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Plate Pouring Device I

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Concept Design and Prototype Development for Portable Agar Plate Pouring Machine

The goal of this project was to build a cost-effective agar plate-pouring machine to increase productivity in biology labs associated with Washington University in St. Louis. The plate-pourer needed to pour at least 120 plates per hour while keeping the agar sterile and preventing contamination.

Plate-Pouring I

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Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Project problem statement

The purpose of this senior design project is to design a device that can pour agar solution into petri dishes, or "plates", so that biologists and lab researchers do not have to do the process by hand. This type of device would be especially useful in university and small lab settings; university research labs generally don't have an overabundance of funding, and even if they do have the resources, they often do not spend money on machines to prepare and pour agar into plates. High-end versions of these machines can cost around $100,000 and pour up to 600 plates in one set; however, this application is not practical for small-scale labs. Therefore, finding a cost-effective solution to this problem, both in terms of dollars spent on the machine and in terms of man-hours saved, is a reasonable endeavor.

The main challenge in this project is designing a system which can pour at least 120 plates in one hour. Each plate needs around 30 mL of agar and the machine must be able to deliver this consistently without bumping the poured plates or otherwise causing the agar in the poured plates to slosh around. Ideally, the plates will be stacked after pouring as this controls cooling and helps prevent condensation from forming on the inside of the plate lids.

Another part of the project is that the device needs to be able to be sterilized. The sterility of the agar cannot be compromised during the pouring process, whether it be in the process of pouring the plates or after the plates get moved. Something as simple as the hot agar sloshing out of the plates after pouring can cause contaminated plates. To keep throughput high, it is necessary to take this into account during the design process.

1.2 Team members

The team members assigned to this project are:

Rebecca Ansolabehere
Katelyn Jones
Lydia Stensberg

Figure 1: Rebecca Ansolabehere

Figure 2: Katelyn Jones

Figure 3: Lydia Stensberg

2 Background Information Study

2.1 Design brief

The goal of our design project is to create an automated system that can handle the process of pouring agar, but is also easily sterilized and operates without supervision. This process will involve precise timing in order to pour agar consistently into stacks of plates. Because the agar pourer must be easily sterilized, the device also must fit into an autoclave, which is a machine that sterilizes equipment using hot steam.

2.2 Summary of relevant background information

There are a number of existing patents for plate-pouring devices and a variety of machines on the market. The relevant sources are referenced in Table 1 below.

Table 1: Relevant Patents

Patent #	Publication Date	Inventors	Title
US4170861 A	10/16/79	P. Snyder D. Freedman	Method and apparatus for filling petri dishes
URL:	www.google.com/patents/US4170861		
WO2014174306A1	10/30/14	P. Kuzan	Method and apparatus for filling a plurality of media plate in a self-supporting stack
URL:	www.google.com/patents/WO2014174306A1?cl=en		
US 3704568 A	12/05/72	O. Duhring et. al	Apparatus for the filling of petri dishes
URL:	www.google.com/patents/US3704568		
US 4468914 A	09/04/84	A. Pestes	Apparatus for filling petri dishes
URL:	http://www.google.com/patents/US4468914		
CN 204079437 U	01/07/15	隋娜	Device for filling culture media in sterile condition
URL:	www.google.com/patents/CN204079437U?cl=en		

Other relevant URLS:

1. Comparison of a variety of high throughput plate pouring machines: http://www.labcompare.com/General-Laboratory-Equipment/854-Automated-Petri-Dish-Filler-Agar-Plate-Pourer/
2. Systec MediaFill machine (900 plates per hour): http://800ezmicro.com/equipment/media-preparation/49-systec-mediafill.html

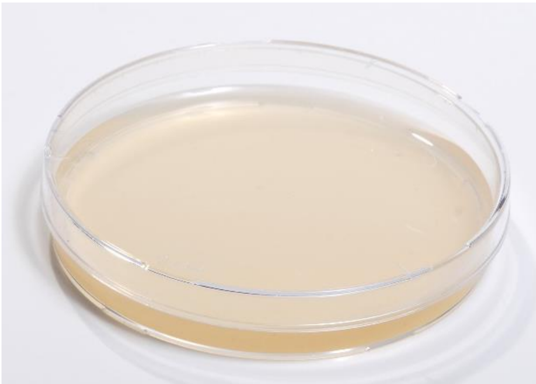
Most plate pourers function by moving stacks of plates through a multi-step process in which the parts of the machine which pour the agar are stationary and fixed to the device. These machines also have very well-manufactured parts to hold the stacks of plates steady and keep the agar from sloshing too much while it is being poured. Some of these machines also have the ability to sterilize themselves, but our device will have to rely on the agar-pourer operator to do this.

Agar itself is a medium that is sold in a dried, powdered form; in its heated, liquid state (when it is poured), the powder is dissolved in solution and the resulting liquid flows easily. It is shown in its powder state below in Figure 4, as a hot liquid in Figure 5 and in a finished plate in Figure 6.

Figure 4: Dried agar (Patel, 2013)

Figure 5: Hot agar in solution, prepared for pouring (AP Biology: Lab Preparation for Transformation Lab, 2012)

Figure 6: Poured, uncontaminated agar plate (Agar Plate)



3 Concept Design and Specification

3.1 User needs, metrics, and quantified needs equations

The following section details the research done to determine user needs for this project. This consisted of a user needs interview with Dr. Jim Goodloe, as well as several discussions with Dr. Mary Malast. These were translated into a set of quantified user needs. Each user need was given a number and connected to a metric, or some quantity or unit that could be used to measure that need.

3.1.1 Record of the user needs interview

The primary user needs interview, recorded in Table 2 below, took place with Dr. Jim Goodloe, who is affiliated with St. Louis Community College Center for Plant and Life Sciences. The college is the primary client for the plate pourer, so Dr. Goodloe's input was critical to understanding what the completed project would look like and how it should function to best complement the needs of the scientists at the laboratory.

Table 2: Customer/Primary User Needs Interview

Project/Product Name: Automatic Plate Pourer			
Customer: Dr. Jim Goodloe Address: Washington University Willing to do follow up? Yes Type of user: Frequent		Inteviewer(s): Rebecca Ansolabehere, Katelyn Jones, and Lydia Stensberg Date: 14 September 2015 Currently Uses: Manual hand-pouring techniques	
Question	**Customer Statement**	**Interpreted Need**	**Importance**
Describe the manual process of plate pouring	Use an Erlenmeyer flask, pour a few plates at a time. Carboy, straight jar with fairly small top. Attach hose at bottom, use pinch clamp and glass tube at end to measure. Need to be wary of steam, need to keep it away from plate.	Ease of use Directs steam/water away from agar	4 5
What is the agar medium?	A little more viscous than water. Similar to Jello. Peristaltic pump.	No splashing	5
How much medium in each petri dish?	30-33 mL per plate (approx. half full)	Consistent volume in petri dish	4

How much medium in each reservoir?	4L reservoir.	4L reservoir	2
How much time for setup?	Shouldn't take too long. Takes around ten minutes for sixty plates.	Quick simple setup (Ease of use)	5
How much needs to be automated vs. manual operation?	Would be willing to move around plates.	Automated system	5
How many petri dishes in a stack?	Should be stacks of ten or so.	Stacked plates	2
Dimensions of hood/workspace?	Will be sent in email.	System fits in hood	3
Which parts need to be sterile?	Autoclave for agar. Anything that touched the agar. Maybe just keep a stirrer in there to keep it moving. DON'T want to make bubbles.	Sterilizable system continued mixing	5 2
What would make you NOT want to use our system?	If it wasn't sterile or took longer than hand-pouring.	Sterilizable system Saves time compared to hand-pouring	5
Any common knowledge among plate pourers (i.e. sloshing in plates) that would be useful for us to know?	Don't want liquid to be towards top or it won't be good. Stacking helps prevent condensation. Want to prevent splashing, plastic tray helps. Sliding possible if you move slowly enough.	No splashing Stacked plates Consistent volume in petri dish	4 4 4
How long should it take?	120 plates in about half an hour. Takes 20 or 30 min to dry, but that's a conservative estimate. Usually leave them for a day. Five minutes or so.	Saves time compared to hand-pouring	5
Material suggestions? (Stainless steel vs plastics or other metals)	Inert materials –can't shed, etc. Plain rubber tubing works, ¼ in inside diameter. Stainless would be fine, stick with that.	Sterilizable Easily cleaned	5 5

	Something without a lot of corners, glass is nice and inert.		
Problems you run into now?	Condensation. Non-uniform thickness, dries out if it's too thin.	Stackable plates Uniform volume in petri dish	4 4

3.1.2 List of identified metrics

After interviewing Dr. Goodloe, the project team condensed the user needs interview into a set of eight metrics, which are well-defined quantities used to measure how well specific needs are met. The team set specific minimum and maximum values for each metric, according to quantitative items such as drying time for the agar and volume of the fume hood, and also according to qualitative data such as user preference and Boolean present or not present values.

Table 3: Metrics Table for Plate-Pouring System

Metric Number	Associated Needs	Metric	Units	Min Value	Max Value
1	1,7,10	time	minutes	10	30
2	4,5,11	volume	ft^3	2.25	5
3	2	steam	integer	1	10
4	3	splashing	boolean	0	1
5	6	sterilizable	boolean	0	1
6	8	automated	boolean	0	1
7	10	stacked plates	boolean	0	1
8	1,10	ease	integer	1	10

3.1.3 Table of quantified needs equations

The user needs interview was condensed into eleven needs, which all appear in the metrics table above. Each user need's presence in the designed system is measured separately, and all are assigned an importance value on a scale of 1 to 5, 1 being the least important and 5 being the most important. The condensed table is created after metrics are decided because one or more user needs may not be quantifiable, in which case they are condensed with and considered in the light of other user needs that can be concretely measured. The table is helpful in the design process because some user needs may or may not be in conflict with one another, and having an objective table of user needs with importance ratings provides a ready-made explanation as to why the team chose to satisfy one need over another.

Table 4: Condensed User Needs Table

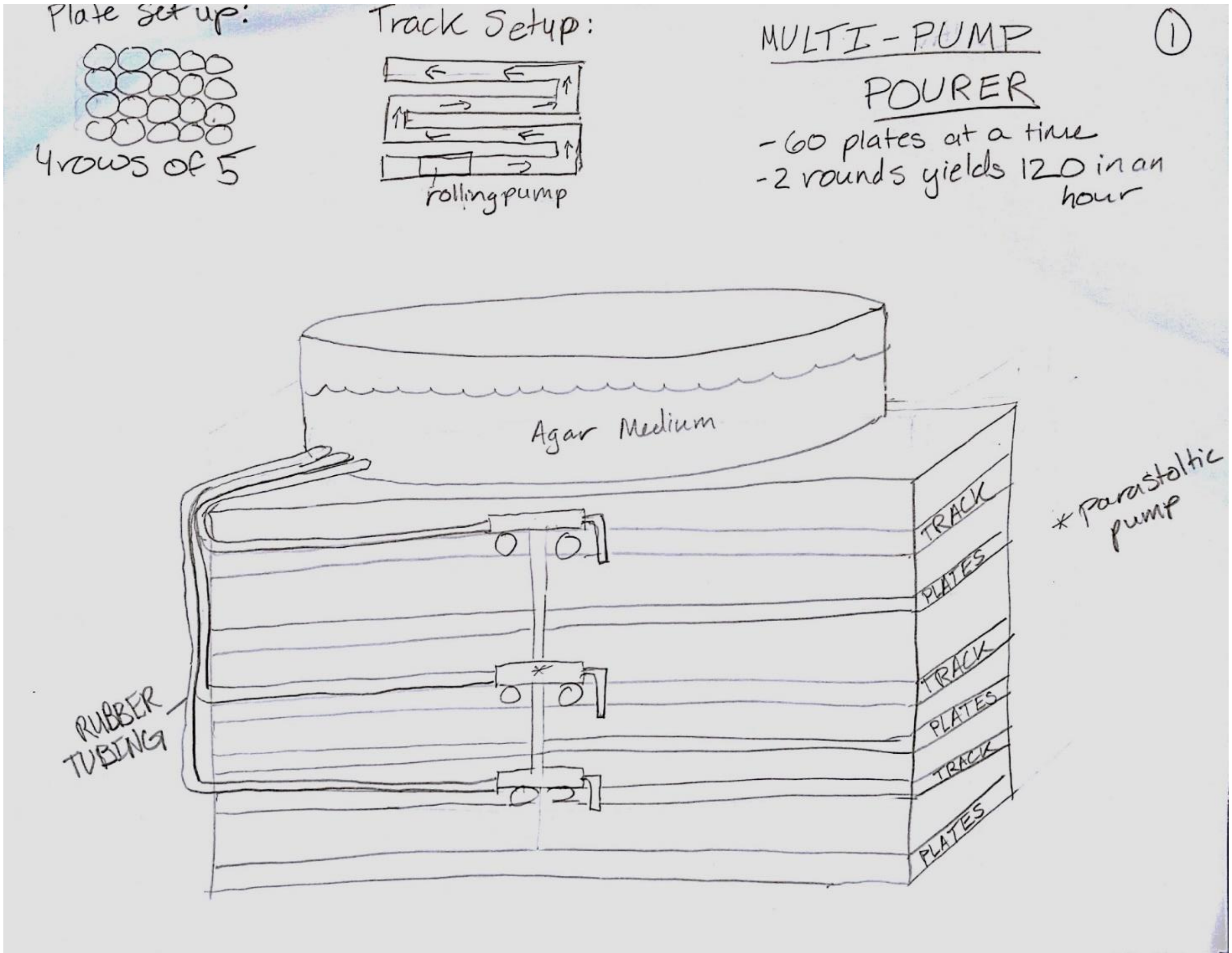
Need Number	Need	Importance
1	Ease of Use	4
2	Directs Steam or Water away from agar	3
3	No splashing	4
4	Consistent volume in petri dish	4
5	4L reservoir	1
6	Sterilizable system	5
7	Time Shorter than Hand pouring	5
8	Automated system	5
9	stacked plates	4
10	Easily cleaned	5
11	System fits in hood	4

3.2 Four preliminaryconcept drawings

After the quantification and ranking of user needs, four concept drawings were generated, as seen in Figure 7, Figure 8, Figure 9, and Figure 10 below.

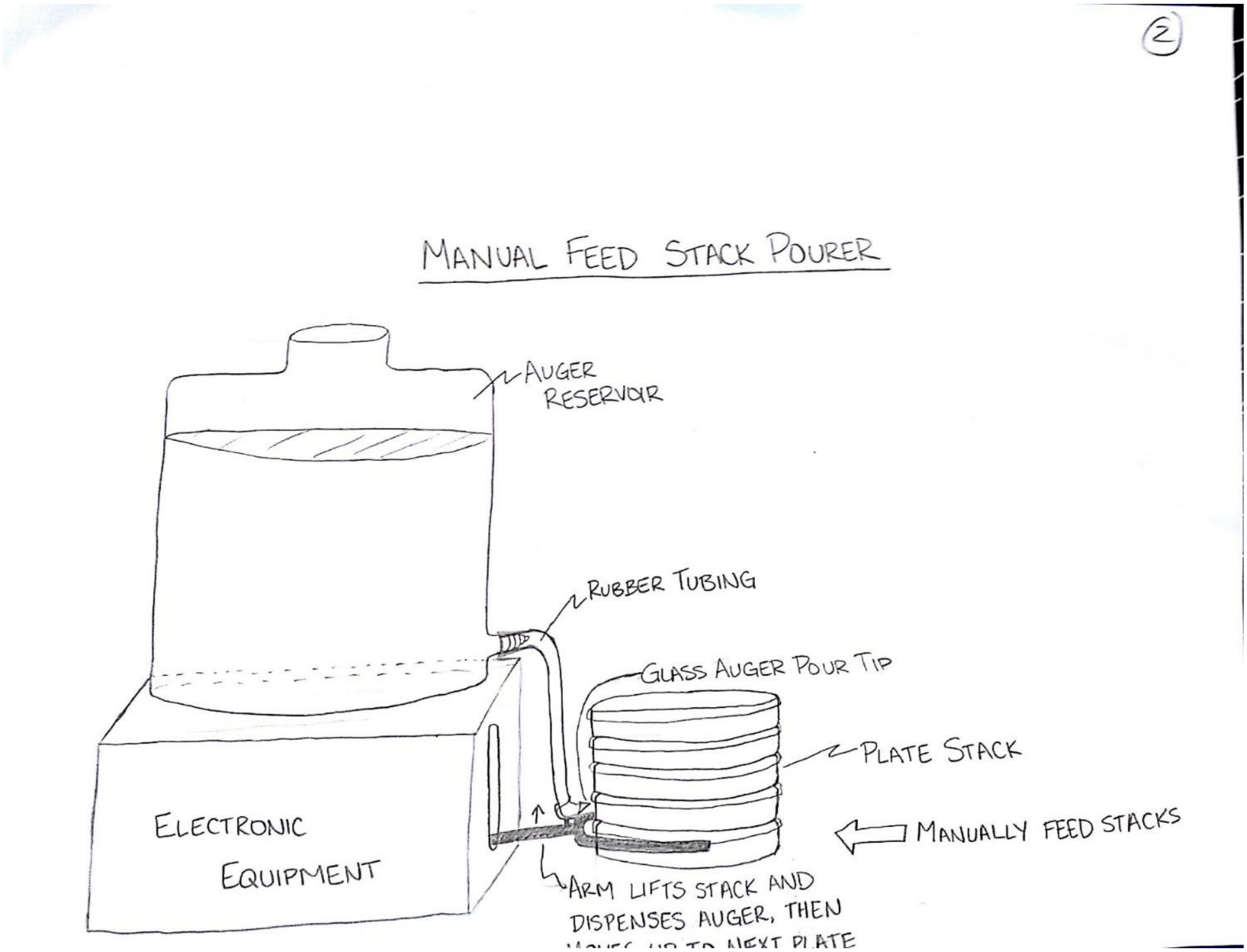
The first concept design took into account the need to prevent splashing of the agar medium and movement of the plates after pouring, as well as the need for efficiency. As seen in Figure 7, this concept, using two pumps, could operate at an efficiency of 120 plates per hour, which is the desired efficiency of the machine given in the design brief. Three separate pourers are driven along the tracks using continuous operation servo motors, and peristaltic pumps are used to give out a consistent amount of agar for each pour.

