ME 4930 Senior Design Project – 2019 Spring Semester

Cookie Lab Project Report

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Abstract

This report outlines the design and implementation processes for the Cookie Lab project which intended to be a miniature manufacturing cell for producing customized cookies. This cell will be used in University events and school visits to spark interests in STEM and to show various aspects of engineering in tangible applications. This section of project development handles the mixing and forming operations of the machine. Mixing of ingredients and dough forming were done to create a more usable finished product in the form of a finished cookie. Outlined in this report are the project requirements, decision-making processes, implementation processes, current operational divisions, and plans for future development.

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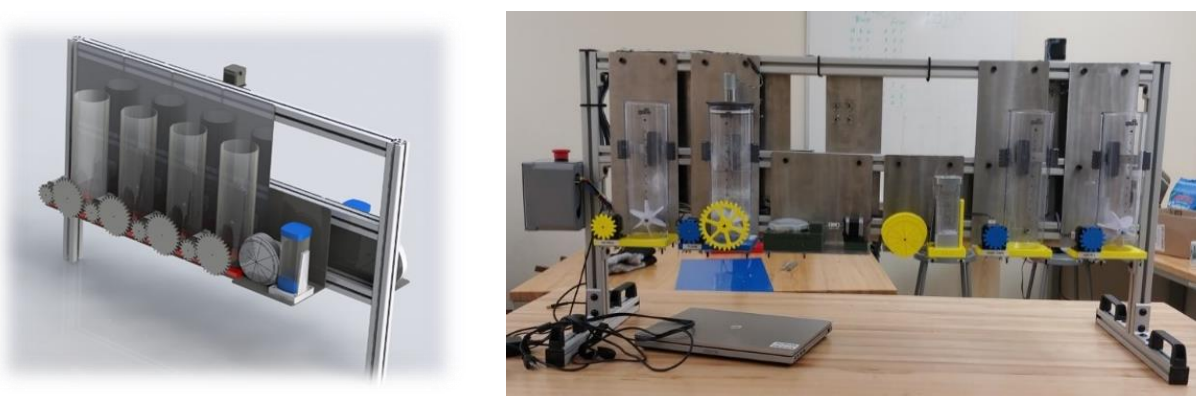
1. Introduction

This Cookie Lab project was undertaken by students in the University of Wisconsin – Platteville Mechanical Engineering Senior Design class. The goal of the project was to continue development of an industrial based cookie manufacturing cell for the University, with the purpose of being used as a tool for teaching science, technology, engineering, and math (STEM). The scope for this project was to design and build a mechanism that mixes and forms dispensed ingredients into cookie dough balls ready for baking.

This report outlines the process and steps taken by a Mechanical Engineering senior design team to continue development of an industrial based cookie manufacturing cell. The sponsors of the project are Dr. Fick, Dr. Lerner, and Tammy Salmon-Steven, of UW-Platteville with support provided by Turck, and the EMS Alumni Association. This project is being developed with the goal of reaching underrepresented groups who would not typically engage with STEM. The goal is to feature as many important engineering concepts as possible, while still allowing a clear and easy understanding of the processes involved.

Stage I, which is already complete, was to construct a device (Figure 1) capable of measuring and dispensing individual cookie ingredients.



(a) *(b)*

Figure 1: Automatic ingredient dispenser which was developed by previous ME senior design group. (a) Concept rendering of dispenser. (b) Final design of dispenser

Stages II-A and II-B are projects tasked to Engineering Physics (EP) and Mechanical Engineering (ME) senior design teams. Stage II-A was led by the EP team to collect the dispensed ingredients and transport them to the next stage. Stage II-B was led by the ME team to receive the transported ingredients and to mix and shape them into dough balls ready to bake.

Stages III and IV will be a collaboration of other groups and departments to produce the user interface and optimize power and control of the complete device. This will likely involve electrical engineering and computer science teams as well as education teams to develop educational learning programs from this device. This report will outline Stage II-B and the process used to develop the mixing and forming, and how it will integrate with Stage I, and II-A to meet project requirements.

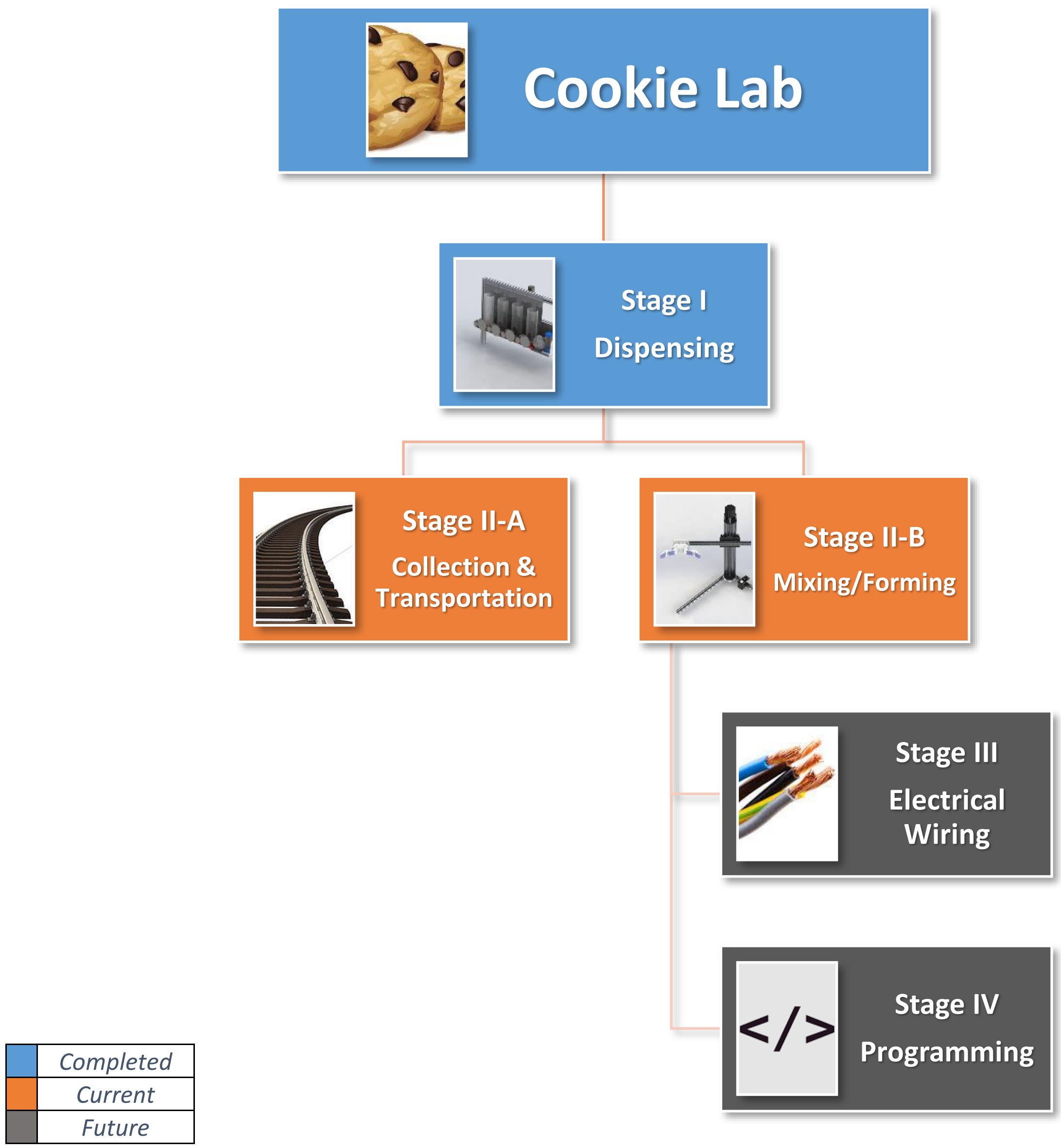


Figure 2: Flow chart of Cookie Lab project stages

One part of the design process involves researching and understanding current solutions. This step is integral to any product and forms a solid base of knowledge on a mechanism or module. Information that pertains to intellectual property that is protected by copyrights, patents, and standards and must be researched. Exploring patents also allows for investigation into the current industry practices and allow adaptation of existing methods. Although the Cookie Lab does not need to be certified, it will still need to be designed to meet or exceed as many standards and codes as possible so that it is a safe piece of equipment to use and demonstrate.

The following patents shown in Table 1 were investigated by the team to provide insight on applicable industry solutions for this project.

Table 1: Patents

PATENT NUMBER	NAME	DATE
US879590A	Dough mixer with attachment	April 19, 1907
US8820221B2	Compact appliance for making flat edibles	Sept. 02, 2014
US371212A	Cookie press	July 26, 1966
US20020098255A1	Auger for a dough transport device	Apr. 17, 1995

Patent US879590A describes a dough mixing machine using bevel gears and a unique mixing head seen in Figure 3 [3]. The spinning of a main shaft, by means of a large gear, drives the rotation of bevel gears and the mixing shaft. This mixing shaft is vertically stationary, so the dough container must be lifted into the mixing head. This patent is a highly simplified and very visual way to see how mixing occurs, which is a desirable characteristic to include in this project.

The 1966 patent, US371212A, regarding a cookie press is shown in Figure 4. This describes a device with a feeding tube and a plunger. The end of the tube features a rotating bezel with different dies of various shapes. The intent of the device is that it is loaded with cookie dough and extruded through the dies leaving a shaped cookie. Initially, there was a thought that this design could be modified to fit our machine's forming processes and the audience might enjoy being able to choose a shape for their cookie with a mechanical device to switch out different patterns. The injection mechanism would provide a good transfer mechanism. After further investigation, the intended output product for this project is classified as a drop cookie. These cookies tend to spread out as they are baked and therefore cannot be shaped pre-bake. As the desired output should be a dough ball that can be placed on a cookie sheet, pre-bake forming was no longer a viable option.

