? Discuss the result.

The final prototype comes very close to meeting many of the design specifications. The assembly can successfully process ~120 plates per hour as it takes 30 seconds to process each plate. The plate pourer is slightly too tall to fit in the specified fume hood, but would easily fit inside a more standard sized fume hood. The assembly does a good job of preventing contamination of the agar, as it is only exposed to open air for ~1 minute and does not come into contact with any surface other than the petri dish. The assembly is also surprisingly lightweight and easy to carry, weighing in at roughly 15 lbs. The plate pourer also allows for slow cooling of the petri dishes by restacking the filled plates to avoid condensation. The agar tubing is easily removed and autoclaved and the aluminum parts are easily cleaned, but some wooden components make the assembly less sterile. The agar solution is easily kept hot as it can be stored in an Erlenmeyer flask on a hot plate and have the tubing from the peristaltic pump fed into it. The assembly is easily turned on by simply switching on the power supply to the microcontroller.

One of the main current issues with the assembly is that it cannot currently pour for at least an hour without interruption. Small reliabilities in the synchronization of the stepper motors and the geometry of the lid stage cones can cause the assembly to get jammed when not being carefully monitored. Additionally, the filled petri dishes do get disturbed somewhat when the top stage of the assembly turns to load a new stack. This can potentially lead to sloshing of the agar before it hardens. Overall, the assembly shows a lot of promise for fulfilling all of its design metric, it simply requires some relatively minor changes in order to increase reliability of certain processes.

8.3 Discuss any significant parts sourcing issues? Did it make sense to scrounge parts? Did any vendor have an unreasonably long part delivery time? What would be your recommendations for future projects?

Our project required fairly large areas of smooth sheet metal to mill the four “stages” out of, so it was not realistic to “scrounge” for these parts. Scrap sheet metal is usually uneven, dirty, and too small for our purposes. For smaller, less vital components, such as connecting brackets on the C-Channel frame, scrap metal and wood from the machine shop was acceptable as less material and precision was required. All vendors, particularly McMaster-Carr, were timely with their shipments of parts, and as a result, our timeline was not strongly dictated by part shipments. We were very proactive about ordering our parts early, and doing so is highly recommended for future projects, as it greatly accelerates your build timeline.
8.4 Discuss the overall experience:

8.4.1 Was the project more or less difficult than you had expected?

The project proved to be around the difficulty we had anticipated. The size constraints created a challenge, but overall we were able to provide a practical design that meets all of the needs of the customer. It did require us to do a major redesign, but we had anticipated making changes and were open to improvements.

8.4.2 Does your final project result align with the project description?

Yes, our final project results align with the project description. Throughout the design and construction of the final project we used the project description as the basis of the design we developed, allowing it to meet the user needs that was specified by our customer.

8.4.3 Did your team function well as a group?

Yes, our team functioned extremely well as a group. We were efficiently able to divide work equally and meet both spontaneously and at regularly scheduled meetings, with all members being flexible and adaptive in their schedule. Overall, we conducted ourselves with a professional attitude and effectively took each member’s opinion into account throughout the progression of the project.

8.4.4 Were your team member’s skills complementary?

Yes, our team member’s skills were diverse and varied, allowing our complementary skills to benefit the project development, as work was able to be split among group members. Our varied skillsets allowed for us to teach each other in topics such as machining, and CAD stress analysis testing.

8.4.5 Did your team share the workload equally?

Yes, our team shared the workload equally. All group members were active in the decisions being made as well, regardless of whether or not they were directly working on
the part in question. The team always did work together, with all three group members present, actively discussing significant changes.

8.4.6 Was any needed skill missing from the group?

The only significant skill missing from our group was the knowledge and expertise with CNC-ing. This was overcome throughout taking advantage of our Washington University resources, and having machine shop experts help guide us through the process and teach our team members how to CNC.

8.4.7 Did you have to consult with your customer during the process, or did you work to the original design brief?

Yes, we consulted with our customer during the design process about what they needed from the product and their space limitations. This resulted in the initial user needs document that was developed.

8.4.8 Did the design brief (as provided by the customer) seem to change during the process?

No, the design brief did not change during the process although our design did change significantly throughout the course of working on the design project. We found ourselves to be over-engineering, going beyond the requirements our customer requested.

8.4.9 Has the project enhanced your design skills?

Yes, this project has greatly enhanced the design skills of our team members. Through developing and closely following a Gantt chart the project was able to efficiently be completed in a timely manner.

8.4.10 Would you now feel more comfortable accepting a design project assignment at a job?
Yes, we now feel significantly more comfortable accepting a design project assignment. This experience has helped to familiarize us with design projects, making them seem less daunting.

8.4.11 Are there projects that you would attempt now that you would not attempt before?

Yes, our team would absolutely be willing to attempt more projects than before. Upon going through this process, attempting another design project would be simpler, as we are familiar with scheduling and allowing for the inevitable design modifications and changes, as well as unexpected issues that will have to be overcome.

9 Appendix A - Parts List

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# Appendix B - Bill of Materials

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11 Appendix C - CAD Models
Link to 3-D models of the project: https://grabcad.com/library/plate-pouring-system-1

12 Annotated Bibliography (limited to 150 words per entry)


This site demonstrates commercially available plate pouring systems. Our design is inspired by this commercial version of plate pouring system. While our assembly could not replicate all of the commercial model due to significant cost restrictions, some fundamental mechanical processes from this system were adapted into our creative design process.


This is a video demo of how to prepare agar solution in order to test the plate pouring system. It helped our team understand that the agar setup needed to be easily installed onto the rest of the assembly in order to reduce the cooling time of the agar in its container.

This book contains an overview of concepts important to the plate pouring process, and how to properly prepare dishes for testing. This offered insight into how the current manual plate pouring process works in biology labs and how we could adapt this method into our design.


This book focuses on the challenges of studying several different types of bacteria and fungi, including sections on different plate preparation techniques for different classes of microorganisms. This showed us the importance of having a system that was relatively modular in terms of agar output, temperature, etc.


This book reviews sample preparation standards in several fields of biology in order to maintain extremely accurate and consistent results from research. This demonstrated how important it was to have an assembly which was extremely consistent from plate to plate.


This article describes an automated plate pouring device with a high plate-per-hour rate with multiple functionalities and which requires very low maintenance. It gave us a few ideas on what kind of assembly
was feasible and offered some ideas on how to mechanically separate the lids from the bases of the Petri dishes.


This website reviews the chemical nature of agar and goes into depth on its viscosity and melting point properties. This helped us understand the challenges associated with pumping a semi-viscous liquid through the peristaltic pump, and to find a sufficient substitute material for testing purposes.