Figure 7: Multi-pump tracking stationary plate system



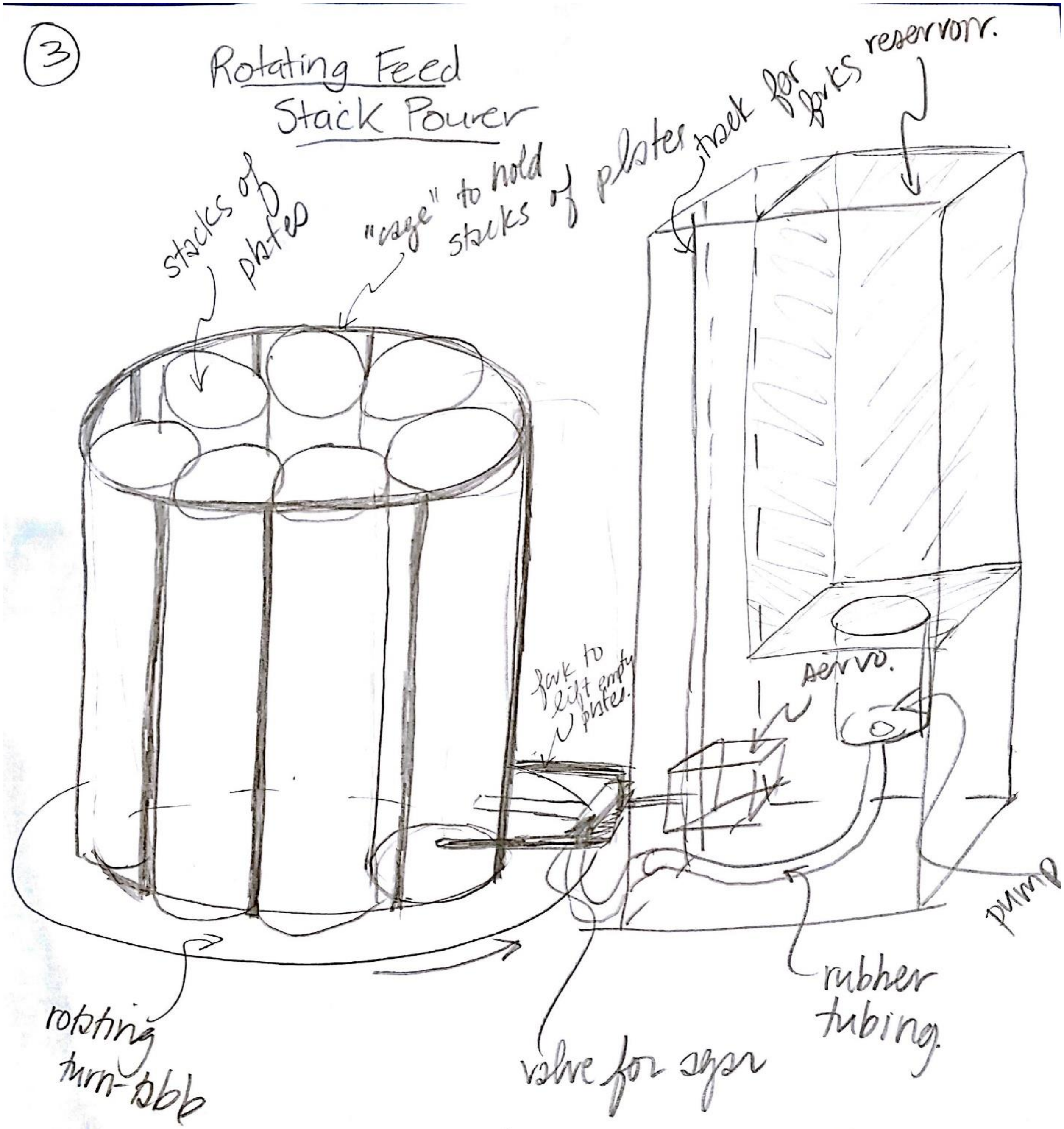
As seen in Figure 8, the manual feed stack pourer provides a simpler alternative to a fully automated pourer. The robotic arm lifts the stack and dispenses the agar, then sets the stack down and repeats with the next plate in the stack. While providing a simpler automation process, this machine does not provide the hands-free automation requested in the design brief, and someone would need to be present throughout the whole process to pour the plates.

Figure 8: Manual, individual stack feed pourer



The next concept, shown in Figure 9, is more similar to a traditional plate-pouring machine, as found in our patent search before beginning the project. The stacks are placed on a rotating turnstile, and after the pourer has worked its way up each stack, the turnstile rotates and the arm lowers to bring the valve to the next stack. A pump is used in this concept to enable a constant pouring rate, even when the arms are at the top of the stack.

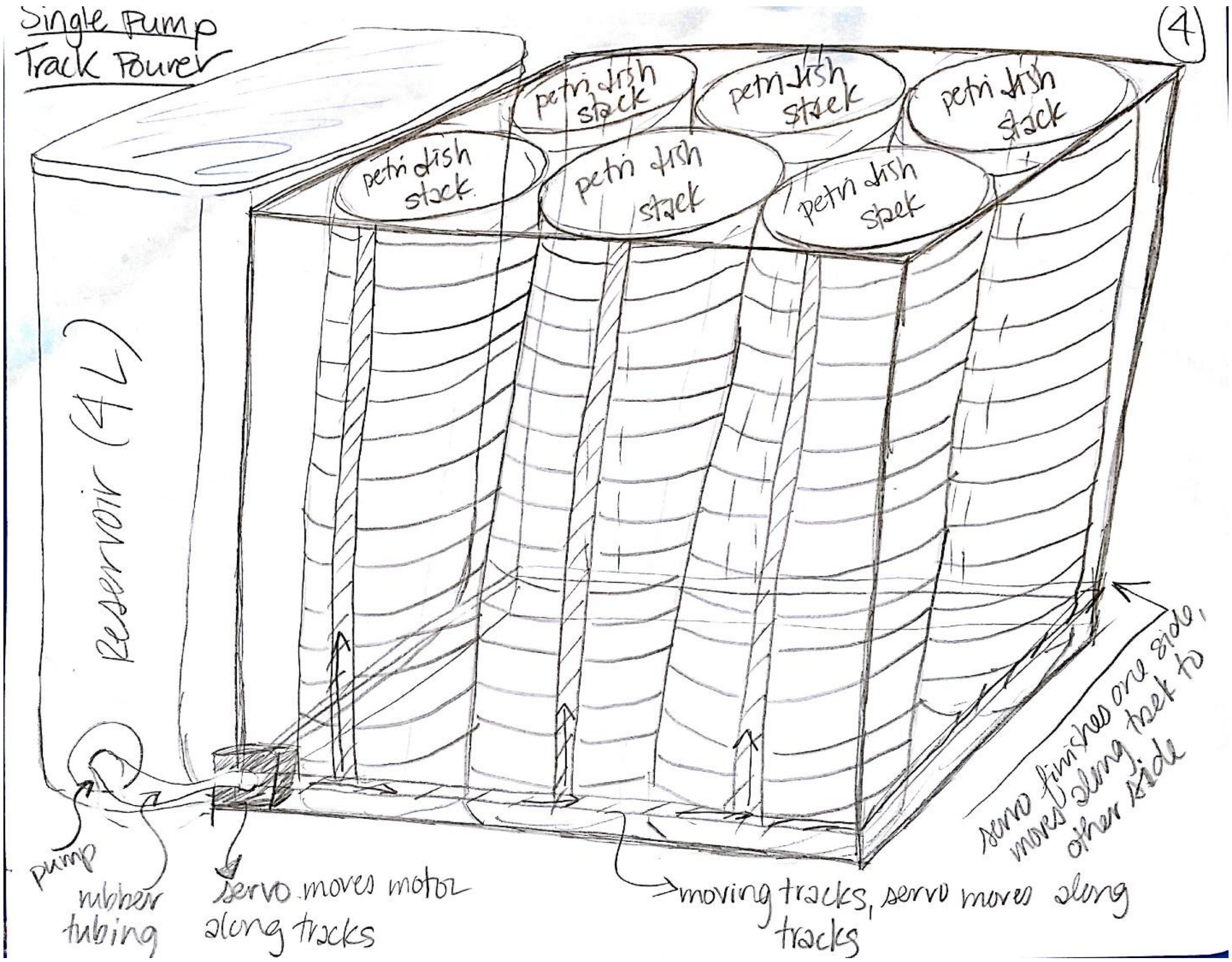
Figure 9: Automatic rotary feed stack pourer



Turntable rotates stacks of plates to be filled. Valve & forks move up and down to lift lids off of each petri dish. Plates are filled from bottom to top of the stack.

The final concept, seen in Figure 10, employs a pump to ensure that fluid reaches a moving pourer that moves along the bottom of the rack. The pouring valve travels up each stack, filling each plate as it goes, then moves down and over to the next stack. When all of the plates on one side of the device are poured, the pourer is moved to the other side of the stack and those plates are poured as well.

Figure 10: Single valve automatic lifting pourer



3.3 Concept selection process

3.3.1 Concept scoring

The four design concepts described above were then compared using the metrics that were adapted from the user needs interview. Each concept was given a final score according to how well we predicted they would fulfill each need.

Plate Pouring Happiness Equation		Metric																
		Time	Volume	Steam?	Splashing	Sterilizable	automated	stacked plates	ease	Need Happiness 1	Need Happiness 2	Need Happiness 3	Need Happiness 4	Importance Weight (all entries should add up to 1)	Total Happiness Value	Total Happiness Value	Total Happiness Value	Total Happiness Value
Need#	Need	1	2	3	4	5	6	7	8									
1	ease of use	0.125							0.75	0.8	0.25	0.5625	0.45	0.09091	0.07273	0.02273	0.05114	0.04091
2	no steam/ water in agar			1						0.88889	1	0.25	0	0.06818	0.06061	0.06818	0.01705	0
3	no splashing				1					1	0	0.58667	0	0.09091	0.09091	0	0.05333	0
4	consistent volume of agar		0.5							0.46667	0	0	0	0.09091	0.04242	0	0	0
5	volume of reservoir		0.25							0.23333	0	0	0	0.02273	0.0053	0	0	0
6	sterilizable system					1				1	1	1	0.45333	0.11364		0.11364	0.11364	0.05152
7	time shorter than hand pouring	0.75								0.75	0	0	0	0.11364		0	0	0
8	automated						1			1	0	1	1	0.11364	0.11364	0	0.11364	0.11364
9	stacked plates							1		1	1	1	1	0.09091	0.09091	0.09091	0.09091	0.09091
10	easy cleanup	0.125							0.25	0.35	0.08333	0.1875	0.15	0.11364		0.00947	0.02131	0.01705
11	system fits in hood		0.25							0.23333	0	0	0	0.09091	0.02121	0	0	0
	Units	minutes	ft^3	integer	boolean	boolean	boolean	boolean	integer	Total Happiness 1	0.49773							
	Best Value	10	3.375	1	0	1	1	1	10	Total Happiness 2	0.30492							
	Worst Value	30	12.75	10	1	0	0	0	1	Total Happiness 3	0.461							
	Actual Value	10	4	2	0	1	1	1	9	Total Happiness 4	0.31402							
	Normalized Metric Happiness	1	0.93333	0.88889	1	1	1	1	0.9									
	Actual Value	30	3.375	9	1	1	0	1	3									
	Normalized Metric Happiness	0	1	0.11111	0	1	0	1	0.33333									
	Actual Value	25	7.25	1	0	1	1	1	7.5									
	Normalized Metric Happiness	0.25	0.58667	1	1	1	1	1	0.75									
	Actual Value	30	8.5	1	0	1	1	1	6									
	Normalized Metric Happiness	0	0.45333	1	1	1	1	1	0.6									

3.3.2 Preliminary analysis of concept physical feasibility

1. Multi-Pump Track Pourer

Concept 1 uses three peristaltic pumps to feed three valves attached to tracks to simultaneously fill 3 trays of 20 plates each (4 stacks of 5 plates). The agar reservoir sits on top of the system and replaceable rubber tubing runs from the bottom of the reservoir to the three valves. The rubber tubing is connected to the peristaltic pumps which are set on a track and moved by a motor and/or pulley system. A forked arm is attached to each pump which starts at the bottom of the each stack and lifts the lid of the bottom plate along with the upper plates, then the agar is poured and the arm lowers the stack, moves up, and repeats the process with the next plate in the stack. All 3 pumps are connected and run by an Arduino electronic system which turns the device on and off and runs the pumps in parallel. After 60 plates are poured, the user shuts the device off and loads another 60 plates on trays so that 120 plates are poured within an hour.

The main difficulty in building this concept is the programming required to move the arm and valve from plate to plate with the correct timing. It is important to not drop plates or dispense agar medium in the wrong places, so the programming is important for the precision of the mechanism. This concept would also require building three peristaltic pumps which may be difficult to build to exactly the same specifications. However, this concept is attractive because it allows for multiple plates to be poured at once (decreasing pour time) and it is easy to load and unload plates because of the use of trays.

2. Manual Feed Stack Pourer

Concept 2 is a manual design which requires the user to load stacks of five plates into the device and unload for the next stack. A forked arm starts at the bottom of the loaded stack and lifts the lid of the bottom plate along with the upper plates, then the agar is poured and the arm lowers the stack, moves up, and repeats the process with the next plate in the stack. The agar reservoir is a large 4 to 8 L carboy with rubber tubing ending in a glass tip attached to the bottom opening. The tubing is attached to the lifting arm and will be opened and closed by a servo motor which pinches the tubing to control the agar flow into the plates. The electronic equipment for the arm and servo is stored in the box below the reservoir and a magnetic stir bar can also be installed here to mix the auger.

The main problem with this concept is the manual requirement for the user to load the stacks of plates each time. The customer stated that they would be happy with a device that was set up in this way because it still eliminates the human error in pouring the plates. However, because manual input is required and the system is not fully automated, this may not be the best choice.

3. Rotating Feed Stack Pourer

Concept 3 includes a rotating tower of stacked plates enclosed in a cage to stabilize and contain the stacks. The agar reservoir is housed with the electronics and a forked arm extrudes from this structure. Rubber tubing runs from the reservoir to the end of the arm where agar will be dispensed. The arm starts at the bottom of each stack and lifts the lid of the bottom plate along with all of the upper plates, then the agar is poured and the arm lowers the stack, moves up, and repeats the process with the next plate in the stack. Servo motors with Arduino programming run the arm movement and peristaltic pumps which dispense agar. The stacks of plates are on a rotating tray and once one stack is completely poured, servo motors will turn the table to the next stack and the process begins again.

A difficulty in building this concept is managing the stacks of plates so that there is not spilling or dropping plates. The tower heights need to be such that the space required is minimized, but the integrity of the stacks is still intact and useful. This system is also slightly more complex because it requires automating the turning of the tray along with the movement of the valve head and forked arm.

4. Single Pump Track Pourer

Concept 4 uses a peristaltic pump to feed one valve which is attached to a single track to fill stacks of plates. The agar reservoir sits beside the system and replaceable rubber tubing runs from the reservoir to the valves. The rubber tubing is connected to the valve and a forked arm which are set on a track and moved by a motor and/or pulley system. The forked arm attached to each pump starts at the bottom of each stack and lifts the lid of the bottom plate along with the upper plates, then the agar is poured and the arm lowers the stack, moves up, and repeats the process with the next plate in the stack. The valve then moves along the track to the next stack of plates. The system is run by an Arduino which turns the device on and off and runs the pump.

This concept meets the user need of ease of use, but it also does not pour as many plates as concept #1. The programming is also another difficulty here with three degrees of freedom and precision being highly desirable.

3.3.3 Final summary of chosen concept

We chose the first concept as the winner for three primary reasons: first, it scored highest on our needs metric, second, it has the capability to finish the largest amount of plates in the shortest amount of time, and third, it was the only one that gave the user the ability to safely move the plates using a method already used in the laboratory. We also felt that a multi-pump design was the easiest way to combine speed with overcoming the limited hood space available to us. Current automatic plate-pouring systems have stacks of approximately three hundred plates and standalone outside the hood. With the current laboratory setup available to us, as well as the requirement of keeping the equipment sterile, this was not a reasonable design option for us. We felt that the first concept made the best use of the space provided and would also provide a satisfactory decrease in man-hours spent on pouring plates. We ruled out the second option, the manual feed stack pourer, almost immediately, primarily because it required a manual feed. We were told in one of our needs interviews that this might be acceptable, but we felt that a manual feed would mean an insignificant difference in the amount of man-hours spent pouring the plates using the machine versus performing the process manually. We initially thought that the fourth design, the single-pump track pourer, would also be a viable option. When we ran it through scoring, however, we realized that it would take up a lot more space than most of the other options, especially because the stacks would not be as high as with the other design. The stacks would also need to be manually loaded into the cage, which would be somewhat inconvenient and contribute to a longer setup time. We also thought the hassle might make the laboratory workers prefer to pour by hand. The main goal of our design is ease of use, so a design that could not beat manually pouring the plates in this category was deemed unacceptable. This reason made the third option, the rotating feed stack pourer, score lower as well. An aspect of the rotating feed stack pourer that we did like was that the plates would be in large stacks, which would help to prevent condensation dripping on the plates and ruining the agar, but this can also be accomplished with smaller stacks in the other designs.

3.4 Performance measures

Performance goals:

1. The system will pour 60 plates in 10 minutes.
2. The whole frame will take up 1.5 ft X 1.5 ft of space and be 2 ft tall (including the reservoir).
3. Each pump will pump 30 mL of fluid into each plate.
4. The rubber tubes will be easily replaced and sterile.
5. The trays will be easy to move without spilling the agar medium.
6. 90% of the plates will have minimal visible condensation.
7. 80% of the plates will not slosh during moving.
8. The frame will take less than 5 minutes to clean.
9. After 30 minutes of rest, the plates can be swapped out for the second set.

3.5 Design constraints

Design constraints are the driving force behind the design concepts used to fulfill user needs. They can take several forms, including functional, safety, quality, manufacturing, timing, economic, ergonomic, ecological, aesthetic, lifestyle, and legal.

3.5.1 Functional

The main functional constraint we faced was overall geometry. Our customer asked that the device fit in the confines of a fume hood that is 18” deep, 17” wide, and approximately 40” long. Therefore, our system needed to be compact, and portable so that it can be moved in and out of the fume hood.

3.5.2 Safety

The main safety constraints that needed to be followed was protecting the electronics from the agar, which would be damaging if splashed on them. This will be accomplished by mounting the electronics below the ceiling on the outer housing and on the inner, sliding housing. Not only will mounting the electronics here make for easier mounting, it will also keep the electronics above any potential splash from the agar.

Another safety constraint is the hot agar, which should be safely contained so it doesn’t spill and burn someone. This will be accomplished by having a closed reservoir, with something that can be removed at put back onto the machine at the user’s convenience.

3.5.3 Quality

The main quality constraint that needs to be followed is that the agar must remain sterile at all times during the process. Therefore, any part of the machine that routinely touches agar will need to be sterilized before each use of the machine. The sterilization technique used is mainly autoclave, therefore every part that touches the agar needs to either be autoclaved or easily cleaned.