Patent US8820221B2 [2] is a compact apparatus for automatically baking bread from raw ingredients. The apparatus includes a storage and dispensing unit that makes it unnecessary for a user to pre-measure ingredients. The apparatus also includes a mixing and kneading unit for making dough to the user's desired consistency. The mixing and kneading unit is configured to prepare dough. The dough is prepared by mixing and kneading the ingredients, then dispensed by the dispensers. Afterwards, the dough is swept onto a lower platen base where it is flattened.

An upper platen and the lower platen of the platen unit may be heated to a pre-programmed temperature for cooking the dough. The temperature may also be manually set by the user based on the user's preference. This design incorporated mixing and forming the bread dough in one container. Incorporating a similar design with cookie dough would allow for limited transfer of the cookie dough allowing less dough loss and less possible areas to jam. The patent also shows the use of an arm for a one-time transfer of dough to the flattener/heater.

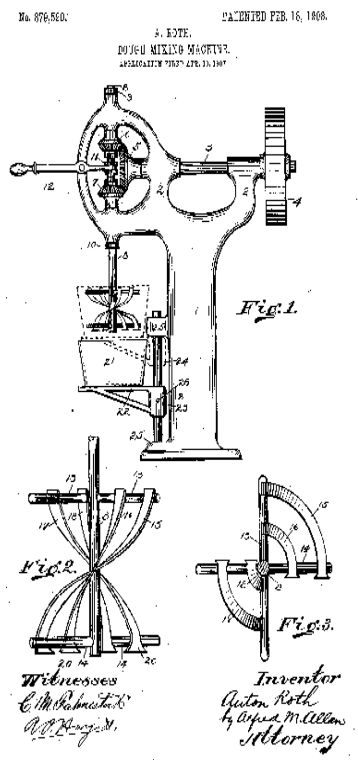


Figure 3: Patent US879590A, A diagram of a dough mixer with attachment

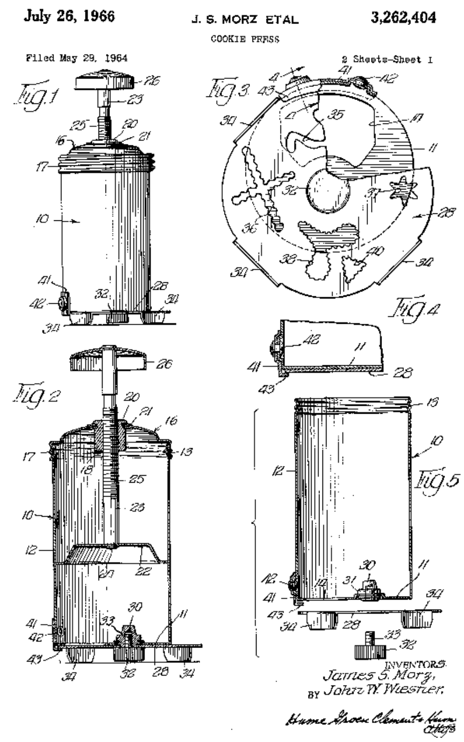


Figure 4: Patent US371212A, A diagram of a cookie press

Patent US20020098255A1 refers to an auger dough pump [4]. The patent states that the device provides for the uniform dividing of a single stream of dough into a plurality of uniform sub-streams of dough. It achieves this using an auger that delivers the dough to a divider in the dough transport device substantially equal portions of dough to different portions of the dough divider as seen in Figure 5. This helps ensure that each of the separate streams of dough created by the divider are uniform with respect to each other and that the divider doesn’t increase the resistance of the dough very much.

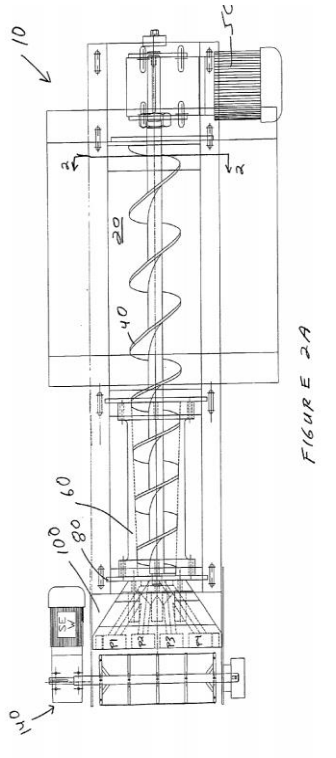


Figure 5: Patent US20020098255A1 for an auger dough pump

Codes and Standards relating to the problem are also important to be aware of because many times a product must undergo strict testing and certification before it can be sold to the customer. This ensures safety and product reliability which is mutually beneficial for both the consumer and the producer. Safe products protect the customer and help prevent the producer from lawsuits for liability regarding safety failures. With that in mind the following codes and standards have been researched and documented for their applicability to the Cookie Lab.

Table 2: Codes and Standards

NUMBER	NAME
FDA CODE 21 CFR 175-179	Food safe materials and substances
CFR 21.177.B	Food approved polymers
FSIS DOCKET 96-037F; 64 FR 56400	Maintaining sanitation of equipment

FDA Code 21 CFR 175-179 provides a list of substances generally recognized as safe (GRAS) [5]. This list can be used in attempt to make the device as close to FDA approved as possible. Cost limitations for this project will probably interfere with fully meeting these requirements, but this list will allow us to identify what parts must be improved in the future. Any instances in which the team cannot meet the standards should be documented. These instances may be lack of necessary materials, such as stainless steel on surfaces with food contact, or it may be there are better mechanisms that can be used if this project were focused around production safety in place of the showcasing of knowledge.

Code of Food Regulations (CFR) 21.177.B lists all the different types of approved polymers which may be used in applications with food contact surfaces [7]. This is helpful for determining what materials may be used in the fabrication of Cookie Lab components which will be in direct contact with food. For this project, that may include any of the polymers (Polylactic Acid, and Polyethylene Terephthalate Glycol) which could be easily 3-D printed and used to create cheap components that may contact any of the ingredients.

FSIS Docket 96-037F; 64 FR 56400 provides details for maintaining sanitation of equipment used in handling food, including washing conditions and frequency. This information is important to properly maintain sanitation on the surfaces of the machine that contact food. Cleanliness between baking cycles is also especially important in cases with food allergies. With such stringent limitations of what is considered food safe after cleaning, the safest route may be to not include any type of cleaning between different batches. Currently this will be accomplished by using semi-disposable containers.

2. Problem Definition and Constraints

To fully understand the problem at hand, it is first necessary to understand what the customer requires. These customer requirements must then be translated into engineering characteristics so that they can be tracked and measured. Some of the important project requirements include the project's ability to maintain cleanliness, transportability, and how well it conveys STEM principles to its intended audience. As a demonstration, it should be very visual and showcase as many STEM concepts as possible. These are explained in further detail below

A requirement of the machine is to automatically dispense dry and wet ingredients of varying amounts into a mixing container. The machine will make one cookie at a time, therefore the amount of ingredients dispensed are in very small amounts. Each recipe must allow for adjustment for both wet and dry ingredients. This will allow for a fully customizable cookie controlled by the user. It also allows for the user to compare changes in recipes to changes in the cookies produced. The functionality of the Cookie Lab involves mixing the collected ingredients and forming the dough, before being transferred to an oven for baking. All components of the machine must be controlled automatically, after the user enters the recipe.

The purpose of the machine is to be able to easily transport it to different locations, therefore, it should be able to fit into a space the size of a mini-van for transportation. The machine must be designed so that sections can be disassembled and reassembled with ease. Alignment is also crucial as certain components of the machine are calibrated in precise locations. To avoid recalibration during reassembly, the design must also self-align while fitting components together.

The machine must be powered by a standard outlet and all other electrical needs will be produced from the machine's internal power supplies. Once the machine is assembled and loaded with ingredients, it will effectively be a "plug-n-play" design. The machine must be up to food grade standards as the cookies produced by the machine must be edible. The materials used must be environmentally friendly and non-toxic. With food, allergies must also be considered.

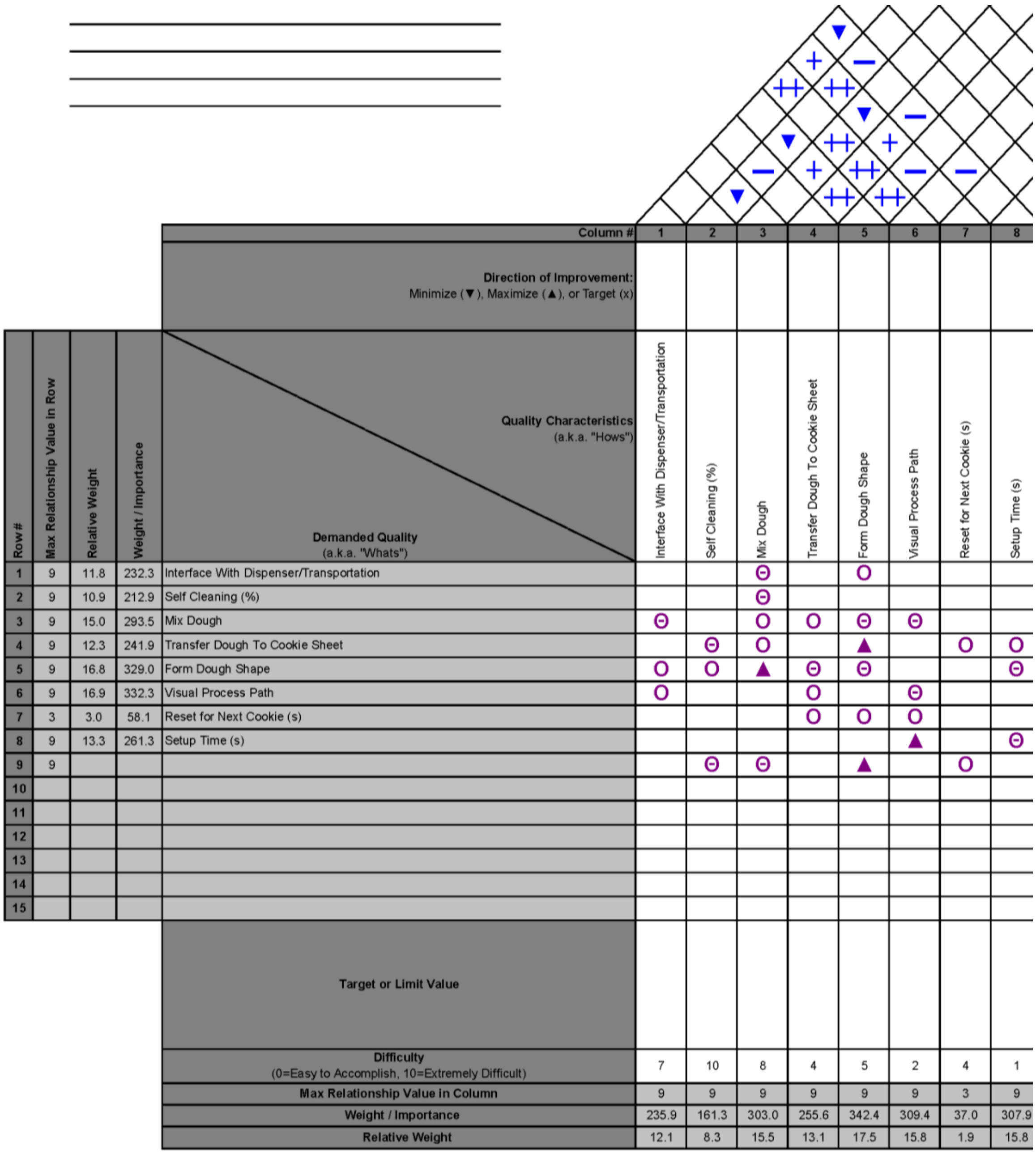


Figure 6: House of Quality defining project requirements and their relative weight

These requirements were organized into a House of Quality. The customer requirements were then ranked according to importance for the success of the project. One of the most important engineering requirements was determined to be the visual process path that the cookie-in-progress will take. This is because the entire project is meant to be a demonstration tool for STEM principles. If the cookie is hidden away behind machinery or in enclosed spaces, then it is no longer effectively meeting the requirements of the project.

The final project completion date is Friday May 17th, 2019. The first key deadline was the Interim Report deadline on March 11th. The interim presentation included the statement of project objectives, approach, current progress, major challenges, tasks for completion, and expected results. The objective of the Interim Presentation is to allow other members of the class to weigh in on the project.

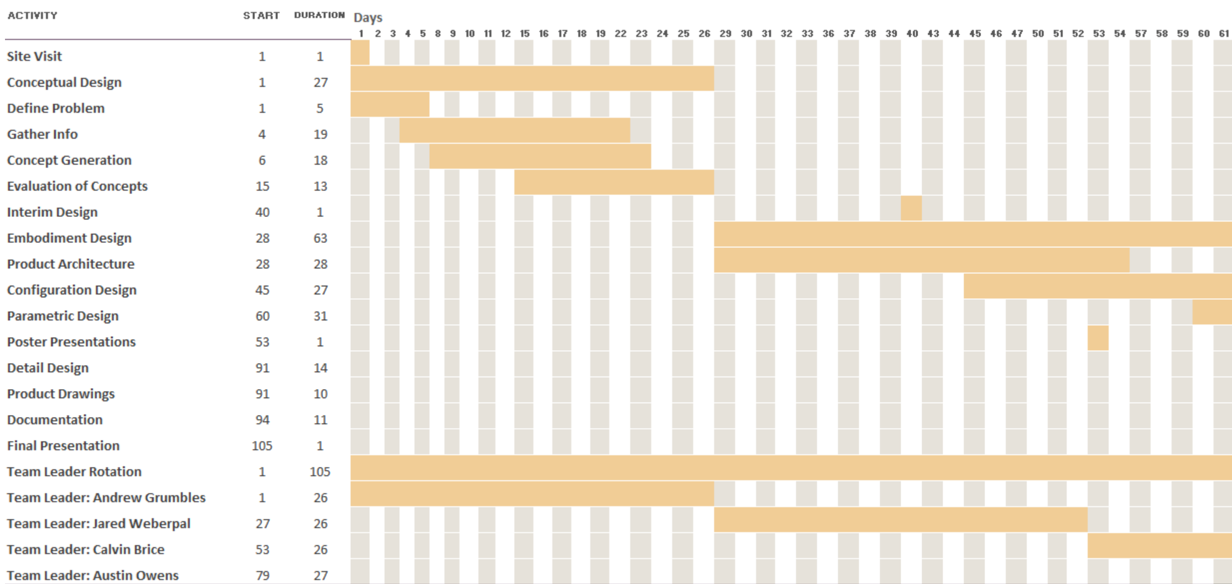


Figure 7: Gantt Chart Project Plan – Part 1

ACTIVITY	START	DURATION
Site Visit	1	1
Conceptual Design	1	27
Define Problem	1	5
Gather Info	4	19
Concept Generation	6	18
Evaluation of Concepts	15	13
Interim Design	40	1
Embodiment Design	28	63
Product Architecture	28	28
Configuration Design	45	27
Parametric Design	60	31
Poster Presentations	53	1
Detail Design	91	14
Product Drawings	91	10
Documentation	94	11
Final Presentation	105	1
Team Leader Rotation	1	105
Team Leader: Andrew Grumbles	1	26
Team Leader: Jared Weberpal	27	26
Team Leader: Calvin Brice	53	26
Team Leader: Austin Owens	79	27

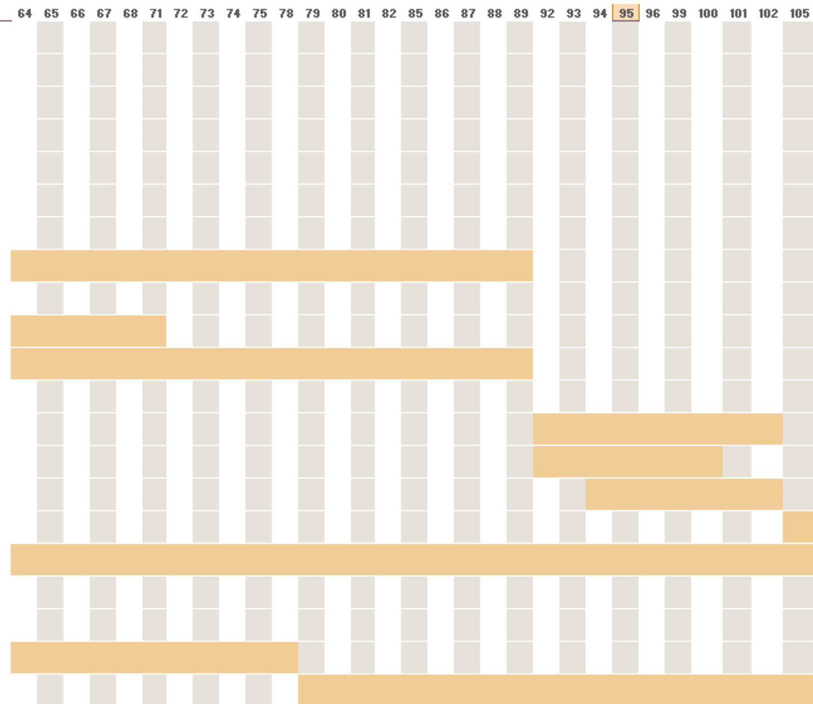


Figure 8: Gantt chart Project Plan - Part 2

The next key deadline was the Final Presentation in which the project was presented to the sponsors by members of the team. This occurred on May 15th and was be the culmination of all the design, production, knowledge, and creation of the project.

The Cookie Lab had a general-purpose budget of $1000 available, which comes from the Student Research and Engagement Fund (SREF). Additional sponsorship is also provided from Automation Company, Turck, and the EMS Alumni Association. Along with instruction from Dr. Fick, further mentorship has been provided by Dr. Horne.

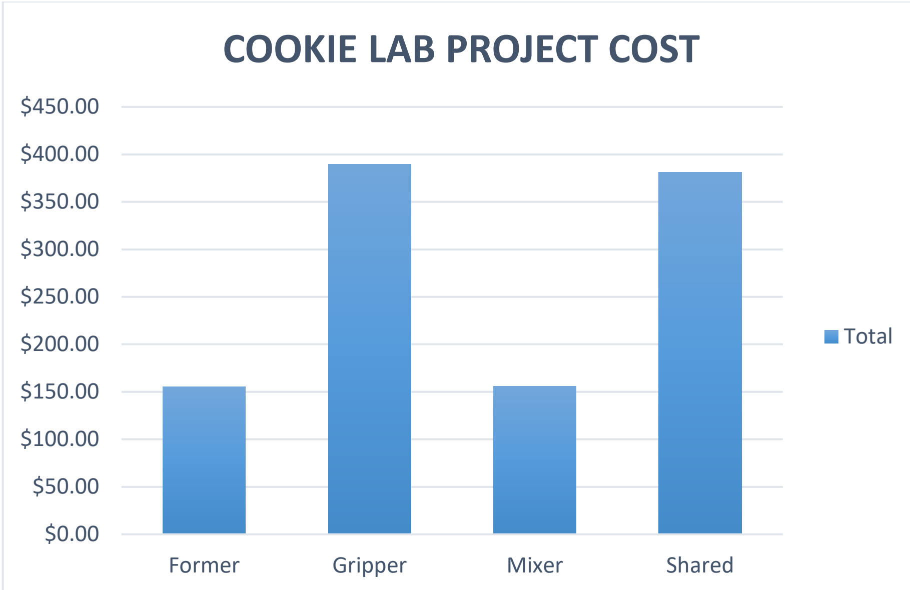


Table 3: Project budget

Category	Cost
Former	**155.42**
Robotic arm	**389.73**
Mixer	**155.9**
Shared	**381.11**
Grand Total	**1082.16**

The budget shown in Table 3 outlines the cost breakdown for the different sections of Phase II-B. While the budget was slightly overspent, it came much closer to the required cost than was originally thought possible during the planning stage.