3.5.4 Manufacturing

There are two main mechanisms that pose manufacturing constraints: the mechanism to dispense the agar, and the mechanism to move the plates. The entire servo system will need to be timed extremely well in order to be effective. Also, it would be most convenient for the valves that dispense the liquid to not touch the agar. That way, the valves would not need to be taken off and sterilized each time, which makes it easier to deal with the electronics in the valves as well. Also, the grippers need to be able to grab and hold onto the plates.

3.5.5 Timing

The system took longer than expected to put together. Finding pinch valves that were in our budget and could be threaded with the tubing (instead of attaching a tube at each end, resulting in the valve touching the agar) took a lot longer than expected and set back building.

Furthermore, after we ordered the electronics, some parts had to be re-ordered. The servos that were supposed to be used to lift up the arms only turned 180 degrees, instead of continuously. Most importantly, originally we ordered the Arduino Pro, because we thought it would be cost efficient but it turned out to need a lot of extensions that were not readily available to connect it to a laptop and power source, so we ended up returning it and ordering an Arduino Uno.

It was assumed at first that the servos would come with mounts, but the ones they came with were not useful to us. We had to make our own, which we were not expecting.

We did not take into account that our pulley system may not work with just string. However, it became clear that we would need to use an actually belt in order to move something as bulky as the inner housing. Luckily we found a belt in the basement, but not before we had been set back a few days.

Another problem that proved a hindrance to timing the construction of our project was that the gripper kit arms were not long enough to grab the plates in the middle, and thus needed extensions which set building back by a half a day.

3.5.6 Economic

At first, economic issues did not seem to be a concern. The initial budget came in well under the limit of $300. When the pinch valves were purchased, however, it was worried that their high cost would push the project over budget. Upon closer examination, however, one of the team agreed to take half of the pinch valves, which were worth $50. Even with the expedited shipping of the new Arduino, the budget came in just under what it was supposed to be. As we were building, we realized we needed more parts that we had not taken into account, such as various electronics or a pulley system. Luckily, we found a pulley system that moved the inner housing effectively, although it was too short for the device to reach as many plates as its intended capacity.

3.5.7 Ergonomic

The main ergonomic constraint is the easy of movement of the plates, both before and after the agar has been poured into them. To this end, we have rigged the plate-pourer to be used with a lunch tray, so that the user may stack the plates without having to worry about the confines of the machine. The lunch tray is already used for moving stacks of plates, thus while the device does not improve ergonomic conditions (aside from the small relief of not having to pour the plates by hand), it does not decrease the ergonomic quality either.

3.5.8 Ecological

Spillage is a primary ecological concern. The machine is designed so that the plates rest for thirty minutes before they are moved, thus the likelihood of spilling from moving the plates is small. Spillage while pouring plates is another issue. Any agar spilled should be caught by the tray. However, if the arms do not move to the precise location of the lid of the plate, spillage will definitely occur. Thus it must be ensured that the plates are in the proper position and that the servos and pinch valves are timed correctly.

3.5.9 Aesthetic

There was not any particular aesthetic that needed to be kept by the machine. The major concerns were mostly to do with function. Many of the electronic items were mounted by duct tape because they needed to be mounted at the last second and in a temporary fashion, in order to make last minute adjustments to the positions of the electronics.

3.5.10 Life cycle

The concern with such a small budget is building a machine that will be durable enough to last through multiple life cycles. Many of the mounts were made of foam, which would be replaced with machined metal mounts. The strings in the servos that raise and lower the arms would have to be replaced a more durable string. A durable reservoir needs to be put in place. The circuit board needs to be mounted and the wires need to be harnessed. If all these steps are followed, the device should have a fairly long life cycle. The limiting factors would be the durability of the pinch valves and reservoir. Ebay did not provide information on the durability of the pinch valves and a permanent reservoir was not ordered. The tubing is replaceable and would have to be removed after every run and either cleaned or replaced with new tubing.

3.5.11 Legal

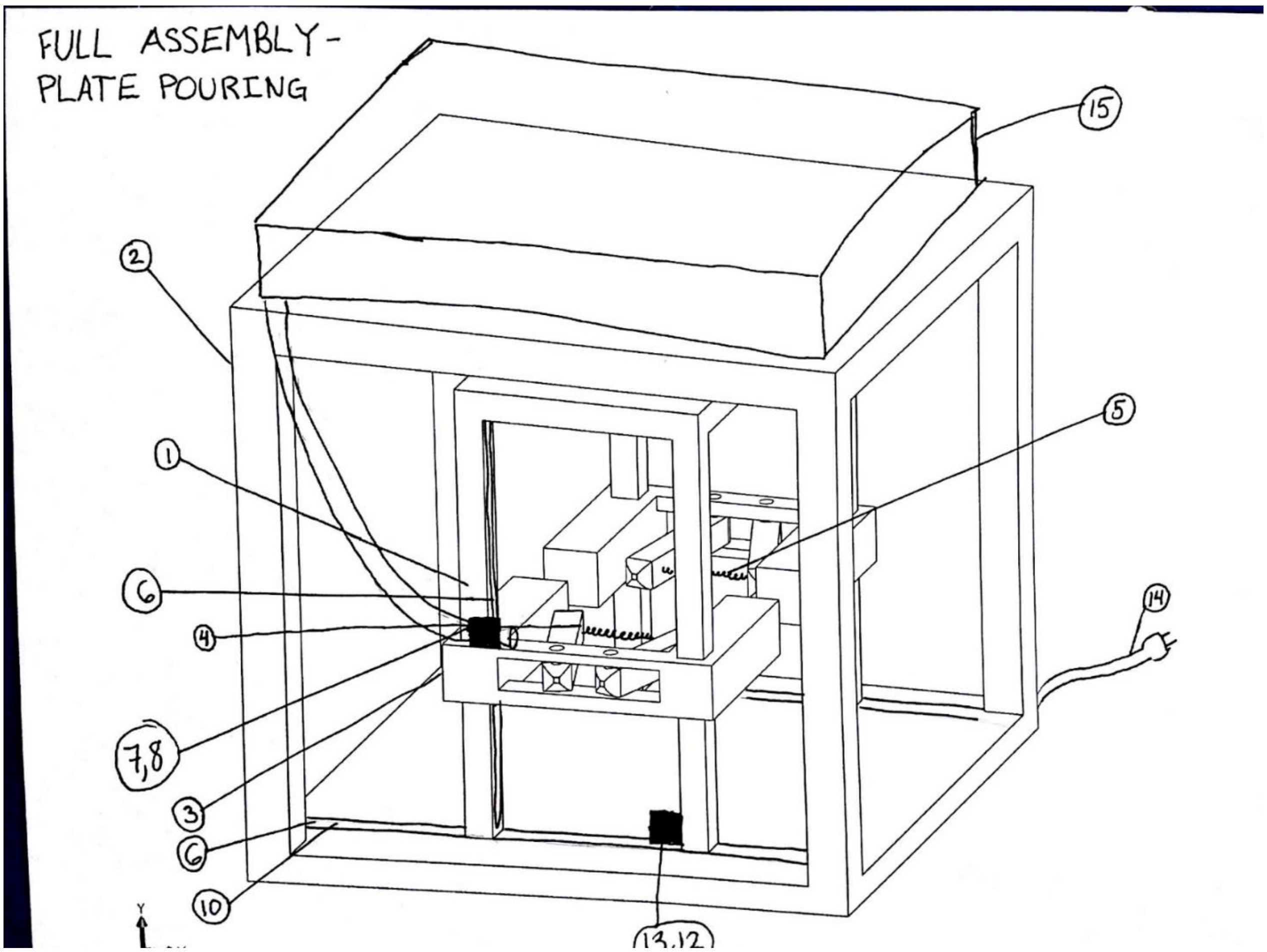
Sterilization standards need to be met. If our reservoir was made of glass, it would need to be placed in dry heat at 350°F for 2-3 hours. All other parts that are reusable must be autoclaved (Thiel 2015).

4 Embodiment and fabrication plan

4.1 Embodiment drawing

Figure 11 below shows the initial embodiment drawing for our selected design concept. There are three main assemblies within the concept: an outer housing on which the reservoir sits, the inner housing which moves horizontally from stack to stack, and the gripper arm which moves vertically from plate to plate.

Figure 11: Initial design embodiment drawing



4.2 Parts List

Table 5: Initial parts list for original design concept and Table 6 below show the initial parts lists for our design concept. These lists were the basis for our first parts orders and initial budget requests; however, they expanded and changed throughout the design process and a full parts list and bill of materials are found later in this report.

Table 5: Initial parts list for original design concept

Miscellaneous Parts List					
Part Number	Part	Catalog Number	Quantity	Cost	Source
1	Housing	8973K154	1	$11.60	McMaster-Carr
2	Outer Frame	9008K81	1	$10.58	McMaster-Carr
3	Grabber Assy.	N/A	2	(from class budget)	WashU
4	Arm grip	N/A	4	$2.10	Amazon
5	Spring	94135K2	1	$6.57	McMaster-Carr
6	Wire	8872K29	1	$3.71	McMaster-Carr
7	Pinch Valve	5031K11	2	$85.00	Cole Parmer
8	Tubing	5155T11	2	$0.88	Mcmaster-Carr
9	Housing track	30636	1	$16.99	Rockler Woodworking and Hardware
10	Housing servo	ROB-11965	1	$12.95	sparkfun
11	Arm servo	ROB-10333	2	$10.95	sparkfun
12	Arduino Pro	DEV-10915	1	$14.95	sparkfun
13	Power cord		1	$3	Amazon
14	Reservoir	N/A	1	$25	eBay
			TOTAL:	$132.98	

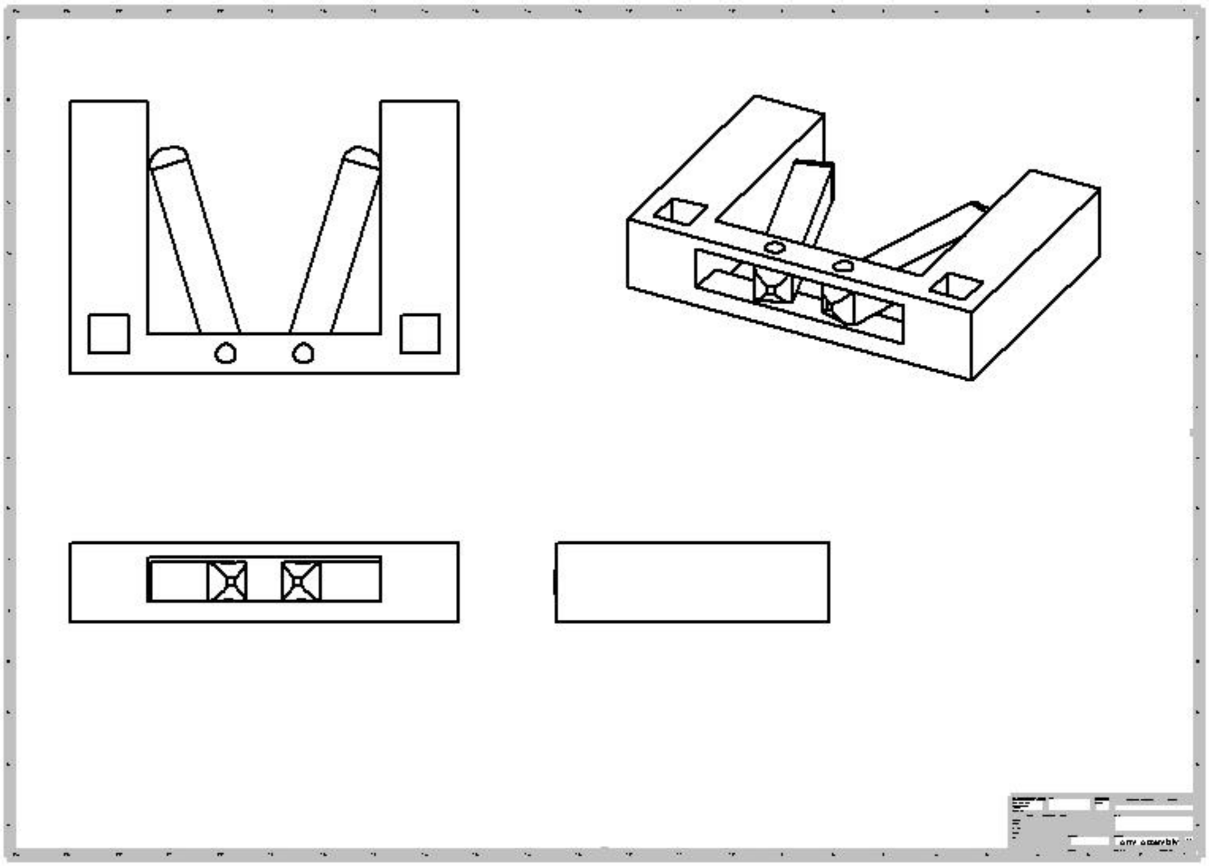
Table 6: Raw Materials Parts List

Specific List: Raw Materials			
Assembly	Catalog Number	Material	Quantity
Housing	8973K154	Multipurpose 6061 aluminum sheet	10 gauge, 6" x 24"
Outer Frame	9008K81	Multipurpose 6061 aluminum stock	1/2" bar stock, 6'
Grabber Assy.	N/A	Plastic, 3D Printed	
Reservoir	(eBay)	Stainless Steel	1

4.3 Draft detail drawings for each manufactured part

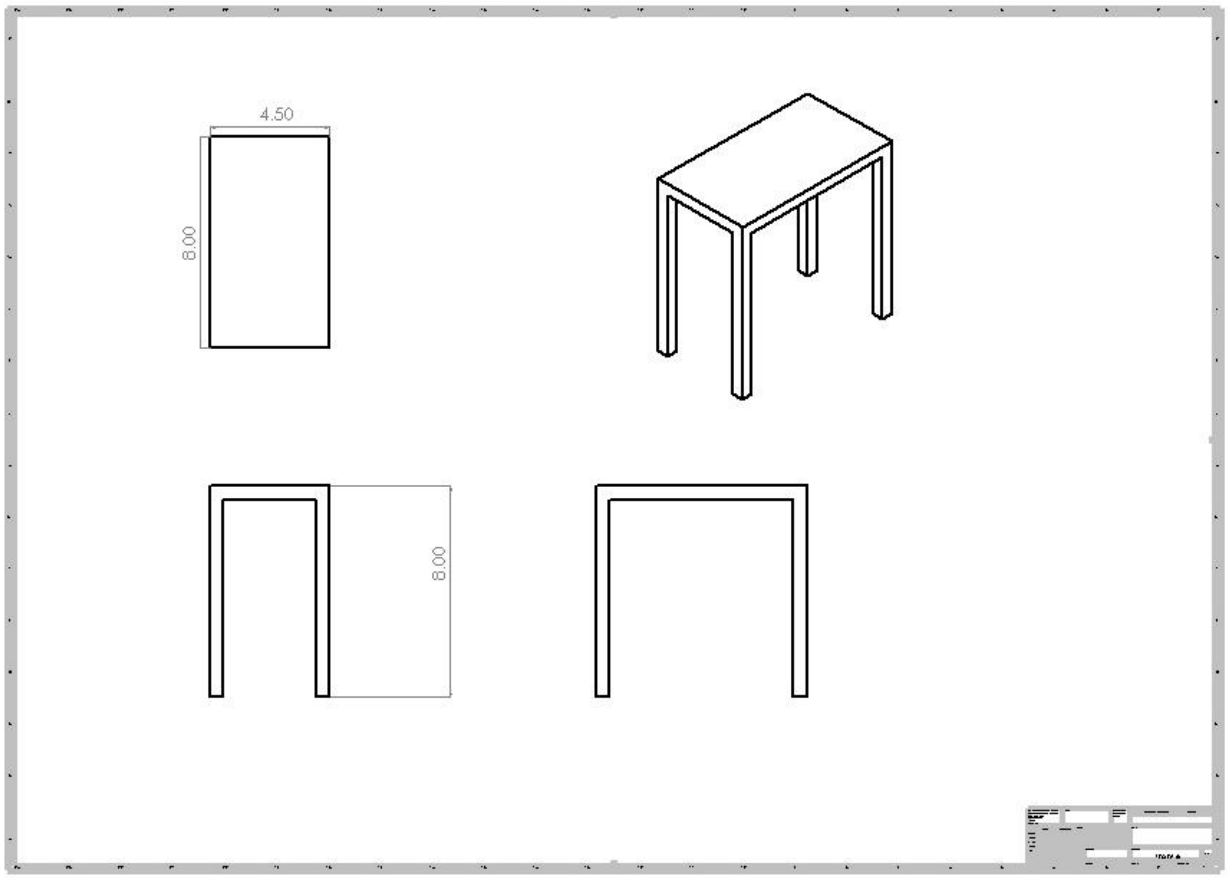
For our initial design draft, we planned on machining each robot arm that we used. Below are the rough specification sheets for the grippers. These were our plan before we were advised that buying the robot arms would be within our budget and would make the manufacturing process much easier.