3. Possible and Proposed Solutions

With the project constraints established and research into potential solutions completed, possible solutions were generated using a functional decomposition and morphological chart. A functional decomposition is the first step in an ideation process where the project goal is broken down into specific functions and sub-functions. This allows the project to be approached in sections that accomplish small goals rather than a single, all-encompassing solution. The process itself is a pre-brainstorming activity, no solutions are contained within the document, just functions and sub-functions. This project has five functions that it must perform, shown in Figure 9. The first four sections will become modules so that the project can be broken down and accomplished individually. After testing small batches of cookie dough, it was determined that mixing wet and dry ingredients separately was not needed and could be removed from the process.

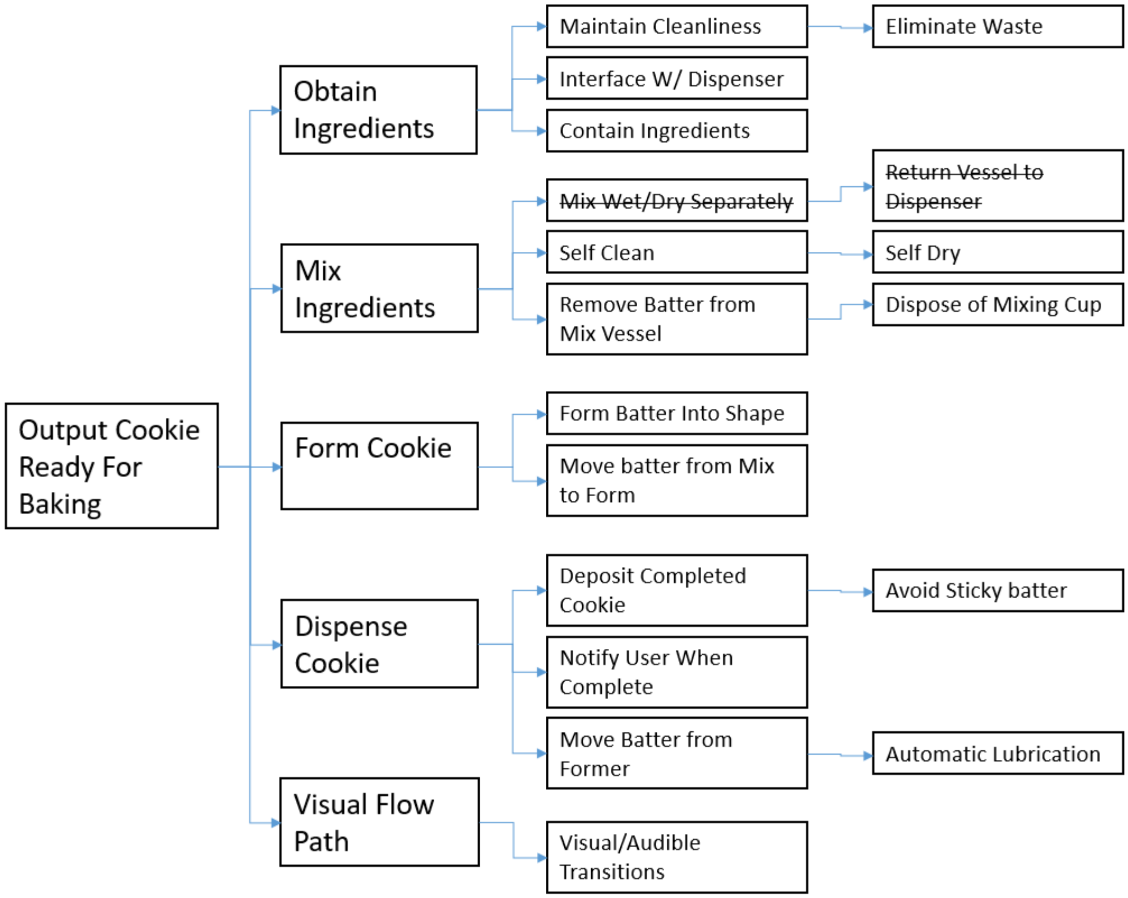


Figure 9: Functional decomposition

The morphological chart follows the functional decomposition in the design process. This method takes the main functions of the project and places them in a table. The table is then filled with either visual or textual cues to inspire creative solutions to accomplish the functions. This chart can be seen in Figure 10 for a subset of the overall functions required of the solution. This process gives the benefits of having a visual chart that records brainstorming activity. Existing products that perform certain tasks can be used to inspire adaptation and adoptions to accomplish the larger goal much more efficiently than starting completely from scratch.

Function	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Interfacing With EP					
Mixing					
Forming					
Visual Aspects	Addressable LEDs	EL Wire	Arduino Con trolled Light Modules		

Figure 10: Morphological Chart

Breaking up the project lends itself to a much higher ease of both interfacing and refinement of existing system, mixing, dough transfer, and forming/finishing. These modules were assigned to individual team members to handle bulk progress, while the rest of the team assists in implementation. It was left up to each module leader to determine final design path with respect to mechanical simplicity, educational opportunities, reliability, and cleanliness.

While selecting forming solutions there were several requirements that each potential solution had to meet to be further explored. The forming mechanism had to be mechanically interesting and visual, the process had to be exposed to the viewer so that material flow can be followed easily through the entire mechanism, this eliminates mechanisms that are closed and rely on internal mechanisms to function.

Though many industrial mixing attachments could potentially be used, a large number of them necessitate the ingredients being mixed to be fluid (in a batter like state). Cookie dough, when fully mixed, is more solid than fluid and thus needs specialized motion or mixing attachments. One design idea relies on two concentric mixing blade attachments that rotate opposite of each other. Having these two blade attachments rotate opposite of each other would allow for the dough to be thoroughly mixed and allows for cleaning of both the inside blade and the inside of the cup using staggered mixing motions after the dough mixing is completed. To be more descriptive, once the dough is fully mixed, the outermost mixing attachment will stop mixing while the inner mixing attachment will continue. This will allow for the inner mixing attachment to self-clean. After it self-cleans, it will cease rotation and be lifted independently of the mixing module frame to allow for the outermost mixing attachment to scrape the side of the transportation cup and form a dough ball in the center of the cup. Once the dough ball is formed, all mixing will cease, the mixing module frame will be raised above the transportation cup, and the cup continue to the next module.

Another design only contains a single mixing attachment, but this attachment rotates around a circle instead of being fixed in the middle of the cup. This is a common design for some home stand mixers and will allow for quality ingredient mixing, self-cleaning, simplified design, and one fewer motors in the module. Once the mixing attachment is placed into the cup the mixing will begin as the mixing attachment is spun to a high RPM and rotated around the cup. Once mixing is completed, the mixing attachment will continue to spin at a high RPM, but it will cease rotating around the cup. This allows for the blade to self-clean between consecutive individually created recipes.

Yet another design countered the need for epicyclical motion with the mixing cup by providing that motion with the mixing attachment. This attachment would have a larger diameter attachment for 120°, a medium diameter attachment for 120°, and a small diameter attachment for the final 120°. This attachment would be able to scrape the inside of the mixing cup in a single rotation but would also have the two other smaller diameter attachment portions that would kick the dough back out to the outside rim. This would produce more vibration when mixing due to uneven weight distribution in the attachment, but it would allow for a single attachment to fully mix cookie dough from a single location.

The forming and finishing module focuses on the removal of the dough from the mixing container and handling it such that it outputs a bake-able cookie. The initial concept involved injection molding a cookie. This device would mimic a CNC turret (Figure 11: CNC turret concept) containing multiple shapes.

Figure 11: CNC turret concept

After the team made a batch of cookie dough and tested a prototype mold, the difference between a sheet cookie and a drop cookie became apparent. A sheet cookie, such as gingerbread, does not flatten and deform during the baking process, on the other hand a drop cookie, such as chocolate chip, is placed on a baking sheet as a ball and as it bakes, flattens out and forms a round shape. Forming the cookie into a defined shape before baking would be useless. As such, other methods of delivery needed to be explored. In the industry, there are multiple methods of forming doughs into shapes. The team explored several potential solutions after producing the morphological chart, including a ball screw design, an extrusion concept, an existing machine called the Rotimatic, and finally a spiral disk design. The first discussed concept solution was a mechanism that had two contacting ball screws and a guide bar. This design was intended to handle flour-based doughs. These doughs tend to be very elastic and retain their shape very well, Cookie dough tends to be less like a solid and more so a viscous fluid. The dough tends to spread rather than form. A ball screw design could be functional, if the dough is well floured but the device itself is designed to accommodate a larger flow rate of material than the project scope requires. This method would require more expensive manufacturing methods to implement than other solutions explored.

The concept of a pneumatic knife extruder was first paired with the injection molding forming concept. The dough would be placed in a tube with an air cylinder which would extrude in calculated amounts and then be cut off to dispense cylinders of cookie dough. This method is simple to implement and is suited to producing a small batch of cookies (3-5) as the dispenser was initially designed to do. A cylinder would be inexpensive to implement but fails to showcase unique engineering solutions or spark visual interest.

The Rotimatic is an all in one design that stores ingredients, mixes dough, and bakes it. Originally the design is meant to create Naan like bread products. This design was adaptable to a sugar-based dough needed for cookies. The method of forming uses a rotating feature which rolls the dough against the surface of a container while top feeding ingredients. The feasibility of adaptation to cookie applications was questioned due to the consistency of cookie dough; there was fear of spreading rather than forming. This would produce a mess that would be non-transferable to the next step of the process.

The interface of the mixing stage with the engineering physics team's delivery system is a complex design process that is covered later in the report. Possible solutions proposed were a conveyor/roller system, a tracked cart mechanism, and various claw/gripper mechanisms.