Figure 12: Initial gripper arm design drawing



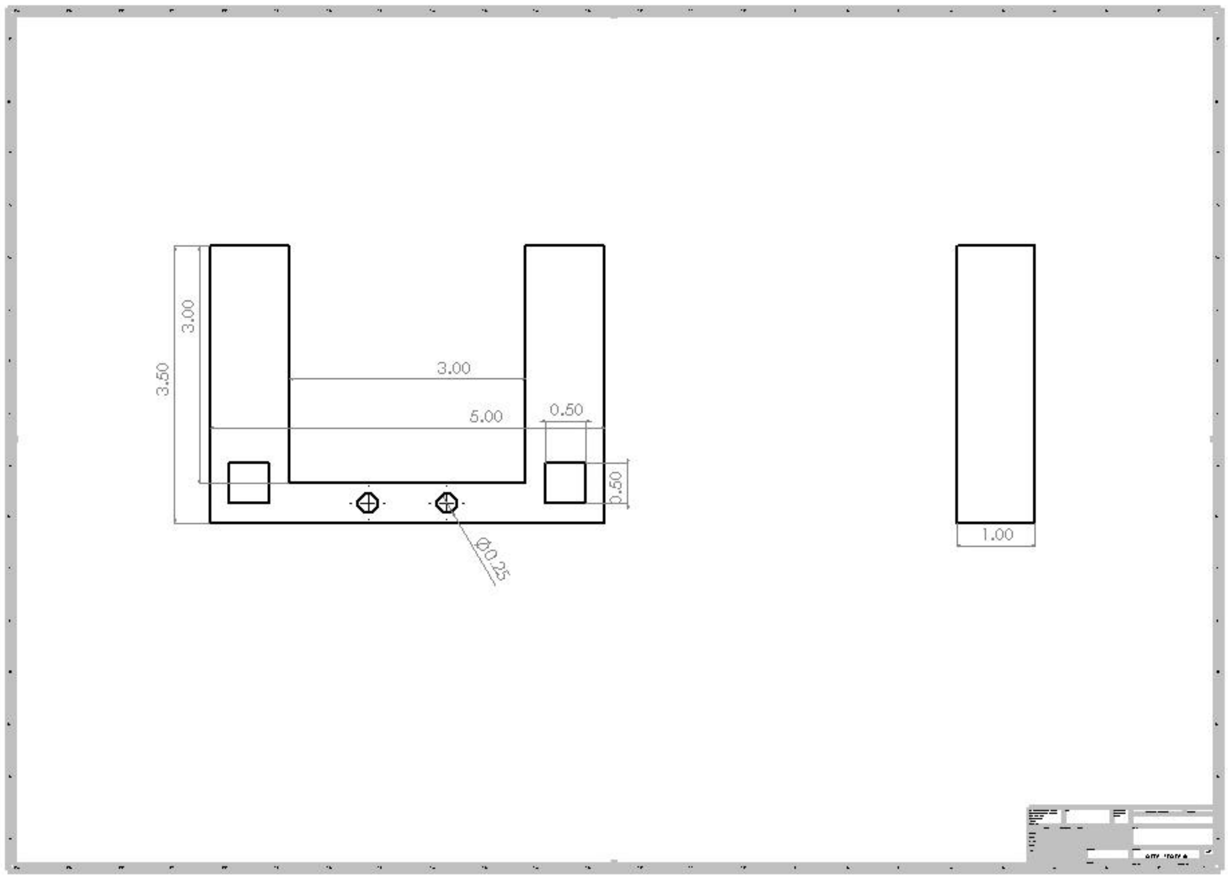
The inner housing is intended to slide on rails underneath the outer housing. It is designed to fit over two stacks of plates, so its dimensions are wide enough to fit over two stacks while carrying the stacks of plates up and down.

Figure 13: Initial inner housing design drawing



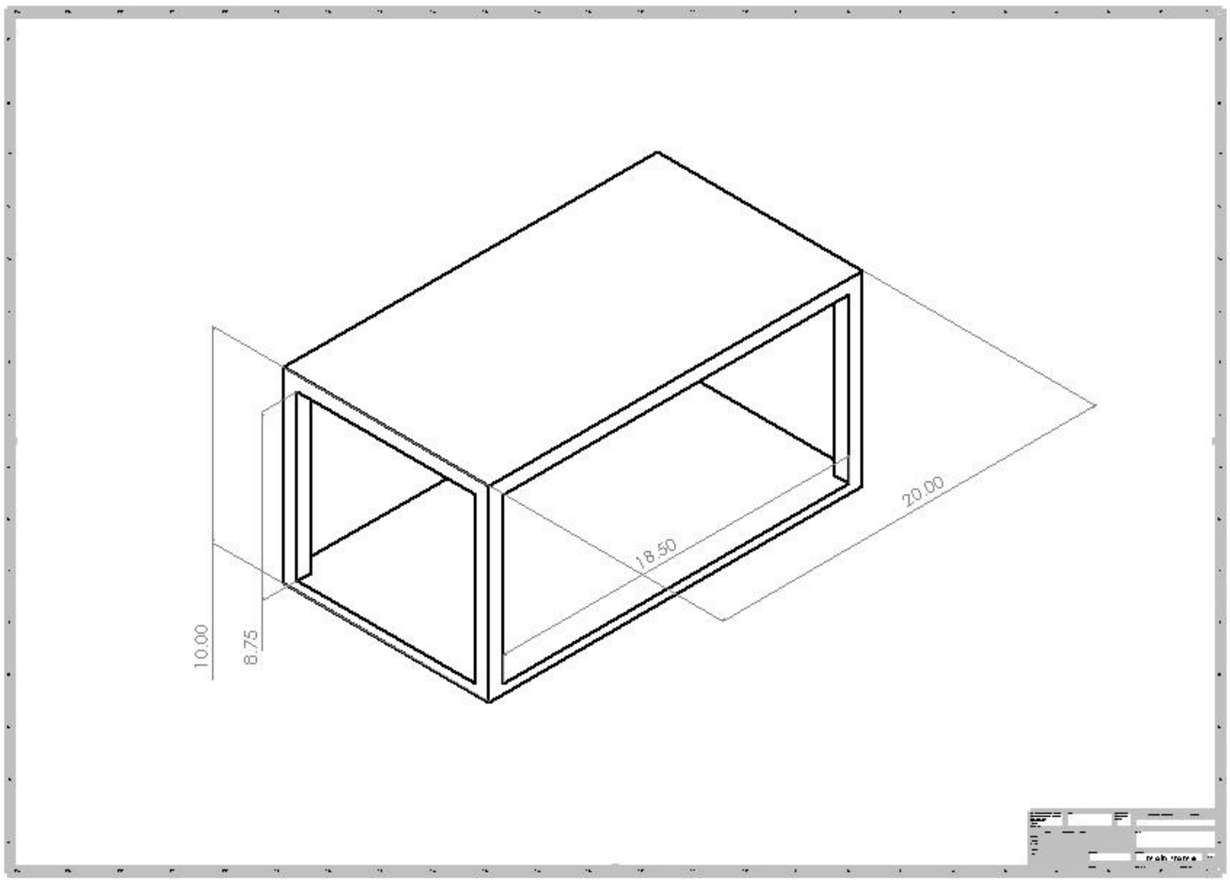
The grabber frame was designed to provide stability to the grabber arms. The two openings for tubing provide stability as the grabber arm slides up and down the inner housing assembly.

Figure 14: Initial gripper arm frame design drawing



The outer frame is designed to support the weight of the electronics and the reservoir, so the braces needed to be made of sturdy material. This seems like it would be extremely expensive, so we are looking for ways to cut down on cost for the stock of this part.

Figure 15: Initial outer housing design drawing



4.4 Description of the design rationale

The following is a short description of the initial rationale for the design and materials chosen. Where applicable, changes in design or material selection have been noted.

4.4.1 Housing

It is important that the housing be structurally sound, but also lightweight and easily machined, so we chose to make it out of 10-gauge 6061 aluminum sheet. Our housing does not need to have any particularly properties other than structural stability because it does not come into contact with the agar. This part won't be sterilized, so we can save some money and manufacturing time by making it out of aluminum instead of stainless steel.

4.4.2 Outer Frame

We wanted to build the outer frame from a material that is cheap, lightweight, and easy to machine. Since the outer frame will not come into contact with the agar, we did not have to worry about choosing a material that won't react with the agar solution. Therefore, Aluminum 6061 was the obvious choice. Half inch, square stock should be enough to hold up four liters of agar in the reservoir and the housing assembly. The yield strength of 6061 Aluminum is listed at 40,000 psi. Half-inch aluminum stock has a cross-sectional area of ¼ in^2, so the total force each arm could take is much more than the reservoir will weigh, as seen in the calculation below:

$$40000 \frac{lbs}{in2} \times 0.25\ in^2 \times \frac{1}{4\ arms} = 2500\ lbs$$

Due to the compact nature of the frame design, we don't anticipate any stability issues. However, any such issues will be easily corrected with the addition of a few braces. After the initial round of manufacturing, we decided to add a stabilizers to the inner housing and had to make small L-brackets which mounted to the outer edge of each leg of the outer housing and secured a small cable.

4.4.3 Gripper Assembly

Originally, the gripper assembly, which includes the gripper arm and frame, was chosen in accordance with design specifications. We need the Gripper Assembly to be lightweight, and because it requires a certain degree of precision in manufacturing, we initially decided to 3D print this part. The gripper assembly was also designed to fit directly over the housing in order to provide some stability while the plates are being lifted up and down. Therefore, the arms, which provide the majority of the structural stability, are thicker. The actual grabbing arms are smaller, and are designed to be normally closed due to a spring between them.

However, after consulting with Dr. Jakiela, we ended up deciding to purchase robotic gripper arms from a vendor and then machine simple extensions for them that would allow them to fit around the plates. This negated the need for the machined gripper arm and its frame because our chosen arm kit included mounts for itself and for a servo motor.

4.4.4 Arm Grip

The Arm Grip was chosen with functionality and budget in mind. Our team chose to repurpose a common silicone pot holder as the grip for the gripper arm. It must be made of a material that has high frictional properties and be customizable in size to fit the arms that are a part of the final design. The silicone pot holder can be easily cut to size and the current design also uses food grade silicone, which is a benefit if cleaning or sterilization of the arm is needed in the lab.

4.4.5 Spring

The spring in the original design of the grabber assembly was critical to the ability of the grabber arm to hold and lift up eight plates. We were planning on using Type 302 Stainless Steel Extension Springs. The spring constant, k, needs to be high enough to pull the arms together with enough force to overcome the downward weight of the plates and lift up without damaging the plates. This calculation involves statics and material properties elements and we are still working through the full calculations currently. However, since we purchased gripper arms, this analysis proved irrelevant.

4.4.6 Wires

The wire that is a part of the Gripper Assembly was chosen for strength and sized to be compatible with the servo motor. We will use Zinc Galvanized 1006-1008 Carbon Steel Wire, with 0.080" Diameter. Again, it was not purchased because the assembly became irrelevant in the final design.

4.4.7 Pinch Valve

We will use a solenoid operated pinch valve because we can electronically program it to open and close in a certain time interval. However, we have not been able to find a cost effective pinch valve that can incorporate ¼" tubing. After a month of searching, we found a vendor on ebay selling 4 solenoid operated pinch valves for $100, roughly half the cost of other pinch valves on the market. Since gelatin has similar properties to agar when heated, we performed analysis of flow of hot gelatin through a ¼" outer diameter tube and determined the pinch valve would be sufficient.

4.4.8 Tubing

For the tubing, we wanted something relatively cheap and easy to sterilize. We also wanted something that wouldn't react with the agar solution and flexible enough that it would be compatible with the pinch valve. For water to flow, the tubing has to be at least a quarter of an inch. We ended up picking tubing based on what would be compatible with the pinch valve. Luckily, we found the proper sized rubber tubing in the basement.

4.4.9 Housing Track

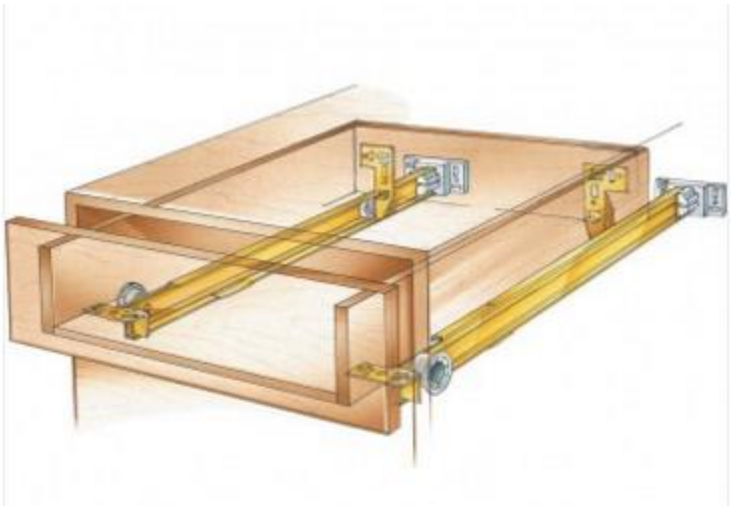
For the housing track, we needed something that would be able to sustain the weight of the entire housing assembly, which would include not only the housing itself, but also two arm servos, two grabber assemblies, and sixteen petri dishes (when fully loaded). Therefore, the housing track needed to be robust, but also something easily fabricated or implemented. We had originally planned on buying miniature I-beams and manufacturing a wheel assembly to attach to the housing assembly so that the housing could be pulled back and forth smoothly. We looked into kitchen drawer sliding assemblies for inspiration and ended up finding a sliding rack that we are able to repurpose for the housing assembly.

Table 7: Weight considerations

Housing Assembly Weight					
Component	Housing	Servo (2)	Grabbers (2)	Plates (16)	Pinch Servo (2)
Weight (g)	700	40	100	160	80
Total Estimated Weight: 1080 g					

The slider assembly we chose is from Rockler Woodworking.

Figure 16: Drawer slide for repurposing



This slider assembly is unique in that it attaches to the back of the kitchen drawer it is mounted on. We can repurpose this connection by bending the metal flat to attach to the top of the frame, then bolting the other slide to the sliding housing. This should be more than enough to hold the weight of the housing assembly at maximum load, which we estimated to be 1.08 kg. The assembly can also be adjusted for our specific length.

4.4.10 Housing Servo

The housing servo was relatively simple to choose because there were clear-cut requirements for its function. First, the servo needed to be strong enough to pull the housing assembly along the track. Second, it needed to be able to interface with an Arduino. We found the servo we needed on Sparkfun at the following link.

Figure 17: Housing servo motor

The servo moves quickly, at 0.16 sec/60°. This is important to keep the automation moving quickly from one stack of plates to the other. It also has 83.47 oz-in maximum torque at its rated 6 volts.

$$83.47\ oz.in\ \div \left(1\ lb\ \times \frac{16\ oz}{1\ lb}\right) = 5.217\ in$$

As can be seen from the calculation above, the output torque will be more than sufficient to pull the housing assembly from one stack of plates to the other. Therefore, this servo will be adequate for our usage. In addition, the servo comes with hardware and is only $12.95, so it is a cost-effective part choice as well.

4.4.11 Arm Servo

The rationale for choosing the arm servo was much the same as for the housing servo. The arm servo needed to be a cost-effective combination of light weight and torque so that it can pull the weight of the plates and grabber assembly upward while not weighing down the housing assembly. It also needed to be compatible with Arduino. Therefore, we chose another, smaller servo from Sparkfun at the following link.

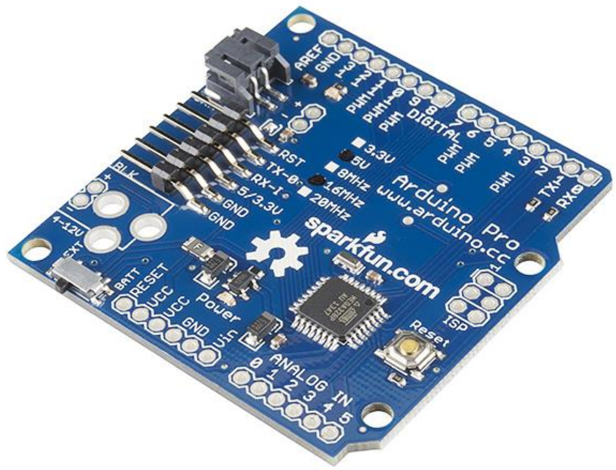
Figure 18: Gripper arm servo motor

This servo is equally fast, with 0.18 sec/60° and a maximum 44.4 oz-in torque. The servo is also exceptionally small, weighing only 20g and having dimensions of 28.8 x 13.8 x 30.2mm. This servo will fit onto the end of our grabber assembly without weighing down our housing. Another constraint we discovered after purchasing a lightweight servo that only rotated 180° was that the servo must rotate 360°.

4.4.12 Arduino Pro

We will need a way to control the entire automation process, so we have chosen an Arduino Pro from sparkfun.

Figure 19: Arduino board



This Arduino can take a DC power input from 5V – 12V, and has six Analog pins. This will be more than enough to control the servos required for our process. The Arduino also has ten digital pins, which will be more than enough to control the two pinch valves required for our process. Another advantage is the Arduino's thin size and lack of headers, which will enable us to customize the wiring so that it doesn't take up a lot of room. We chose to purchase this Arduino without a starter kit because we anticipate being able to scrounge the wiring we'll need from one of the labs at school. Additionally, most servo starter kits only include one servo, and there are plenty of circuits online to use as reference points. We were able to save a significant amount of money by just getting the Arduino for around fifteen dollars instead of paying fifty for a kit.

However, it turned out we needed extra adapters to be able to connect the Arduino Pro to a laptop and it also did not have enough pins for the number of servos we used, so we had to exchange the Pro for an Arduino Uno, which functioned much better for our purposes.

4.4.13 Power Cord

We chose a simple 12V off-brand cell phone charger as our supply. This connector is compatible with the Arduino Pro, and will also be enough to power our housing track servo. The charger can be found at Amazon.com:

Figure 20: Power cord

We won't need anything more complicated than this for the power supply, although we may also need to splice a few wires together, cut off the end of the charger, and wire it back together again. This will depend on whether or not we can power the housing servo through the Arduino or not. From the specifications we should be able to, but we need flexibility in case we have to make last-minute changes.

4.4.14 Reservoir

Our reservoir needs to have smooth sides so that the agar doesn't congeal in the corners of the pan. The system user must also be able to sterilize it, and we need to be able to customize it so that we can add mounts for the pinch valve. To that end, we chose a lunch cafeteria pan, which can be found on eBay for around $30.