4. Discussion of the Final Design and Assembly

Figure 12: Final machine as designed and assembled by Mechanical Engineering and Engineering Physics teams

The final design is a result of working through the functional decomposition, and morphological chart processes. Outlined below are the individual element designs incorporated into the project to meet the design requirements.

Robotic Arm

During the process of brainstorming ideas for the overall mechanism with the Engineering Physics team, it became clear that a key piece would be the interfacing elements between the two teams. This can be broken down into the hardware and the software sides.

For the hardware requirements it was determined that a method needed to be developed which would allow for transportation of the ingredients from the EP team's tracked cart to the ME team's mixing mechanism.

It was first necessary to define physical requirements and constraints of this design problem. The mechanism needs to be easy to disassemble for ease of transportation and repair of individual components. It needs to be robust enough to handle repeated motions. Simplicity was also critical. Physically it needs to be strong enough to lift and manipulate a cup of ingredients weighing at least 100 $grams$. The vertical range of motion needs to be at least 200 mm. Horizontally it needs to be able to traverse between the tracked cart, the mixer, and the former to deliver the ingredients in the various stages to all necessary elements. A wide variety of objects must be able to be grasped and manipulated to accommodate for design changes of ingredient container. Precision and repeatability are necessary to ensure the proper functioning of the system without human intervention so that automation can be achieved.

Different industry standard solutions were researched to provide insight on current practices in transporting and manipulating objects which will be discussed during the concept generation process. Referencing back to the morphological chart (Figure 10), the first concept was that of a conveyor mechanism. This was initially suggested by the EP team but was abandoned when research indicated that integrating a conveyor into the current dispenser design would not be feasible with the tight turn radii required. Another proposal by the ME team involved an x-y gantry system which would move underneath all mechanism elements. Concerns were raised that this would not be large enough to work, or that it would be heavy and expensive. The final concept proposed was a tracked cart. To make this design work, the ME team decided upon using a robotic arm to manipulate the ingredients cup once delivered by the tracked cart.

Once the basic concept of the mechanism had been selected, it was necessary to determine the motions that it had to be able to go through. This was done with a degree of freedom analysis. Vertical travel was necessary as well as rotation in the x-y plane around the vertical axis. The end effector needed to be able to open and close as well as rotate 180 degrees to flip its payload upside down. A whiteboard sketch during this design phase can be seen below in Figure 13.

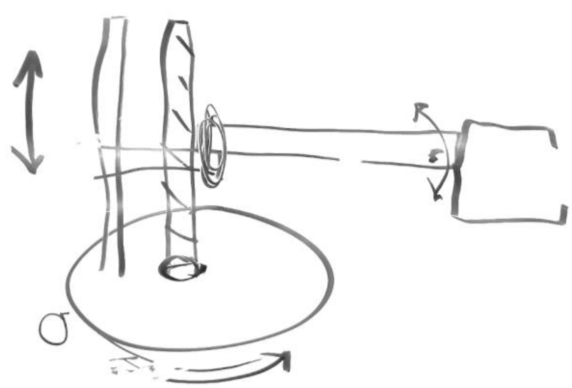


Figure 13: Concept sketch of robotic arm during degree of freedom analysis

This was a very useful process as it allowed for a variety of configurations to be visualized and inspected for design requirements.

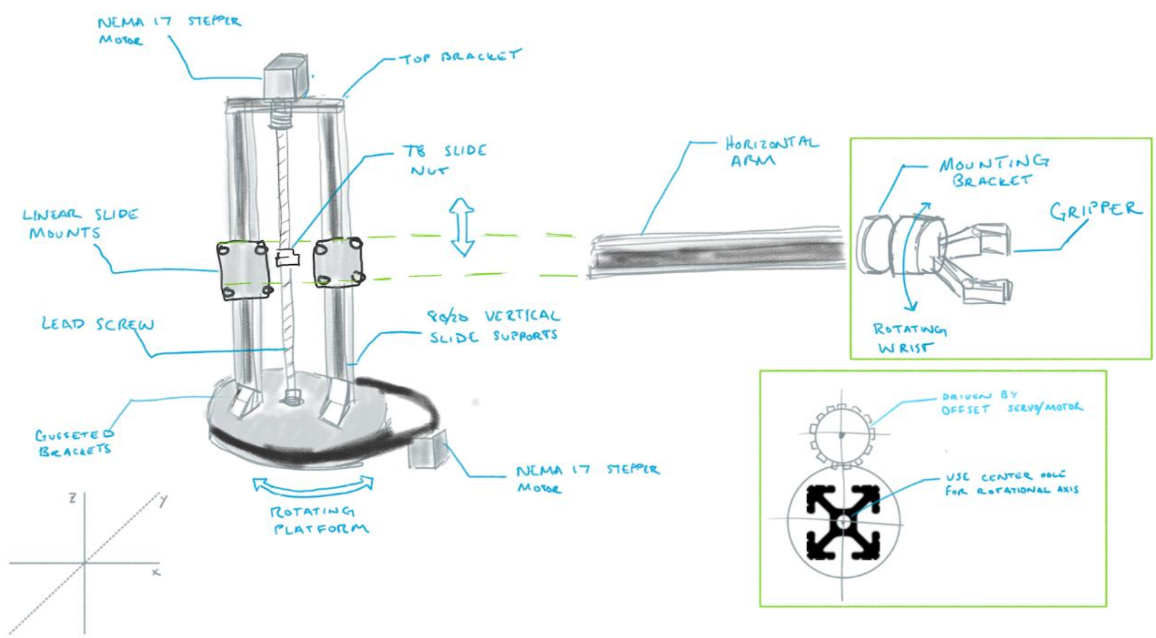


Figure 14: Configuration design of robotic arm to help select components

Key to the final design were certain concepts such as Design for Manufacture (DFM) and Design for Assembly (DFA). Since it may be necessary to manufacture replacement parts in the future, modify or upgrade certain elements, or even just assemble the robotic arm in the first place, it was critical that components be well designed. Make vs. buy decisions were also an important consideration at this stage. Since most of the Cookie Lab was being built around 80/20® it was decided to continue with that for the main components of the robotic arm. Research into compatible 80/20® components led to the discovery of a linear actuator based on V-Slot® components from OpenBuildsPartsStore.com. V-Slot® has an advantage over regular 80/20® because it allows for roller wheels to be run along the channel slots. This was important for stabilizing the vertical motion and reducing binding. The linear actuator can lift 26 lb. which is significantly more than the project requirements of 100 $grams$ for the payload. The payload is cantilevered by approximately 10-12 in (design allows for positional adjustment in many areas) from the center of the linear actuator which creates a moment force. An unforeseen side effect of selecting this specific linear actuator was the need to purchase an additional stepper motor driver for controlling the Nema 23 stepper motor that drives the leadscrew. This also introduced a power requirement of 24 V. This drove the decision to use a 24 V power supply and step down to the correct voltage for other components using buck converters. Since the buck converters selected had a limited throughput current of 2 $amps$ it was necessary to use multiple so that the servos could operate at maximum torque (6 V) without draining the power supply. Future modifications can be made to consolidate the buck converters or replace them entirely with a separate 6 V power source.

Figure 15: Buck converter used to step down from higher voltage to a lower voltage (limited to 2 amps)

Figure 16: 20 Kg Servo used to drive "finger" elements and "wrist" rotation

The servos were used in a couple of places throughout the robotic arm. This is because they offer relatively high torque for a light footprint (both weight and size) along with positional control. Initially a servo was used to control the rotation of the base Figure 17. However, after assembling and attempting to control it, the rotational inertia of the arm was high enough to cause the servo to exceed the dead band limits and create and unstable system. This means that while the servo was trying to maintain a specified location, the arm would continue to rotate (due to the rotational momentum built up) and overshoot the location. This caused the servo to compensate and swing the arm in the opposite direction to correct the error which started the process over. Since the servo never reached and maintained the desired position it created a pulsating or jerking motion which was undesirable and quickly strained the soft plastic of the servo horn to the point of failure. A redesign was quickly implemented which utilized a stepper motor in place of the servo as well as a belt driven system to allow for a modified gear ratio (Figure 18).

Figure 17: Servo rotation mechanism which had too much rotational inertia and backlash to maintain correct position

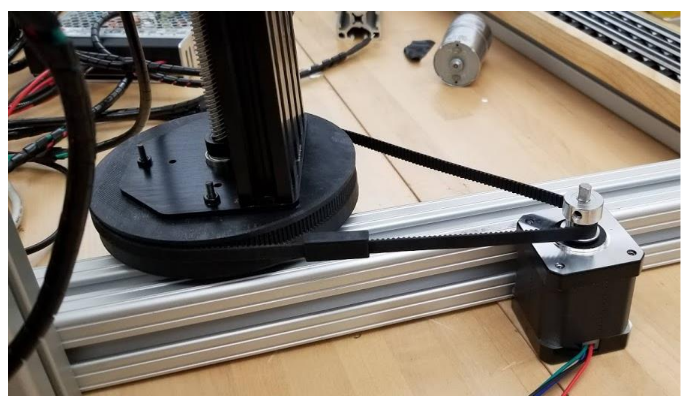


Figure 18: Improved belt driven rotation mechanism which allows for a better gear ratio, but loses precise location tracking because of using a stepper motor for the drive mechanism

The main disadvantage of using a stepper motor is the loss of positional tracking which was present with the servo. This could be regained by a future implementation of a rotary encoder and is recommended.

Most of the mounting brackets as well as gears were designed in SolidWorks and 3D printed using a Prusa i3 Mk3 printer using PETG or PLA filament. This was done to allow for quick prototyping and revision of certain components. Since most of the gears do not undergo continuous rotation wear over time is not a large concern. Nylon would have been a better choice of material but is extremely difficult to work with due to its hygroscopic nature. Most of the mounting hardware used was M3 nuts and screws of various length due to their ready availability.

One of the most critical elements of the robotic arm is the end effector (also nicknamed "the gripper"). This allows the arm to interact with the payload in a dexterous manner. Much research was done to determine the best design to use. A lot of end effectors can be readily purchased for use in hobby grade robotics, but most did not meet the requirements necessary for this project. The end effector needed to be able to grasp objects large as 3 $in.$ in diameter as the EP team would be delivering the ingredients in a cylindrical container with those dimensions. It also needed to have high enough grip force and surface contact area to prevent any slipping during manipulation. An initial design was prototyped and tested but did not allow for grasping of different sized objects very easily or have enough grip force (Figure 19). Pneumatic actuation was considered but was avoided due to the need to have additional components such as an air tank or reservoir with a compressor. The final design chosen was the T-42 from the Yale OpenHand Project (Figure 20).

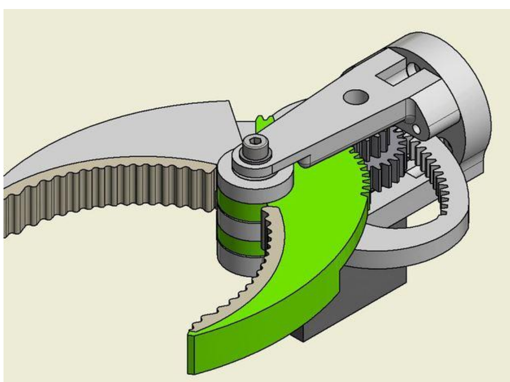


Figure 19: Initial design of end effector which was not large enough or allowed for enough grip surface area to be in contact with the payload

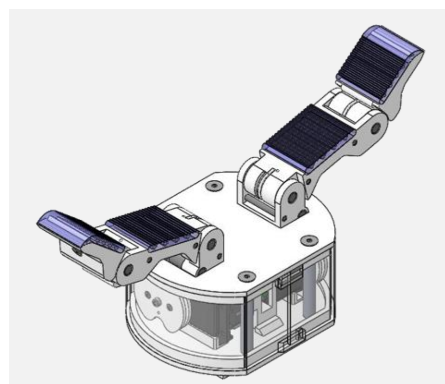


Figure 20: Model T42 end effector from the Yale OpenHand Project which was used as the final design

The Yale OpenHand Project is an initiative to advance the design and use of robotic hands designed and built through rapid-prototyping techniques to encourage more variation and innovation in mechanical hardware. Since it is open source that meant that all the necessary files needed to construct the hand were readily available and could be used in the project without needing to worry about licensing. Very detailed build instructions and bill of materials were also available and proved invaluable to properly constructing the mechanism. The stated specs indicated that it has a holding force of up to 10 N and only weighed 400 g itself. This design differs from most end effectors by utilizing a "tendon" actuation mechanism which converts the rotation of servos into a contraction of the proximal and distal links. This occurs in an underactuated manner which allows for “molding” the fingers around irregular objects which proved invaluable to design updates with the payload diameter. The manufacturing process of the T-42 utilizes a hybrid manufacturing technique where the proximal and distal links are first 3D printed and then a urethane casting is used to create the surface pads which contact the payload. Modifications to the base plate of the T-42 were made to accommodate a wrist rotational mechanism that was designed from the ground up by the ME team to interface with the rest of the robotic arm. The final design of the robotic arm is shown in Figure 21.

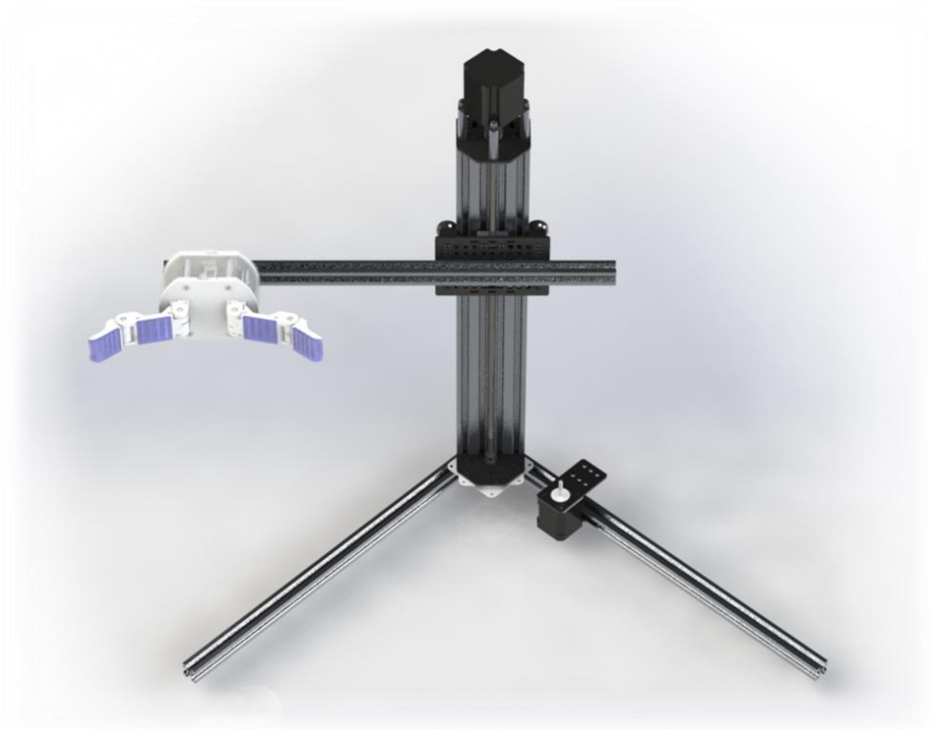


Figure 21: Final concept rendering of robotic arm and how it will mount to 8020® frame system

Mixing Cup

The initial design requirements for the cup were identical to that of the overall project. It needed to be visible and help share topics within STEM. These requirements along with size requirements to accommodate small amounts of cookie ingredients and also large enough to fit a standard mixing attachment, and food safety requirements led to the use of a translucent plastic that would allow for visibility with mixing, easy cleaning, and a quality area for mixing. This initial cup proposal can be seen in

Figure 22: Initial Mixing Cup Iteration

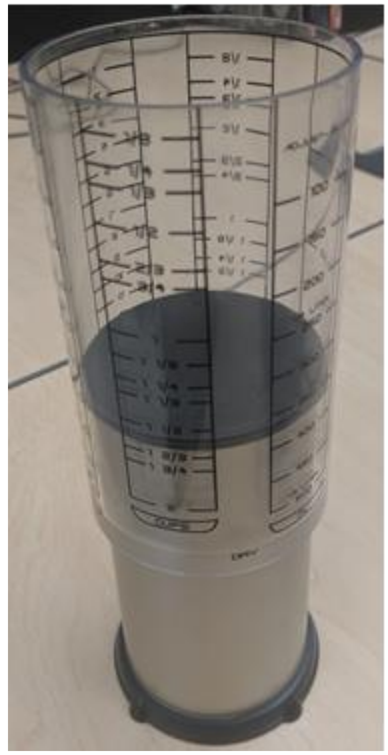


Figure 23: Unshortened Tube Cup

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The next proposed cup was another plastic cup, but this cup was a variable volume measuring cup with a tube and piston type arrangement that can be seen in Figure 23. This variable measuring cup has a movable base that assists in removal of the dough by having the ability to scrape the walls of the cup and push the mixed dough to the top edge of the cup. In this way it is possible to scrape the mixed dough off the top edge of the cup in a perfect circular shape of consistent depth. Through testing, the base of the cup that moves through the tube portion

had to be shortened to 1.8 inches to allow for proper transportation and extrusion, as will be covered later in this report.

Figure 22: Initial Mixing Cup Iteration

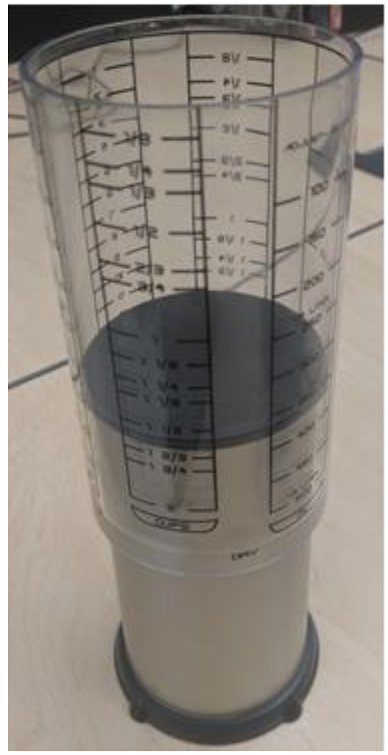

Figure 23: Unshortened Tube Cup

Mixer

The mixing of cookie ingredients must take place in a specific, consistent location to allow for the robotic arm to transport the ingredients cup to and from the mixing module. While in location, the ingredients must also be effectively mixed into a dough that is uniform in its consistency.

One of the main stages of cookie creation is the mixing of the accumulated ingredients prior to baking. Mixing has different constraints and problems that are inherent for different batch sizes. For the single cookie batch sizes that happen within this project, the most prominent problem is that of the accumulation of dough from one batch to another. This accumulation that could occur and either prevent effective mixing of future batches or require more mixing time to become fully mixed dough. For this reason, the most pressing problem with the mixing module is the effective removal of dough between batches. A secondary problem that may affect effective mixing is mixing attachment placement within the ingredients. This means, the mixing attachment must reach every part of the compiled ingredients to get a well-mixed dough for the former. One of the last major problems of mixing is securing the ingredient cup during mixing. Allowing movement in the mixing process may allow for some of the ingredients to not be fully mixed into the rest of the dough.

Through these problems, information about mixing attachment self-cleaning, effective mixing techniques, and arresting movement of the mixing area were gathered. The mixing cup also must be secured while mixing occurs, yet also be easily removed once mixing has ceased.

A mixing attachment had to be selected for the even mixing of all ingredients within the mixing cup. Throughout the concept generation of the initial design, two mixing attachments were designed. Each was based off a simple hand mixer mixing blade attachment design, with one being smaller than the original and the other being much wider than the original and with rotation supplied by a belt instead of a shaft. The purpose of the belt was to allow for the middle of the larger mixing attachment to be open and allow for lifting and removal of the smaller inside mixing attachment. This necessary movement required the open center of the larger mixing attachment.