Figure 21: Possible agar reservoir

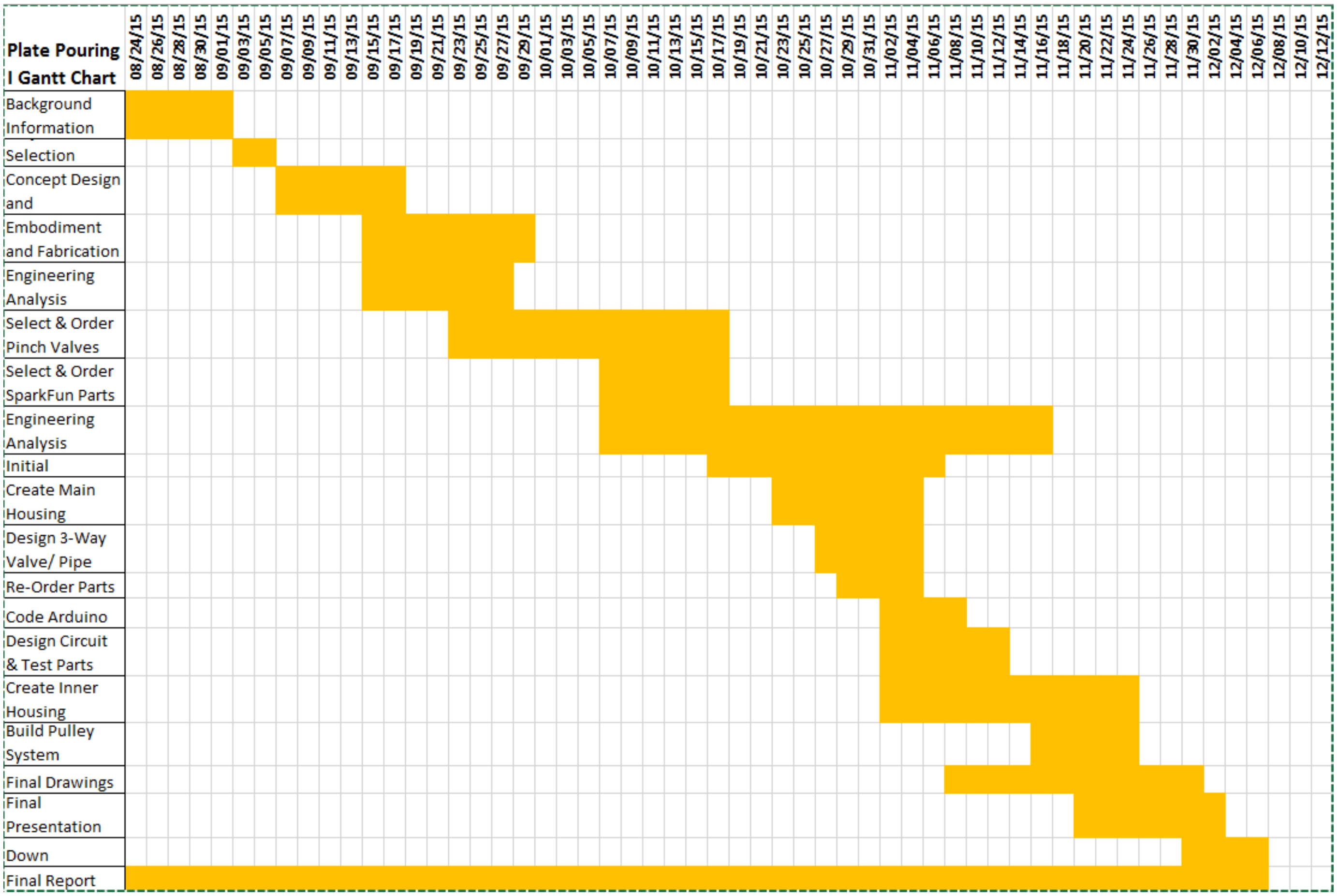
The reservoir must be at least four liters, a qualification which is met by most of the models we found on eBay, and we would like to put the reservoir on top of the outer frame, so we want something thinner. This means that a stainless steel serving pan would be perfect for our purposes. This specific tray is not necessarily one we would purchase, but similar pans can be found all over eBay.

Due to budget constraints, we purchased a water jug for $10 as a placeholder for the reservoir. It would not be fit to actually use in the lab due to leaks and inability to withstand heat.

4.5 Gantt chart

The following Gantt chart outlines our proposed semester plan and schedule for completing the plate pouring machine during the Fall 2015 semester.

Figure 22: Gantt chart for semester planning



5 Engineering analysis

5.1 Engineering analysis proposal

5.1.1 Proposal approval

NOTE: Professor Jakiela verbally signed off on our engineering analysis during recitation.

5.2 Engineering analysis results

5.2.1 Motivation

The analysis we are performing concerns both the viscosity of the agar, and the timing of the servos. We have found a paper confirming that gelatin can be safely compared to agar. To this end, it was determined that it would be best to perform an analysis of the agar to make sure that it would not solidify in the tubing.

The servo timing also needed to be worked out so that the testing of the machine would work out much more smoothly. We did not want to spend a lot of time working on perfecting the programming of the automated system, so figuring this out beforehand will save us a lot of time.

5.2.2 Summary statement of analysis done

The agar analysis was done using research and a simple experiment where the temperature of gelatin was recorded before the gelatin was passed through 1/8" outer diameter tubing. The servo timing analysis was completed after construction of the device to ensure that the machine could precisely lift and control plates.

5.2.3 Methodology

After our research on the viscosity of agar, we ran experiments to confirm our hypothesis that 1/8" tubing would be sufficient for our purposes. To do this, we used tubing, gelatin, and one of our kitchen sinks to confirm that the gelatin would run through the tubing without solidifying.

5.2.4 Results

From the results, it became obvious that the agar would not become stuck in the tubing and it achieved a flow rate that would allow us to pour agar steadily and quickly. Therefore, the tubing system planned (⅛" inner diameter) would be adequate. We expected these results because the agar is poured at hot temperatures, typically above 60 degrees Celsius. Therefore, we expect that the system will only need to be cleaned in between uses to prevent clumping of the agar. Even at moderately high viscosity testing conditions, the gelatin solution was able to flow through the tubing we tested.

Table 8: Results of agar and tube size testing

Tube size (ID)	Gelatin mix	Temperature	Time period (s)	Volume (mL)	Flow rate (mL/s)	Viscosity and pinching observations
⅛”	Pkg recommendations	60	15	75	5	Flows similar to water at this temp
	1 pkg gelatin, 1/2 c water	65	15	30	2	Although flow rate is lower, could be due to air in the line
	Add 1 pkg to previous 1/2 c	50	Would not flow through either tube			

5.2.5 Significance

From these results, we confirmed that the prototype would be able to be built with 1/8” outer diameter tubing, instead of with ¼” outer diameter tubing as had been previously planned. This allowed for the purchase of more inexpensive pinch valves, which kept the project under budget. Pinch valves adequate for ¼” outer diameter tubing are approximately $100 each, which would be 2/3 of our budget and would be cost-prohibitive. Therefore, the analysis performed was crucial to continue our project.

The servo timing also needed to be worked out so that the testing of the machine would work out much more smoothly. We tested and worked this out after construction with real stacks of plates to ensure that our machine could actually complete the assigned task.

5.2.6 Summary of codes and standards

In order to build a prototype of the system, chose to not address the client’s need for the machine to be able to be sterilized. This would have made the manufacturing phase much longer because it would have been necessary to modify a stainless steel reservoir, as well as machine other parts from stainless steel, and purchase tube holder that could screw in and out. In a second prototype it would be more time effective to switch to stainless steel parts.

5.3 Risk Assessment

5.3.1 Risk Identification

The most prevalent risk in this system would be that a system leak occurs and, because of this, the agar would no longer be sterile. This risk has been emphasized several times in the report. Because this machine will be used in an environment where biological agents are also used, it is critical that the system be closed to those biological agents, so that the agar is not contaminated.

5.3.2 Risk Analysis

Several assets are at risk, including laboratory time and manpower, if the agar becomes contaminated.

5.3.3 Risk Prioritization

The first priority for prevention is the continued sterilization of the agar. The second is the continued functioning of the electronics. A 12V power supply is required for the pinch valves, while only 5V are required for the Arduino and the servos. Therefore, careful planning was taken with the placement of the electronics, so that they were above any potential spills from the agar. Therefore, even if the agar spills, the electronics should be fine.

6 Working prototype

6.1 A preliminary demonstration of the working prototype

The preliminary demonstration of our prototype was completed in class during the fall semester.

6.2 A final demonstration of the working prototype

The final demonstration of our prototype was completed in class during the fall semester.

6.3 Prototype images

Figure 23 shows a side view of the prototype with the reservoir, outer housing, inner housing with gripper arms, and partial views of the pulley system and valve system. The inner housing is seen hanging on the repurposed drawer track with two gripper arms (one on each side) to grab the plates. The string running horizontally along the bottom of each side is to keep the gripper arms from swinging during movement.

Figure 23: Side view of final prototype

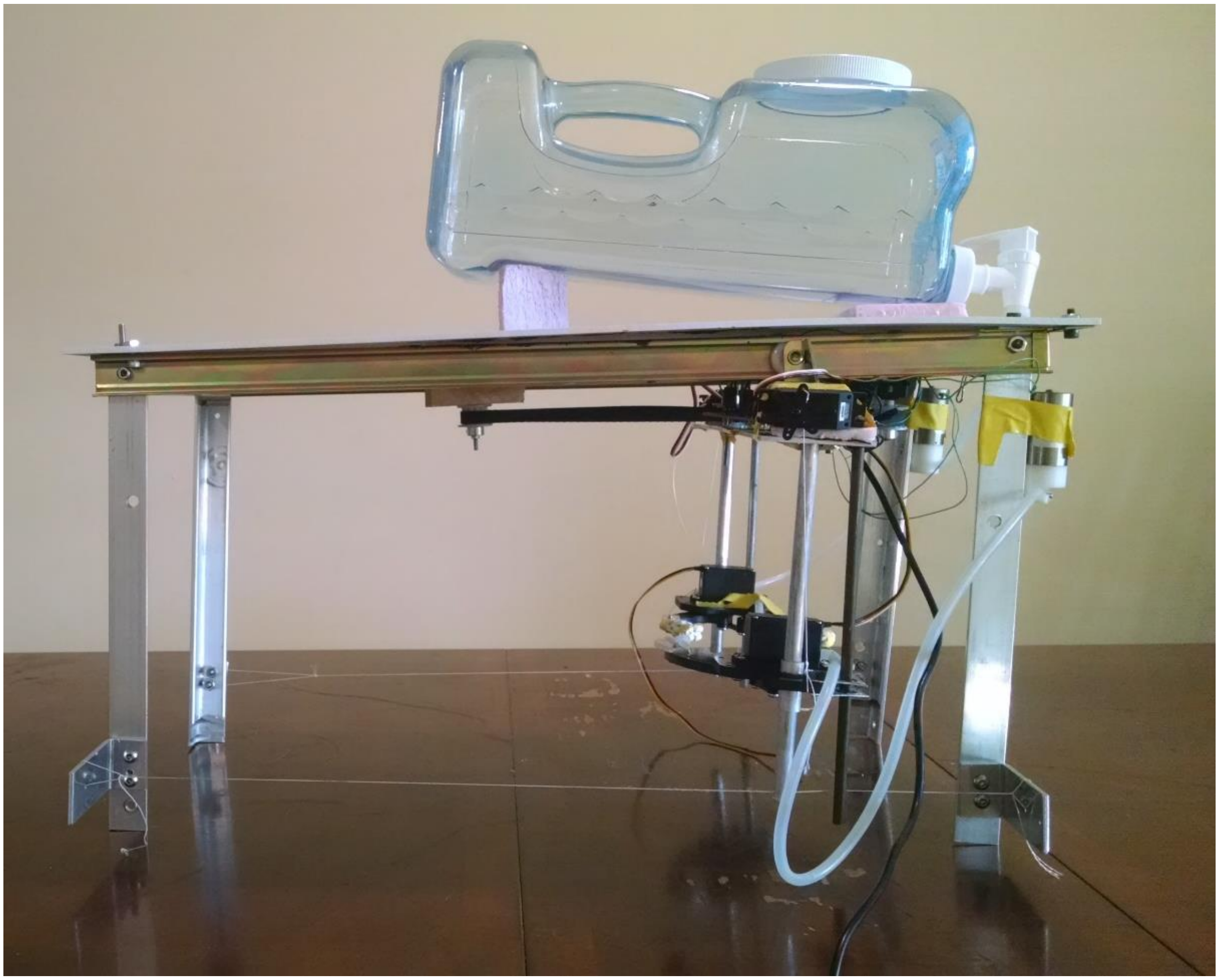
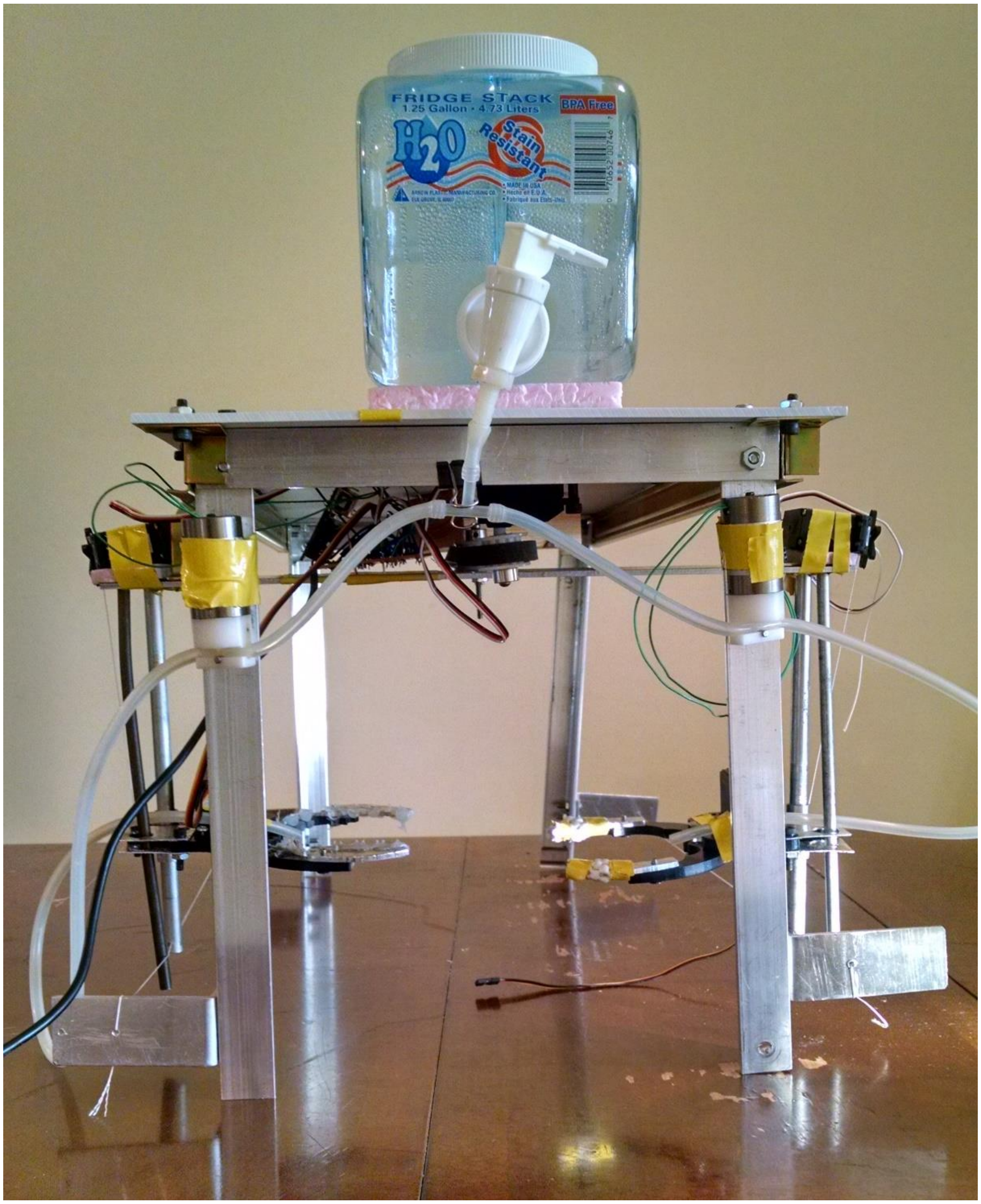


Figure 24 shows a front view of the prototype with the full valve system and reservoir. The tubing is split into two lines immediately after leaving the reservoir and each line runs through a pinch valve (controlled by the Arduino board) and then is attached to the top of the gripper arms to pour the agar into the plates.

Figure 24: Front view of final prototype



6.4 Final prototype performing

A short video clip of the final prototype performing can be found at this link.

6.5 Additional prototype images and explanations

Figure 25 shows the full assembly for the mounted gripper arm. The main supporting rod in the center is a “track” for the arm to follow as it moves up and down along the stacks of plates. The secondary supporting rod was added in a design revision during the manufacturing process to add stability to the gripper arm; the arm was swinging right and left in the horizontal plane during movement which knocked the plates out of line. Adding the secondary rod restricted the horizontal movement of the arm and resulted in more consistent vertical motion. The white string seen running through the bottom of the main supporting rod keeps the arm from swinging in an arc-like motion side to side when moving.

Figure 25: Final prototype gripper arm assembly

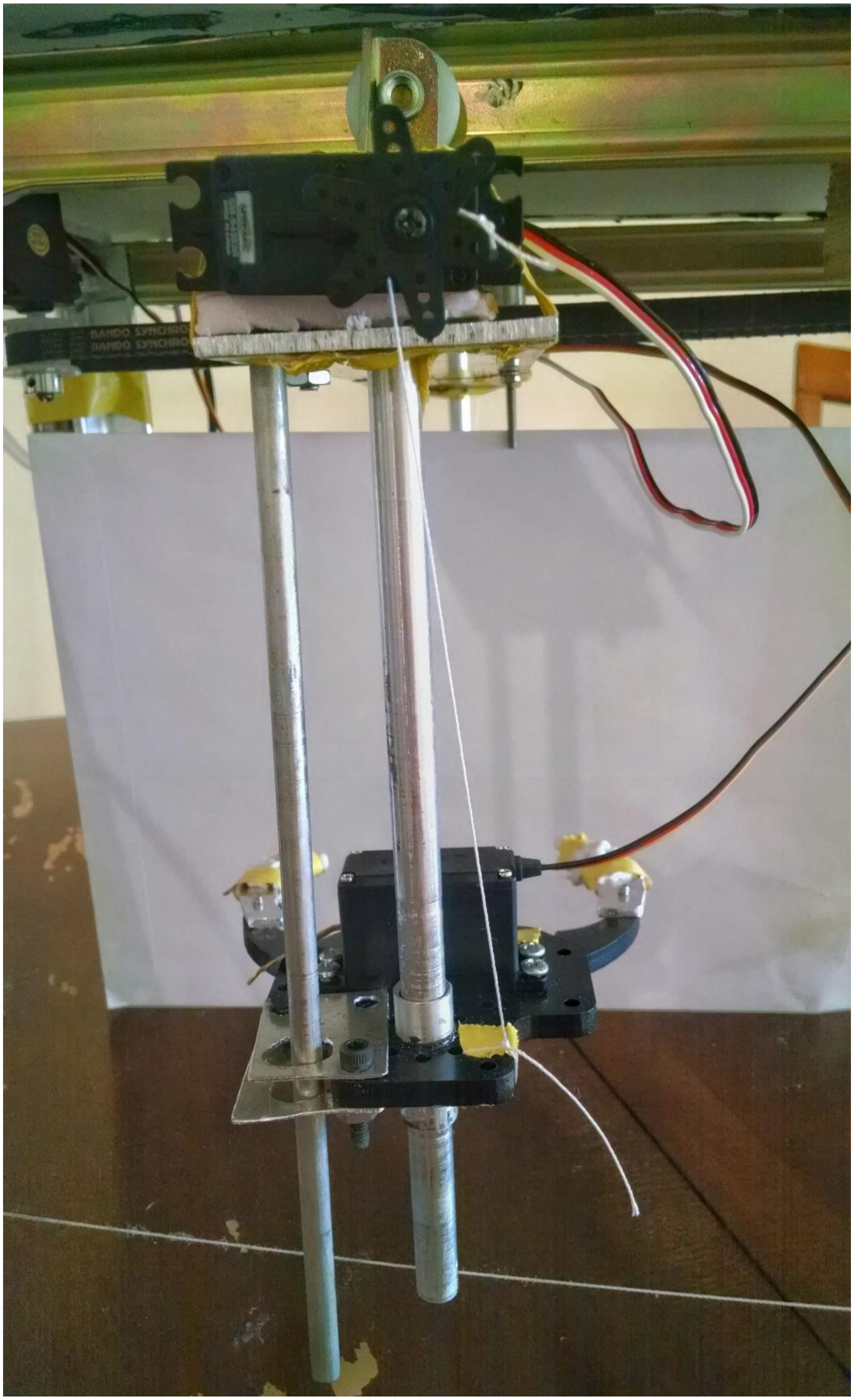


Figure 26 is a close-up view of the gripper arm and attachments. The two stabilizing rods can be seen at the top of the frame, then the servo and tubing attachments, and finally, the gripper arms with the machined extensions and added material for gripping capability. In the next iteration of the design, the tubing attachment would be machined in place and a more effective material would be used on the gripper extensions which would allow the plates to be more stable when lifted by the arms.