The final mixing attachment design is the hand mixer standard mixing attachment. It is easily sourced, cleaned, very effective, and cost efficient. This mixing attachment can be used as it fits inside the mixing cup.

As for securing of the mixing cup during mixing, the initial plan was to move the mixer down onto the mixing up that would be held in place with a cup holder of sorts. This design was modified in favor of moving the mixing cup and cup holder up into the mixing attachment. In that way, the mixer wouldn’t have to move as it was the heavier of the two portions.

The vertical movement of the cup holder and mixing cup was initially designed to be in the form of a platform that was elevated by a lead screw. This design would allow for very accurate control of the height of the platform and would be easy to control. This design was then modified to include two stabilizing pillars that will also support the mixer above the platform. These pillars hold two sliders that stabilize the vertical movement of the platform that is pushed up by the lead screw.

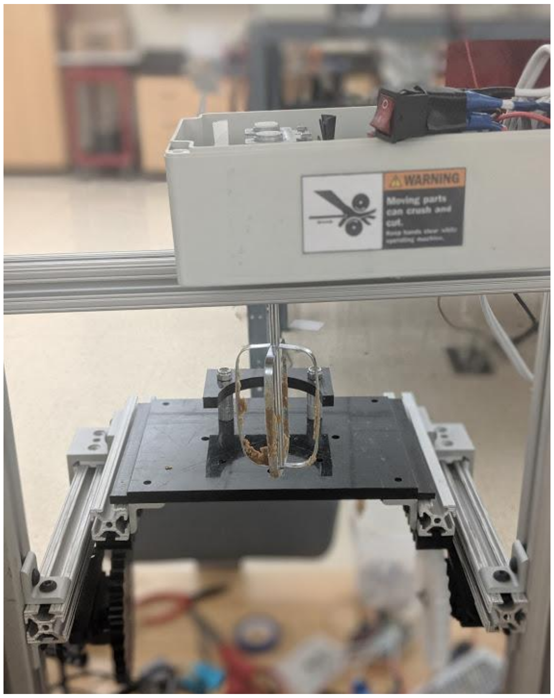

Figure 24: Final mixing module design

Finalization of the design was done by removing the lead screw elevation and all of the problems that came with it. Looking back on the initial problem that necessitated a separate elevating mechanism, the gripper arm strength not being enough to hold the cup up to the mixer while mixing, a new solution was created. This solution was to slide a platform underneath the cup as mixing occurs. In that way, the gripper arm would not have to vertically support the cup while mixing, only horizontally supporting the cup while mixing. The new platform would slide out of the way horizontally to allow for the gripper arm to place the cup into the reach of the mixer attachment. The platform would slide underneath the cup, the gripper arm would release but still press the cup against a fixture on the platform, and mixing would take place. Gripper arm and platform support would still allow for the cup to spin between them, but they would resist the rotation enough that mixing of ingredients would still occur.

Once mixing is completed the gripper arm would grasp the cup fully, the platform would retract away, and the cup would be lowered out of the mixing attachment. Movement towards the extruder would continue until the extruder is reached and the cookie fully formed.

Throughout the design process there were multiple concepts that were created. For the mixer concepts each subsequent concept was more of a refinement over the previous concept than it was an entirely new concept. For this reason, it was very easy to evaluate which concept would lead to the best performing mixer module as it was the final concept that was created.

Dispensing

The initial design was to use a forming mechanism to output a ball of cookie dough. The mechanism developed can be seen in Appendix E. the mechanism was removed after the realization that the dough need not be shaped but rather simply deposited onto a cookie sheet.

After the dough is mixed it must be transferred onto a cookie sheet for baking. To simplify the process the original mixing beaker was exchanged with a liquid measuring cup with a push out base. This cup allows the mixed dough to be extruded out of the cup with ease. The robotic arm is to invert the cup and with the support of a frame, push the dough through the cup and out onto a cookie sheet. Because the dough sticks, the arm must then push the dough ball over some sort of cutoff mechanism. The design that was chosen utilizes a wire cutoff mechanism.

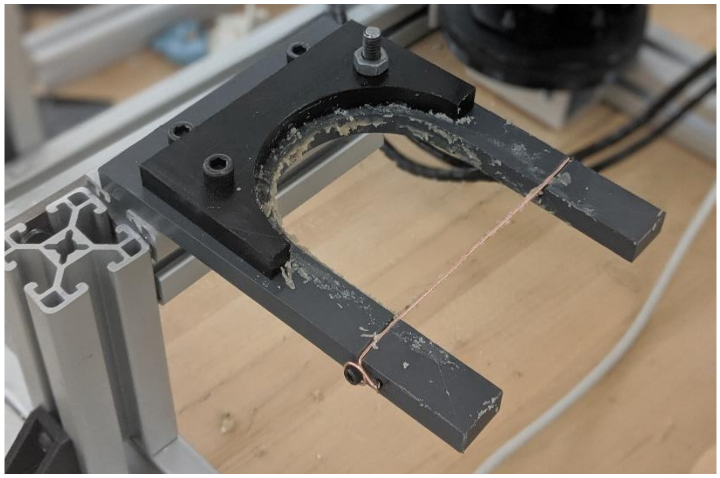

Figure 25: Extrusion frame with wire cutting mechanism

The extrusion is performed by a linear actuator with a 6 inch travel. This actuator was used because it allows the cup to swing in without collisions and push out the entirety of the dough. The frame must be robust enough to account for the extrusion forces but low profile enough to allow a cookie sheet fit below and allow clearance for the cup. The frame, shown in Figure 25, was designed with a crescent shape to allow the cup to swing in on the arms radius with no required height change and simplify scraping. Once the dough has been extruded and the actuator retracted, the arm can swing out and use the wire to clean off the top of the cup and allow the dough to drop onto the sheet below. A wire cutter was chosen over a blade because of the material shedding abilities. The wire is easy to clean and will leave behind minimum residue in between cookies.

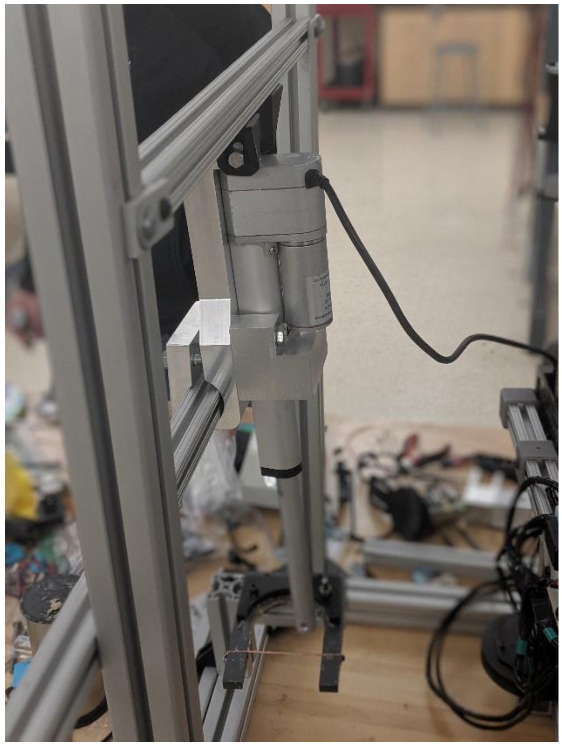

Figure 26: Linear Actuator frame above extrusion frame

User Interface

The development of automatic dispensing controls is one that will involve a complete redesign of the current programming and will morph to meet current project requirements as further developments demand. The current setup uses C++ and Java based code. This is used in Processing (commonly used to create art installations) to create a graphical user interface (GUI) consisting of sliders and buttons which allow for selection of ingredients. This is then sent through a serial cable (USB) to a master Arduino. Then this converted into i2c communication protocol and directed to the correct slave Arduino for each controlling element (Figure 27).