Figure 26: Final prototype gripper arm and attachments

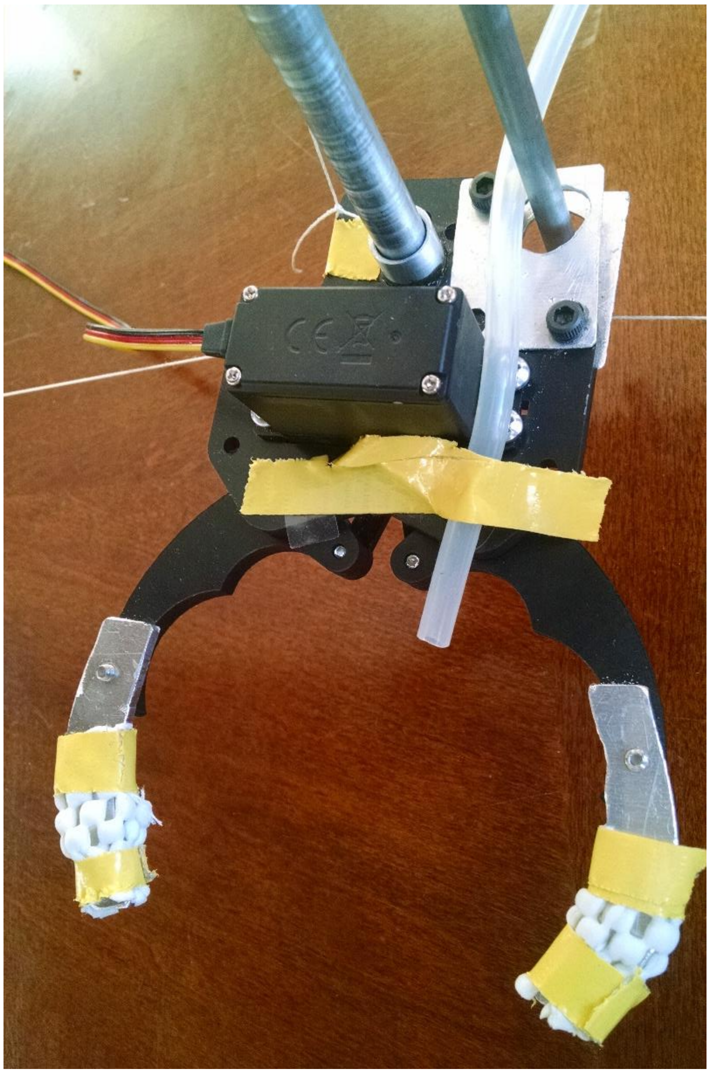


Figure 27 shows the repurposed drawer track which supports the inner housing assembly. The servo which lifts the gripper arm is also seen here. As the servo rotates, the white wire wraps around the servo wheel and pulls the gripper arm up – or lowers the gripper arm down – to the next plate position.

Figure 27: Final prototype inner housing servo and slide

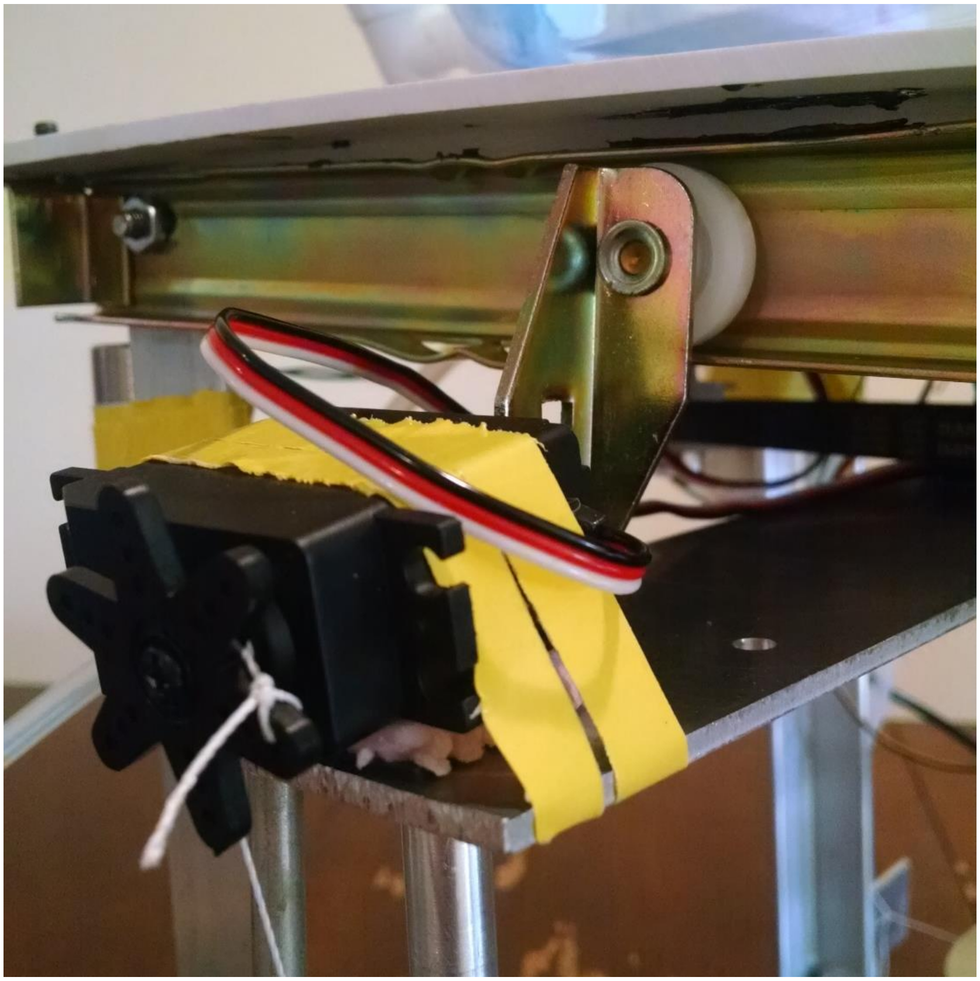


Figure 28 and Figure 29 show the pulley system which moves the inner housing from one stack of plates to the next. The servo seen on the left side of both images is controlled by the Arduino and rotates the first pulley. The second pulley – mounted to the inner housing – is fixed to the belt; thus, when the other pulleys rotate, the belt is driven and pulls the housing along with it. The third pulley is mounted to the outer housing with the wood for spacing. The pulley is not the full length of the housing because we were unable to find a belt that was long enough within the time and budget restraints present at the end of the semester. However, in future design iterations, a full length pulley system would be implemented.

Figure 28: Final prototype pulley system (side view)

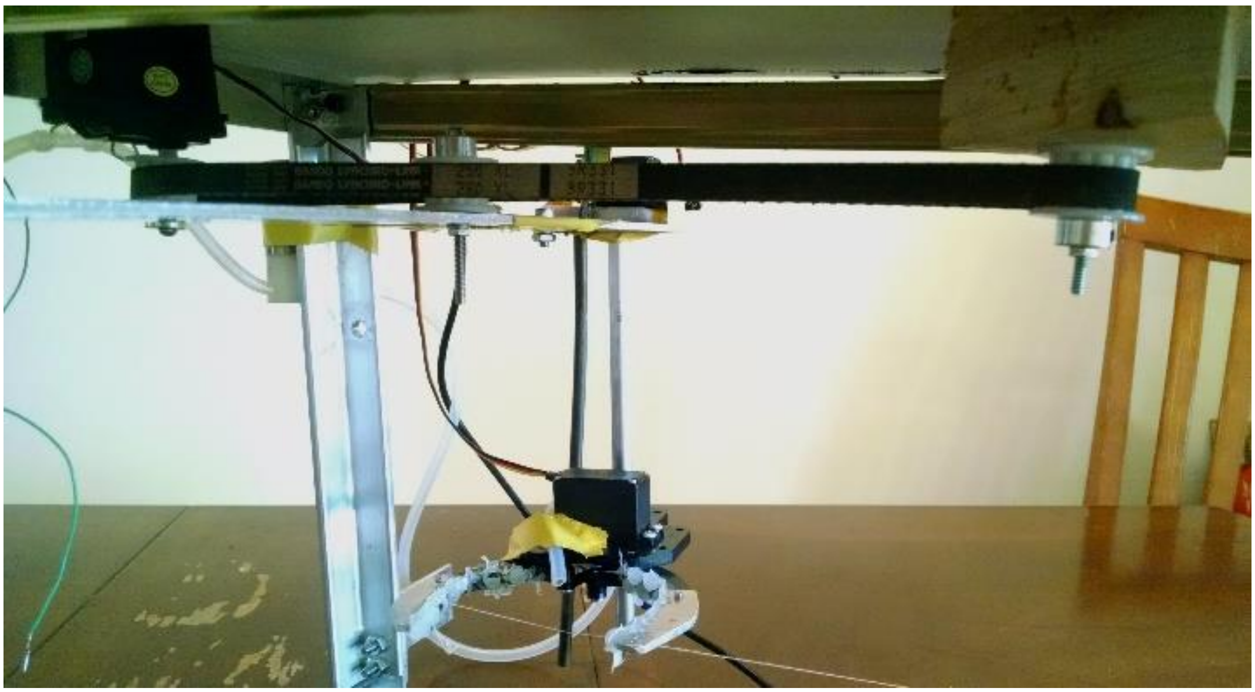
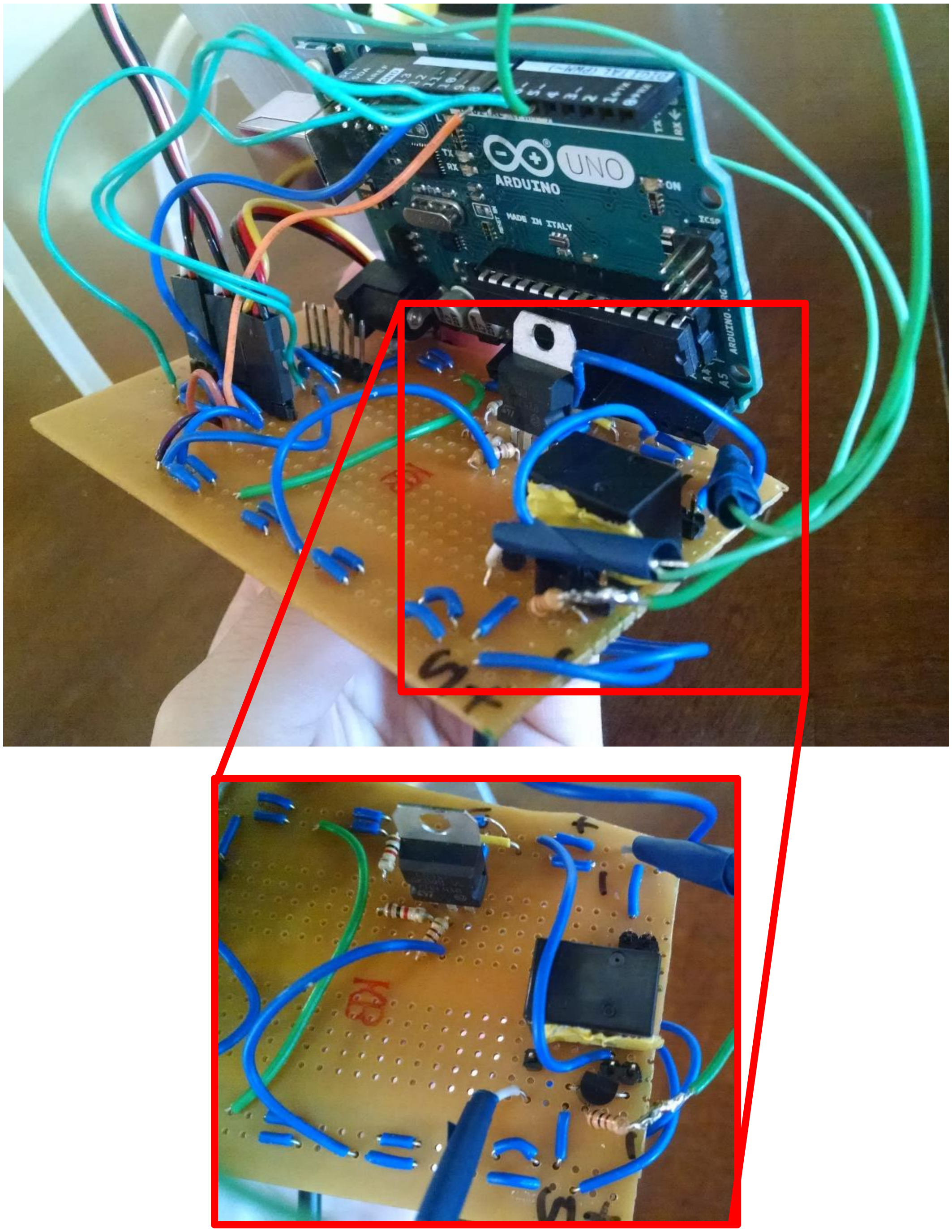


Figure 29: Final prototype pulley system (lower view)

Figure 30 shows the circuit and Arduino connections used for the prototype. The top figure shows all of the connections for the servo motors on the right into the headers seen there. The bottom figure is a closer view of the relay circuit used to run the 12V pinch valves from the Arduino, which only accepts 5V.

Figure 30: Circuits and Arduino connections



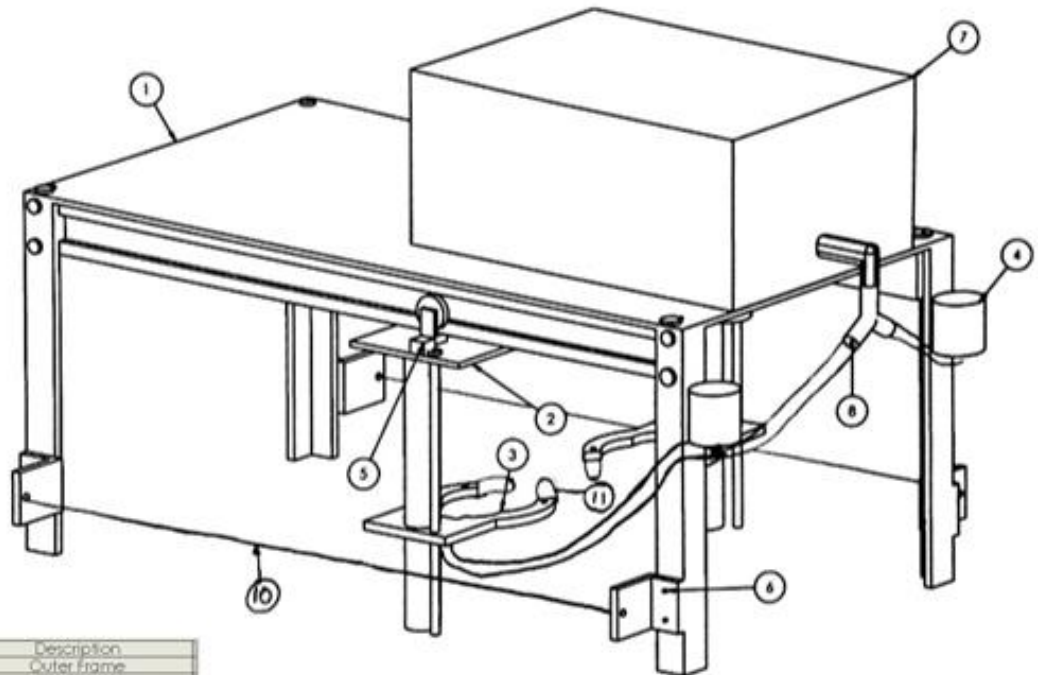
7 Design documentation

7.1 Final Drawings and Documentation

7.1.1 CAD model files and all CAD drawings

See Section 11: Appendix C for the CAD models. Units: Inches.

Figure 31: Final prototype CAD (isometric)



Part Number	Description
1	Outer Frame
2	Inner Frame
3	Standard Gripper Kit A
4	Bio Chem 1/4" Pinch Valve
5	Servo
6	10-32 Screw
7	Reservoir
8	3-way valve
9	1/4" Tubing
10	String
11	Gripper Extensions

Figure 32: Final prototype arm extension: units in inches

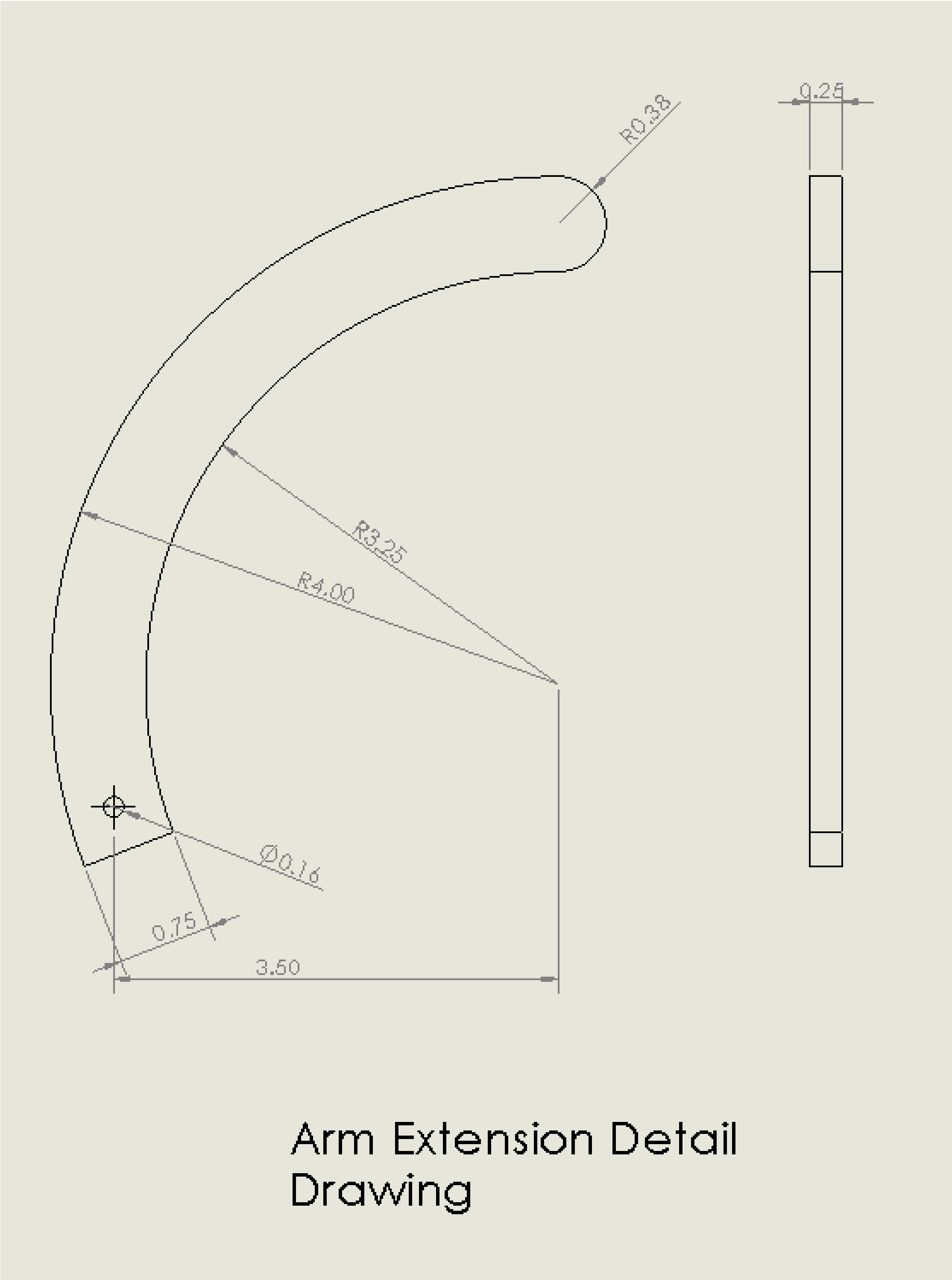


Figure 33: Final prototype main frame: units are in inches

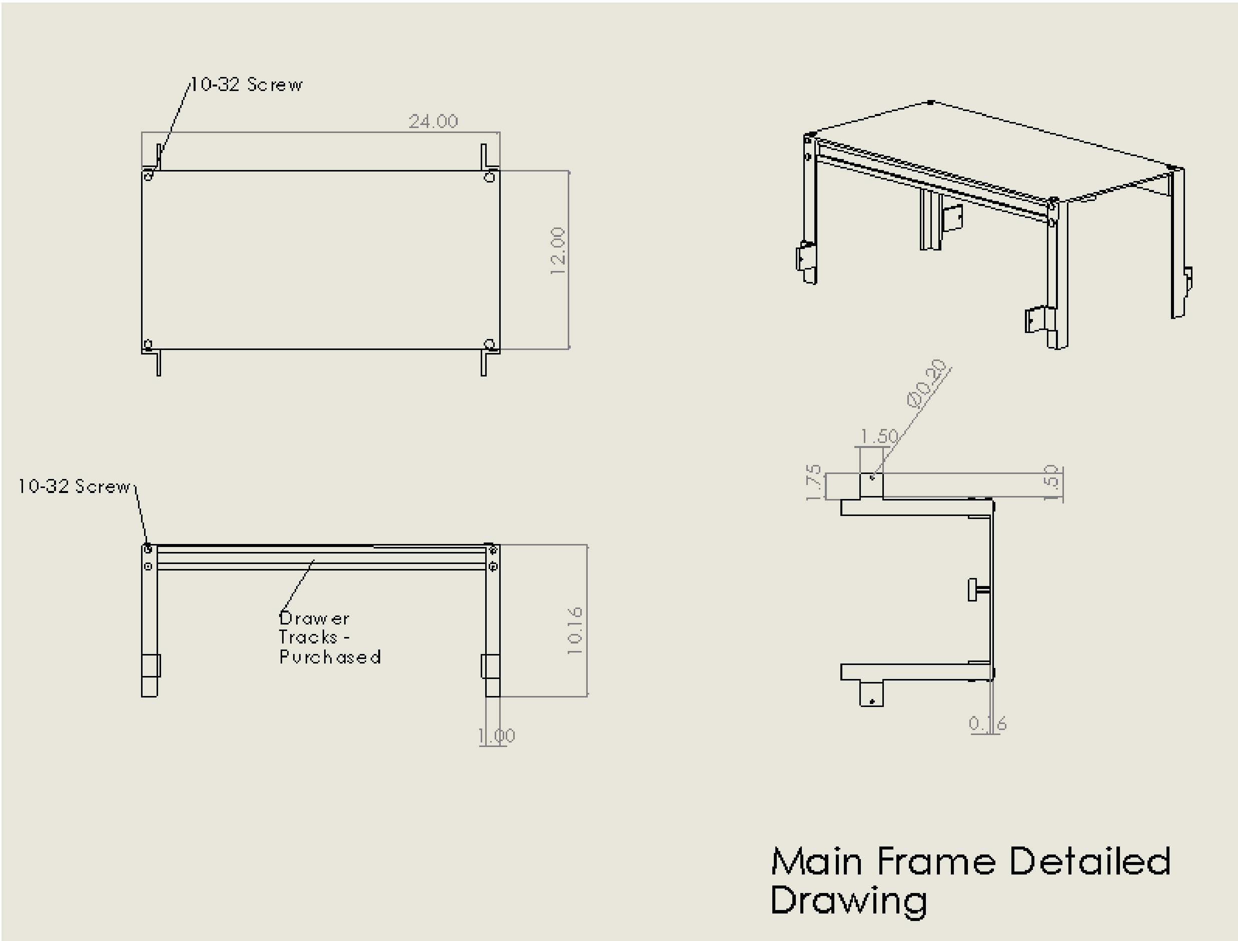
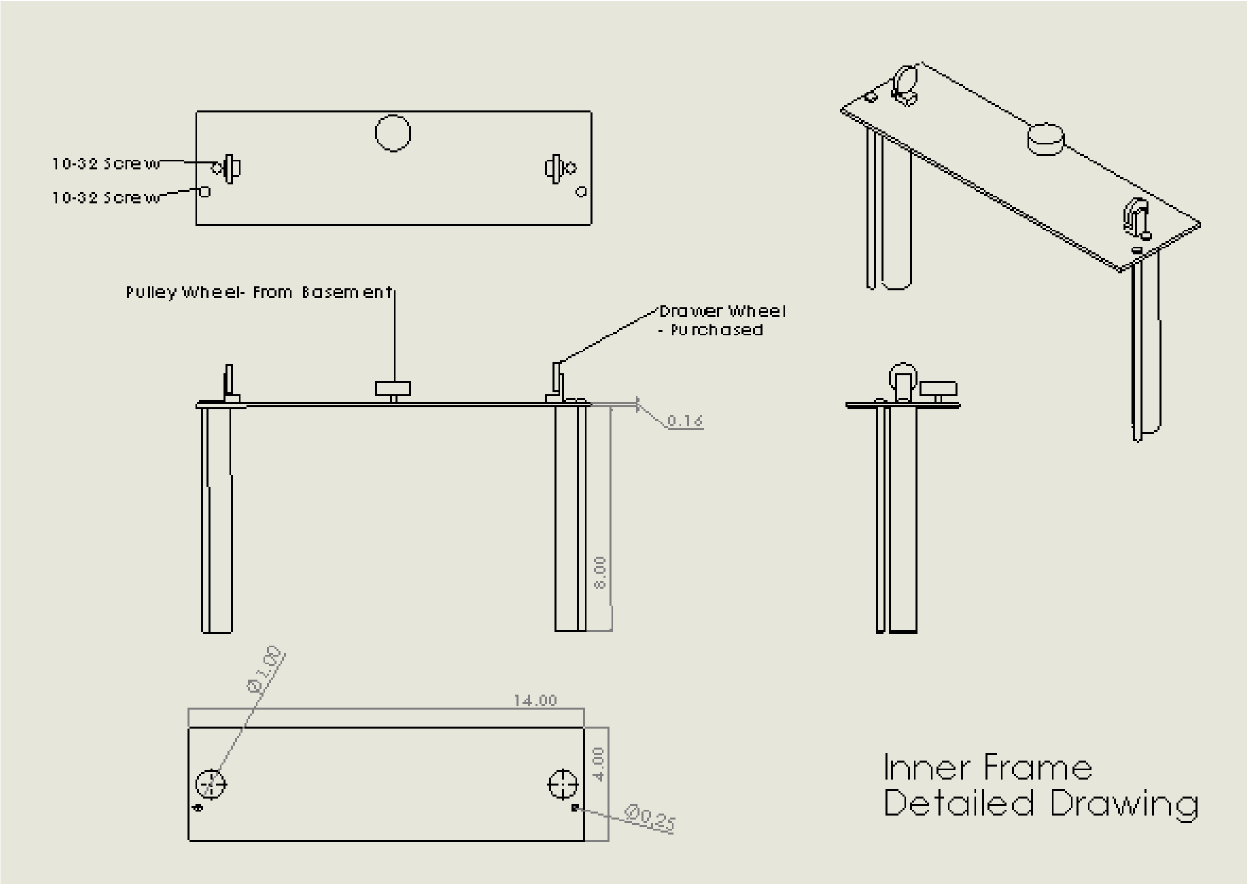


Figure 34: Final prototype inner frame: units are in inches



7.1.2 Sourcing instructions

The table found below is the final parts list. Items with the source MEMS Dept. were items recycled from the Washington University School of Engineering and Applied Science's Department of Mechanical Engineering and Materials Science (MEMS) storage rooms and machine shop. Therefore, these parts had no monetary cost to the group, and no catalog number as manufacturer information was often not available for these parts. Other parts, such as the gripper extensions, were machined with materials found in the MEMS Department machine shop, and did also not have any catalog number or additional cost to the team.

Table 9: Final parts list

Plate Pourer Final Parts List					
Part Number	Part	Catalog Number	Quantity	Cost	Source
1	Housing	N/A	1	$11.60	MEMS Dept.
2	Outer Frame	N/A	1	$10.58	MEMS Dept.
3	Standard Gripper Kit A	ROB-13174	2	$19.90	sparkfun
4	BioChem 1/4" Pinch Valve	100P2NC12-068	2	$50.00	eBay
5	Arm servo	ROB-11884	2	$21.90	sparkfun
6	10-32 Screws	N/A	30	N/A	MEMS Dept.
7	Reservoir	00746	1	$12.19	Amazon
8	Three-way Connector	N/A	1	N/A	MEMS Dept.
9	1/4" Tubing	N/A	1	$0.88	MEMS Dept.
10	String	N/A	1	N/A	MEMS Dept.
11	Gripper Extensions	N/A	2	N/A	MEMS Dept.
12	Arm Grip Material	N/A	1	$2.10	Trivet
13	Pinch servo	ROB-10333	2	$21.90	sparkfun
14	Housing track	30636	1	$16.99	Rockler Woodworking and Hardware
15	Housing servo	ROB-11965	1	$25.90	sparkfun
16	Arduino Uno	DEV-11021	1	$24.95	sparkfun
17	Power cord	N/A	1	N/A	MEMS Dept.
18	Pulley System	N/A	1	N/A	MEMS Dept.
19	Breadboard	N/A	1	N/A	MEMS Dept.
20	Arduino Cable	N/A	1	$9.99	WUSTL Bookstore

7.2 Final Presentation

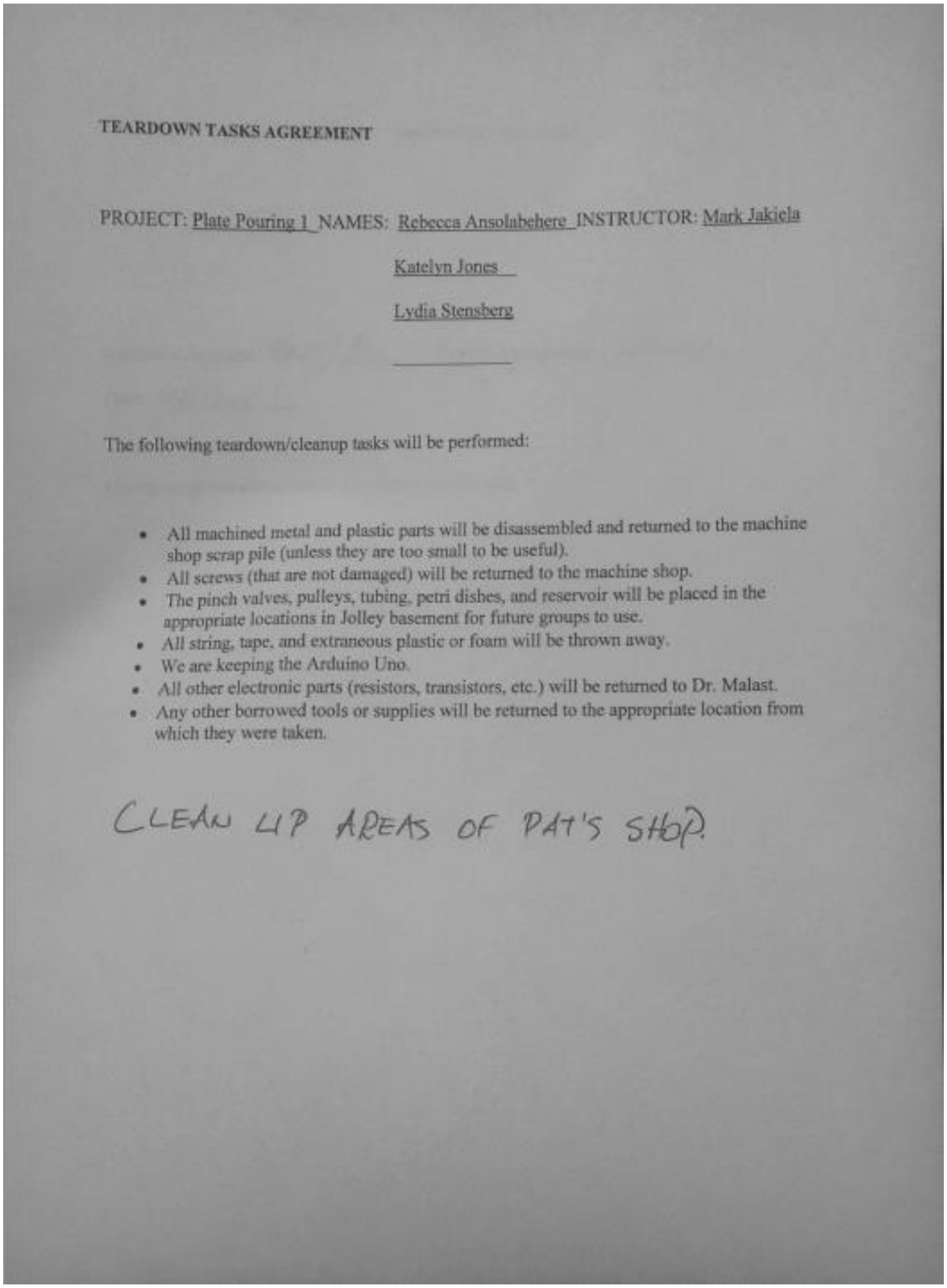
7.2.1 Presentation slideshow

The final presentation was given on November 31st, 2015. A video PowerPoint presentation was used, the link to which can be found at this link.

7.2.2 Live presentation

A link to a video of the live presentation and video question and answer can be found at this link.

7.3 Teardown



TEARDOWN TASKS AGREEMENT

PROJECT: Plate Pouring 1 NAMES: Rebecca Ansolabehere INSTRUCTOR: Mark Jakiela

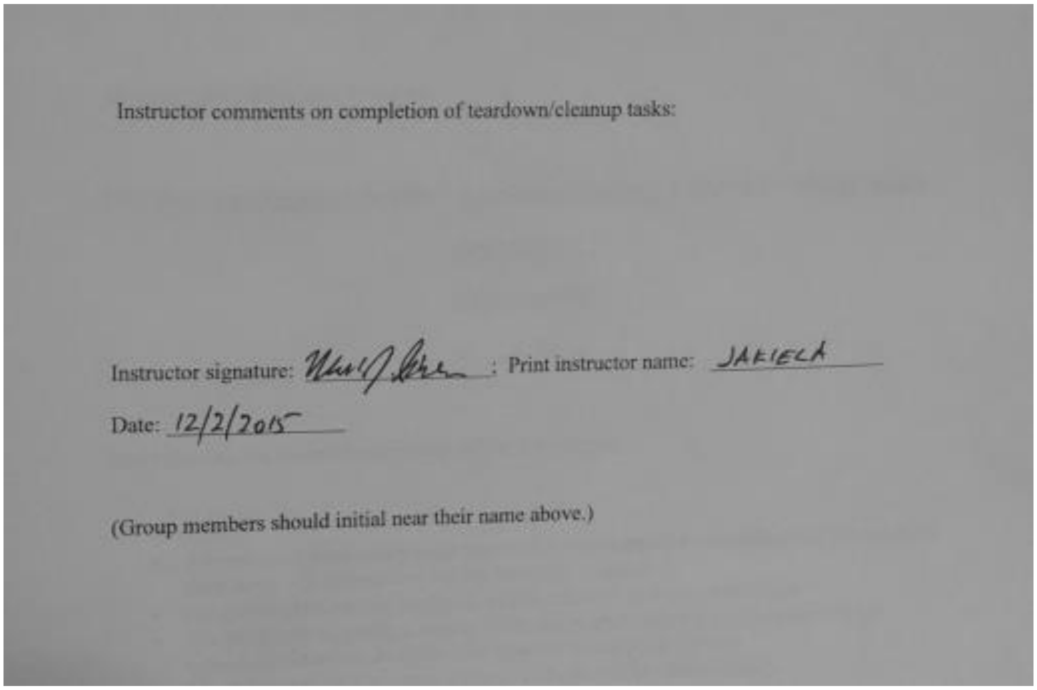
Katelyn Jones

Lydia Stensberg

The following teardown/cleanup tasks will be performed:

- All machined metal and plastic parts will be disassembled and returned to the machine shop scrap pile (unless they are too small to be useful).
- All screws (that are not damaged) will be returned to the machine shop.
- The pinch valves, pulleys, tubing, petri dishes, and reservoir will be placed in the appropriate locations in Jolley basement for future groups to use.
- All string, tape, and extraneous plastic or foam will be thrown away.
- We are keeping the Arduino Uno.
- All other electronic parts (resistors, transistors, etc.) will be returned to Dr. Malast.
- Any other borrowed tools or supplies will be returned to the appropriate location from which they were taken.

CLEAN UP AREAS OF PAT'S SHOP.



Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: [signature]; Print instructor name: JAKIELA

Date: 12/2/2015

(Group members should initial near their name above.)

8 Discussion

8.1 Final prototype evaluation

Plate Pouring Happiness Equation		Time	Volume	Steam?	Splashing	Sterilizable	automated	stacked plat	ease	Need Happiness 1	Importance Weight (all entries should add up to 1)	Happiness
Need#	Need	1	2	3	4	5	6	7	8			
1	ease of use	0.125							0.75	0.8	0.09090909091	0.072727
2	no steam/ water in agar			1						1	0.06818181818	0.068181
3	no splashing				1					0	0.09090909091	0
4	consistent volume of agar		0.5							0.5	0.09090909091	0.045454
5	volume of reservoir		0.15							0.15	0.02272727273	0.003409
6	sterilizable system					1				0	0.1136363636	
7	time shorter than hand pouring	0.75								0.75	0.1136363636	
8	automated						1			1	0.1136363636	0.113636
9	stacked plates							1		1	0.09090909091	0.090909
10	easy cleanup	0.125							0.25	0.35	0.1136363636	
11	system fits in hood		0.35							0.35	0.09090909091	0.031818
Units		minutes	ft^3	integer	boolean	boolean	boolean	boolean	integer	Total Happiness 1	0.4261363636	
Best Value		5	3	1	0	0	0	0	10			
Worst Value		30	15	10	1	1	1	1	1			
Actual Value		5	3	1	1	0	1	1	9			
Normalized Metric Happiness		1	1	1	0	0	1	1	0.9			

Our system scored a 42.6% on the metrics evaluation chart. This score seems reasonable to us, due to the lower scores of our initial prototypes, and the issues we encountered when testing the prototype. For example, the system would theoretically work well with the needed efficiency, but its construction is currently not precise enough for the automated lifting actions to be consistent. This is one of the major flaws in the final construction that prevents the system from operating within the design parameters.

The system performed very well with regards to the system footprint within the fume hood. The system itself was three cubic feet, which we were very pleased with. With the potential to fold the legs in added, the system would have an even smaller footprint. The process also would have been automated completely, minus the inserting and taking out plates, which is also is reflected in a higher score in this area.

In evaluating our metric of 120 plates per hour, while we never poured a full set, we were able to extrapolate data from our prototype testing. During our performance testing, the gripper arm was able to move and “pour” approximately 5 plates in 10 seconds using only one side of the machine. If both gripper arms were operational, then 10 plates in 10 seconds is a reasonable estimate. Extrapolating from this data, 60 plates could be poured in one minute. Since our device holds eight stacks of eight plates (64 total plates), we could safely assumed that it would take well under 2 minutes to pour 64 plates. The plates must sit for 30 minutes before they can be safely moved without spilling, bringing the total time to around 32 minutes. Then another tray of 64 plates could be placed in the device and poured. Thus, we estimate that in just over an hour, our device could pour 128 plates if fully operational.

8.2 Future plans

We believe that if we were given another semester and a larger budget, we would be able to produce a usable and convenient product for our customer. However, to do this we would have to make a number of mechanical refinements. First, we would purchase a new track and wheel system, since repurposing drawer slides proved to be less stable than anticipated. The track had groves for the drawer to lock into place once closed, which is great for a drawer, but not for a track that something slides along. The wheel was also wobbly in the track since it designed to move under a different configuration of forces. We would also need to purchase a pulley system like the one we used, but twice as long so that the inner housing can go along the length of four stacks of plates instead of two stacks. We would also want to redesign the outer housing so that the legs folded inward (and possibly the inner housing folded upwards) and the device could be easily be stored in a drawer. We would need to purchase a new reservoir that can be sterilized, does not leak and is durable. Finally, we would need to design a tray/base that could hold the plates up to the level of the arms (which ended up being about ¾" off the ground) and indicated the proper location to place the plates either with indentations of where to place the bottom plate in the stack or markings so that the arms moved to precisely the right location every time.

We would also need to make a number of electrical refinements. The code was never refined enough such that the gripper arms could reliably picked up the lids of each plate, give the pinch valves enough time to pour, and then gently place the lids back down. This would probably have taken much more time of trial and error to perfect these motions. The wiring also proved too short to be able to mount the breadboard in any location that wires would be able to reach no matter the location of the arms or inner housing. In order to mount the breadboard, we would have needed a wire harness before we mounted the breadboard to the underside of the top of the outer housing. This would have required more purchasing and possibly machining.

8.3 Part sourcing

The vast majority of our parts were scrounged or recycled from various sources, partially because our concept changed over the course of manufacturing. The inner and outer housing frames were made from scrap metal recycled from the machine shop. We also attempted to repurpose holes that were already present in the metal parts, which made machining more complicated.

Regarding vendors, Sparkfun had exceptional delivery time: we always received parts within 1-2 days of ordering them. The biochem pinch valves which we bought from eBay also came within two days of ordering. The longest we had to wait for any of our parts was when ordering from Amazon, but it was still only about 3-4 days.

8.4 Overall experience

8.4.1 Project difficulty

We knew that our chosen project would be challenging, but it still proved to be more difficult than expected. We learned that we had to expect to fail or to be set back, and incorporate time for the unexpected to occur into our schedule. Machining took about twice as long as expected due to our inexperience in the machine shop. We also had to order new servo motors and a different type of Arduino after we realized that the ones we ordered did not meet the specifications needed. Additionally, our project had a lot of parts from different sources that we needed to make sure fit together. For example, the tubing we purchased from the chemistry stockroom was labeled as ¼" outer diameter tubing, but when we tried to fit it into the pinch valve, we re-measured the tube realized it was much larger than ¼". However, we were able to find some quarter inch diameter tubing in the basement that was perfect for our project. Finally, programming and designing the circuit proved to be more technically extensive than previously predicted because we had to power the Arduino and pinch valves at much different voltages. The code also required a lot of timing adjustments after it was completed which were time consuming

8.4.2 Final project description

Our final prototype aligns well with the original intentions of the project description. Although we went through several iterations of our original multi-valve design concept, we finished the semester with a device that addressed the customer needs and, if continued for another semester, could be refined and re-manufactured to be useful to the customer.

8.4.3 Team dynamics

Overall, we think our team functioned well as a group. We all have different skill sets and experiences, and we all had the chance to contribute expertise in separate aspects of the project. We also were all very willing to be flexible in schedules and work long hours toward the end of the semester to get everything completed that needed to be done. Everyone was a dedicated worker who respected and appreciated everyone else's time and effort.

8.4.4 Team skill set

Our team member's skills proved to be very complementary. Lydia was the programming expert who took charge of the electronics, circuits, and Arduino coding, as well as leading in the machine shop where she has the most experience. Kate's ability to repurpose parts and general ability to think on her feet when solving unexpected problems proved invaluable when parts did not fit together. Rebecca's SolidWorks skills came in useful when creating the CAD model and final drawings. Each of us stepped up to the plate at different points in the semester. For example, Rebecca took the lead on creating a building schedule for the mechanical parts, while Kate took the lead on rallying the group for the final stretch once the rest of us started experiencing burnout.

8.4.5 Workload distribution

We were very respectful of the work each person put into the project. We chose to work together at the beginning of the semester because we knew each of us were self-motivated and would put in the time necessary to get the project finished. At different points in the semester we put in more effort in the many areas of the project that had to be addressed; Lydia was doing more work as she was coding or building circuits and Kate was testing the final prototype and working on the presentation and Rebecca was finishing the final CAD drawings. Because of our well-rounded set of skills as a group, we naturally shared the workload among the three of us.

8.4.6 Missing skills

We would have liked to have more collective experience in machining and manufacturing. This would have made the construction process go more quickly, and welding would have been a nice skill to have, as that would have changed the design flexibility of our prototype. It would have been helpful if all three of us were competent in robotics since it turned out to be a very robotics-heavy project, however Lydia did an excellent job programming and designing the circuit board.

8.4.7 Customer relationship

We consulted with our customer, St. Louis Community College Center for Plant and Life Science, several times throughout the semester to get additional information about the requirements for the process beyond the original design brief. This was helpful to have access to someone who could help us with design ideas and provide any extra information about how the device would potentially be used in the laboratory one it was done. We also were allowed to use small equipment from the St. Louis Community College lab, namely the tray on which the plates were placed and the plates themselves, as we were deciding on overall sizing and design for our prototype.

8.4.8 Design brief alterations

The original design brief from our customer was very direct and simple to begin the semester; thus, their design requirements did not change much through the semester. They had a simple need - to automate the plate pouring process - and as long as our device fit within the parameters they gave, they were very flexible about how we chose to go about solving the design problem. However, in the needs interview, the lab technician explained there was wiggle room as to what needed to be automated, the dimensions, whether design actually had to be put under the hood, and most unsettling, whether there was even a need in the lab for the device. After the interview, we decided to stick to the originally assignment.

8.4.9 Has the project enhanced your design skills?

The project was a great lesson in time management. After retroactively filling out a Gantt chart, we realized this would be a great tool to complete at the beginning of the project to get a rough timeline of what needs to get done so that we are not scrambling at the end. We also gained a better knowledge of machining, robotics and coding in the design context. Creating the complex CAD drawing also made us more comfortable with SolidWorks. Finally, we gained a better understanding of how to integrate parts from different suppliers into one cohesive product.

8.4.10 Would you feel more comfortable accepting a design project assignment at a job?

Regarding accepting a design project assignment at a job, it would depend on the project. We are unsure in our ability to design something and have the project come together seamlessly without any modifications needed. We are confident that we could assemble parts and make modifications as needed in order to develop a project, but still feel that we would benefit from being on a design team, especially a team with experienced engineers.

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

We are more comfortable working with Arduino products and robotics in general and are interested in gaining more knowledge and attempting more projects related to robotics. We gained more confidence in taking on projects outside of our expertise and picking up the skills as we go by trusting our instincts and asking for help from the right people.

9 Appendix A - Parts List

Table 10: Final parts list

Plate Pourer Final Parts List					
Part Number	Part	Catalog Number	Quantity	Cost	Source
1	Housing	N/A	1	$11.60	MEMS Dept.
2	Outer Frame	N/A	1	$10.58	MEMS Dept.
3	Standard Gripper Kit A	ROB-13174	2	$19.90	sparkfun
4	BioChem 1/4" Pinch Valve	100P2NC12-068	2	$50.00	eBay
5	Arm servo	ROB-11884	2	$21.90	sparkfun
6	10-32 Screws	N/A	30	N/A	MEMS Dept.
7	Reservoir	00746	1	$12.19	Amazon
8	Three-way Connector	N/A	1	N/A	MEMS Dept.
9	1/4" Tubing	N/A	1	$0.88	MEMS Dept.
10	String	N/A	1	N/A	MEMS Dept.
11	Gripper Extentions	N/A	2	N/A	MEMS Dept.
12	Arm Grip Material	N/A	1	$2.10	Trivet
13	Pinch servo	ROB-10333	2	$21.90	sparkfun
14	Housing track	30636	1	$16.99	Rockler Woodworking and Hardware
15	Housing servo	ROB-11965	1	$25.90	sparkfun
16	Arduino Uno	DEV-11021	1	$24.95	sparkfun
17	Power cord	N/A	1	N/A	MEMS Dept.
18	Pulley System	N/A	1	N/A	MEMS Dept.
19	Breadboard	N/A	1	N/A	MEMS Dept.
20	Arduino Cable	N/A	1	$9.99	WUSTL Bookstore

10 Appendix B - Bill of Materials

Table 11: BOM

Plate Pouring I Final Bill of Materials								
Level								
1	2	3	Part Number	Part	Catalog Number	Quantity	Cost	Source
1			1	Housing	N/A	1	$11.60	MEMS Dept.

	2		29	Aluminum sheet, 10 guage, 6" x 24"	8973K154	1	$11.60	McMaster-Carr
	2		10	String	N/A	1	N/A	MEMS Dept.
1			2	Outer Frame	N/A	1	$10.58	MEMS Dept.
	2		28	Easy-to-Machine Polystyrene Sheet, 5/32", 12" x 24"	8734K35	1	$9.03	McMaster-Carr
	2		6	10-32 Screws	N/A	30	N/A	MEMS Dept.
	2		28	Aluminum stock, 1/2" bar stock	9008K81	1	$10.58	MEMS Dept.
	2		18	Pulley System	N/A	1	N/A	MEMS Dept.
	2		14	Housing track	30636	1	$16.99	Rockler Woodworking and Hardware
1			3	Standard Gripper Kit A	ROB-13174	2	$19.90	sparkfun
	2		11	Gripper Extensions	N/A	2	N/A	MEMS Dept.
	2		12	Arm Grip Material	N/A	1	$2.10	Trivet
1			7	Reservoir	746	1	$12.19	Amazon
	2		4	BioChem 1/4" Pinch Valve	100P2NC12-068	2	$50.00	eBay
	2		8	Three-way Connector	N/A	1	N/A	MEMS Dept.
	2		9	1/4" Tubing	N/A	1	$0.88	MEMS Dept.
1			26	Electronic Circuit	N/A	1	$7.00	MEMS Dept.
	2		27	Motors and Drives	N/A	1	N/A	N/A
		3	5	Arm servo	ROB-11884	2	$21.90	sparkfun
		3	15	Housing servo	ROB-11965	1	$25.90	sparkfun
		3	13	Pinch servo	ROB-10333	2	$21.90	sparkfun
	2		16	Arduino Uno	DEV-11021	1	$24.95	sparkfun
	2		20	Arduino Cable	N/A	1	$9.99	WUSTL Bookstore
	2		19	Breadboard	N/A	1	N/A	MEMS Dept.
		3	17	Power cord	N/A	1	N/A	MEMS Dept.
		3	21	Wire, 16-gauge	N/A	1 foot	N/A	MEMS Dept.
		3	22	3-terminal adjustable regulator	LM317	1	$2.50	Radioshack
		3	23	Voltage relay	275-0241	1	$4.50	Radioshack
		3	24	1 kOhm resistor	N/A	3	N/A	MEMS Dept.
		3	25	510 Ohm resistor	N/A	1	N/A	MEMS Dept.

11 Appendix C - CAD Models

Engineering drawings including CAD model files and drawings derived from CAD models are uploaded to the “Plate I (Ansolabehere, Jones, Stensberg)” file exchange in a file entitled “Final Report Attachments”. Clicking the file should initiate download of a file entitled **“plate1attachments.zip”**

12 Annotated Bibliography

Agar Plate. (n.d.). Retrieved from http://www.realmagick.com/agar-plate

Amazon.com,. 'Amazon.Com: Generic Wall Charger For Samsung Galaxy S3 - Non-Retail Packaging - Black: Cell Phones & Accessories'. N.p., 2015. Web. 7 Dec. 2015.

This website is the link to the power source that we used in order to power our system. The power cord was not used as is; rather, the connector was cut off and the wires were soldered to the breadboard.

AP Biology: Lap Preparation for Transformation Lab. (2012). Retrieved from https://notoriouspbakecc.wordpress.com/2012/01/27/ap-biology-lab-prep-for-transformation-lab/

eBay,. '6 Liters Standard Gelato Ice Cream Stainlesssteel Pan Diplay Cabinet Show Case'. N.p., 2015. Web. 7 Dec. 2015.

This webpage is the link to the reservoir that we were initially going to use for the agar. After further consideration, we used a plastic verstion for the ground zero prototype that was cheaper, but not sterilizable like this one was.

Labcompare.com,. 'Automated Petri Dish Filler / Agar Plate Pourer Manufacturers'. N.p., 2015. Web. 28 Oct. 2015.

This website was used as a database to brainstorm concept ideas for agar plate pourers. It proved to be a reliable source for different designs, price points, and constraints.

Patel, A. (2013, August). Thickening and Gelling Agents in The Food Industry. Retrieved from http://www.altrafine.com/blog/page/6/

Singer Instrument Company Ltd Kreo Technologies Inc.,. 'Method And Apparatus For Filling A Plurality Of Media Plates In A Self-Supporting Stack'. 2014: n. pag. Print.

This patent was used to aid the design process of brainstorming various device ideas, as well as an avenue through which to research the design process. This, and the other patents, was also a valuable source for design constraints.

Slide, Suspension. 'Suspension Drawer Slide - Pair - Rockler Woodworking Tools'. *Rockler Woodworking and Hardware*. N.p., 2015. Web. 7 Dec. 2015.

This webpage links to the sliding drawers that were used in order to suspend the inner housing from the outer frame.

Sparkfun.com,. 'Arduino Uno - R3 - DEV-11021 - Sparkfun Electronics'. N.p., 2015. Web. 7 Dec. 2015.

This is the sparkfun page with the Arduino that was purchased after it was determined that the Arduino Pro would not be suitable for our purposes due to some connector, output pin, and power incompatibilities.

Sparkfun.com,. 'Servo - Generic High Torque (Standard Size) - ROB-11965 - Sparkfun Electronics'. N.p., 2015. Web. 7 Dec. 2015.

This servo was used to pull the inner housing back and forth on the pulley system suspended from the outer frame. This model provided more than enough torque necessary to accomplish this task in a timely manner.

Sparkfun.com,. 'Servo - Generic Metal Gear (Micro Size) - ROB-10333 - Sparkfun Electronics'. N.p., 2015. Web. 7 Dec. 2015.

This was the original servo used to pull the standard gripper kits up and down on the inner housing, until it was discovered that the servos only rotated 180 degrees. Therefore, new servos needed to be ordered.

Sui, Na. 'Device For Filling Cultural Media In Sterile Condition'. 2014: n. pag. Print.

This patent, like the other patents, provided a summary of strategies for filling plates, with a particular emphasis on agar with a biological component mixed in.

Sui, Na. 'Device For Filling Culture Medium Under Aseptic Condition And Aseptic Filling Method'. 2014: n. pag. Print.

This patent provided a summary of filling agar with a biological component mixed in for plates, with a particular emphasis on reaction to certain design constraints that was useful for the analysis presented in this paper.

Thiel, Teresa. 'Sterilizing Laboratory Materials For The Classroom'. *University of Missouri-St. Louis Department of Biology*. N.p., 1999. Web. 7 Dec. 2015.

This paper was an especially useful example of a laboratory standard operation procedure (SOP) with regards to sterilization of laboratory equipment before use. This SOP was used as a reference to ensure that the device designed would be sterilizable in any laboratory.