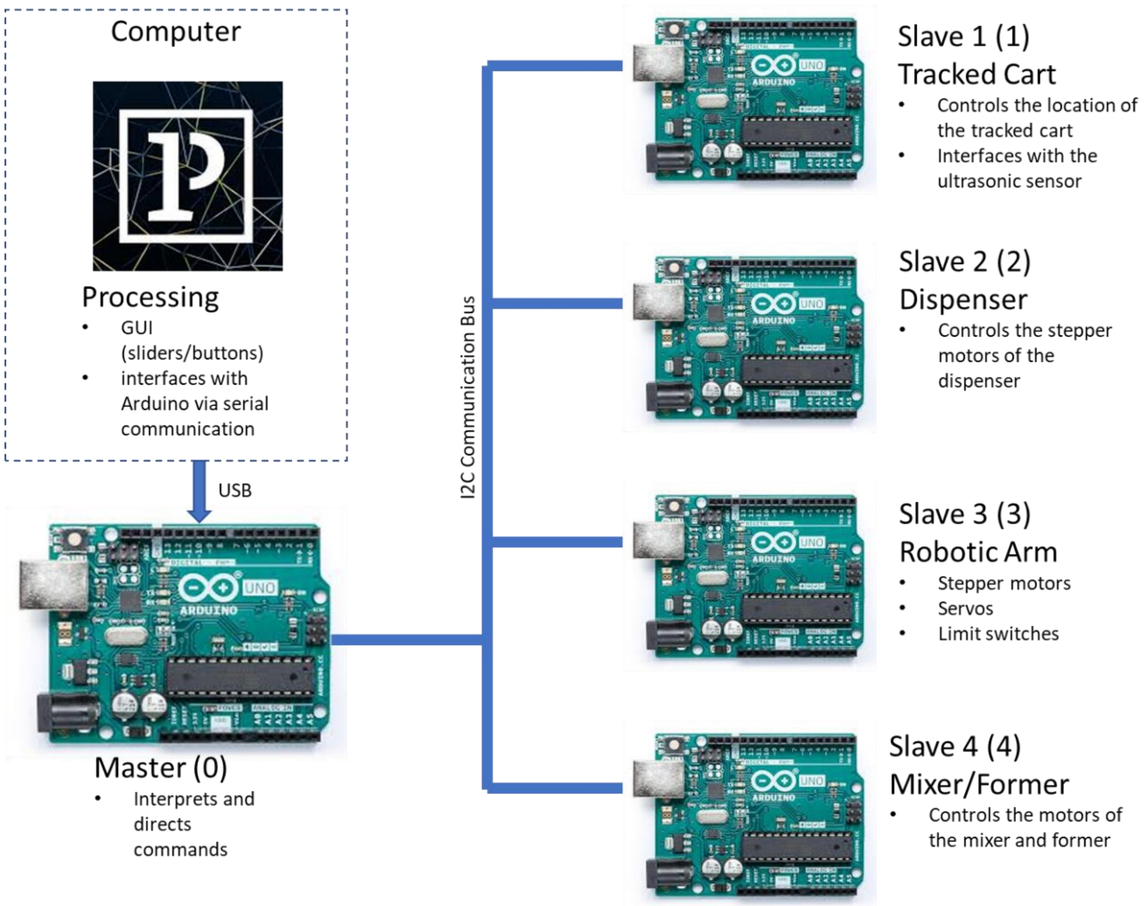

Figure 27: Arduino communication layout diagram

The first slave Arduino is used to control the position of the tracked cart responsible for transporting the ingredients. The positioning is accomplished using multiple ultrasonic distance sensors provided by Turck to the EP team. The sensors emit an ultrasonic signal which reflects from the tracked cart to be converted into a voltage signal with a strength that is proportional to the intermittent distance traveled by the ultrasonic signal. The second slave Arduino is responsible for activating and driving the array of motors in the dispensing machine. This is accomplished through a stack of motor shields which are controlled through the Adafruit library V2. The third and fourth Arduinos control the mixer, former, and robotic arm by a similar method of shields, stepper motors, and servos. The main exception being the Nema 23 stepper motor which uses a separate driver module that is still controlled by an Arduino.

To make the development as simple as possible, while also offering integration of future developments, the current setup with the Arduino receiving serial commands can be retained while an entirely new GUI can be created using Visual Studio or similar integrated development environment (IDE) during Phase IV. For Phase II of the project Processing was chosen. Processing is an open-source graphical library and IDE built for the electronic arts, new media art, and visual design communities with the purpose of teaching non-programmers the fundamentals of computer programming in a visual context. The Arduino IDE was a fork of the Processing IDE and shares a very similar development interface. Current experiments have proved the working concept that Processing will be able to successfully replace Megunolink (the development software used during Phase I) for the GUI portion of the project. The code can be viewed in Appendix A

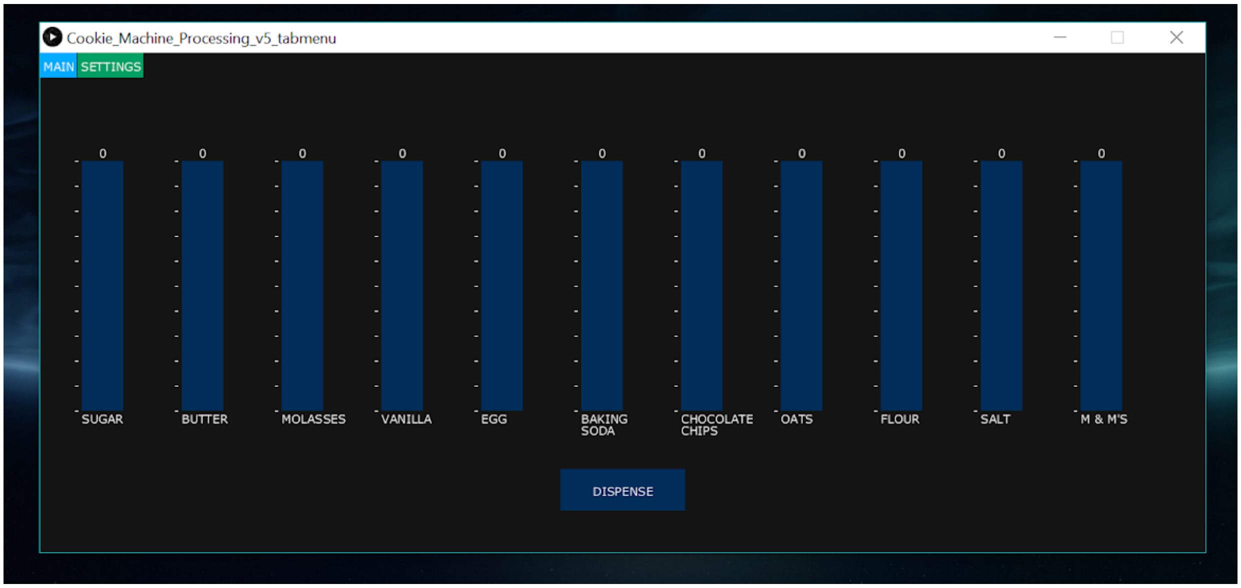

Figure 28: Graphical user interface demonstration made in Processing

5. Conclusion and Recommendations

Due to time constraints and the vast scope of the entire project not everything can be implemented in its final configuration. Certain aspects of the current mechanism will need to undergo revision or even complete redesign. The following will mention updates that can occur to the dispenser, the mixer, the extruder, and final cookie handling.

For the first area of consideration, that of fine powder dispensing, the current state of industry solutions was looked at. Namely, commercial dispensing of fine powders for packaging such as flour, protein powder, sugar, etc. It was discovered that fine powders are typically classified into two categories, free flowing and non-free flowing. Free flowing powder has a natural tendency to fill any voids or pockets created in it with a good example being that of sugar. Non-free flowing powder will retain the shape of voids created in it with an example being baking powder. Both present unique challenges for accurate and precise dispensing. Most commercial solutions use a form of an auger/screw to control the movement of the powder. Some automated dispensing machines found in chemistry labs operate by mixing the powders with a liquid to create a solution which can be dispensed volumetrically. Because all the powders needed to dispense in this project, which are need in quantities smaller than 10 grams for a single cookie, also happen to be water soluble, and because liquid dispensers have already been successfully designed and implemented, this seems like a logical solution which will not take much additional modification to incorporate. A ratio of liquid to powder was experimented with to ensure that doesn't add too much additional liquid to the mixture, while still accurately dispensing small amounts of the correct ingredient.

The second area of recommendation is automating the dispensing process so that the least precise ingredient is dispensed first. A load cell will need to be incorporated into the tracked cart to measure this amount. Then the next ingredient to be dispensed can be proportionally updated to match the first ingredient and so forth until the most precise ingredient is dispensed last (this will probably be the liquids as the plunger/lead screw mechanism is very accurate and precise).

Another area of recommendation is in the mixing attachment. The current attachment cannot reach the entire mixing cup within a single rotation, nor can it evenly mix without the need for additional movement. In the future, a metal mixing attachment that consists of three different radii would need to be manufactured such that the outer radii would contact the inner diameter of the mixing cup throughout the entire rotation of the attachment and the inner two different radii would be able to mix the dough that is moved towards the center of the attachment. The only new downside to this new mixer attachment would be the need for a new attachment cleaning method to be created.

The dispenser, although functional does require modification before final implementation. The flour dispenser currently dispenses in a highly variable nature which negatively affects the precision of the dispenser. There was preliminary experimentation with adding inserts to the dispenser wheel to shrink the cavity that moves the flour. By reducing flow area, the accuracy of dispensation can be greatly increased. 3D models of spacers can be found in the project files, there was not ample time to fully implement this solution though. The butter dispenser currently requires manual cutting of the butter. This process can be easily automated by using a wire cutter mounted to a linear actuator. The wire, like a cheese cutting wire, can cleanly cut the butter and minimalize the accumulation of residue on the mechanism.

In the mixing module, there are currently four controls that need to be armed before the mixer can be operated. The mixer power plug, Arduino and motor power switch, mixer power switch, and mixer Arduino relay must all be armed before mixing takes place. These are necessary and redundant safety steps that will ensure the mixing takes place only when and where it should. The next step in safety would be to limit things out of the control of the system, such as stray fingers entering the cup while mixing takes place. This can be done by adding acrylic plates to the mixing module frame the drop down before mixing occurs. These acrylic plates would ensure visibility while also providing insurance that no foreign objects would be entering the mixing cup during mixing. Caution stickers have been added to the mixer to ensure visibility and adherence to good safety practices as well.

A small x-y gantry can be implemented under the extrusion frame to allow the dough to be deposited onto a cookie sheet and allow multiple cycles before the mechanism required human contact. In order to accomplish this the frame will need to be remounted to the support post to provide clearance for the gantry. Due to time and material constraints this mounting design was not able to be implemented.

Currently there is no mechanism designed to handle dirty cups or reset the plunger in them for use on another cookie. The linear actuator can be used to press the plunger back if it is deemed possible to reuse the cups, the arm would have to invert the cup beforehand. The arm does not have the reach to place a dispensing or disposal machine for cups so it would have to be implemented elsewhere on the machine or operate independent of the arm. A potential solution is to place the empty cup back on the tracked cart and deliver it back to the start to be manually swapped out for a fresh cup. Doing this would minimize all human contact required to keep the machine running.

In conclusion, this report outlined the customer requirements communicated to the design group, definition of the project in engineering terms through functional decomposition and a House of Quality, as well as research into existing applicable patents and standards. The development phase covered the processes and decisions used to design the modular components of the final design. The team delivered a functional machine that can effectively turn raw ingredients into cookie dough ready to bake.

6. Acknowledgements

This project would not have been possible without the support of our sponsors, Tammy Salmon-Stephens, Director of Student Success Programs for the College of Engineering, Mathematics, and Science at the University of Wisconsin – Platteville, Dr. Anne-Marie Lerner, Associate Professor at the University of Wisconsin – Platteville, and Dr. Jessica P. M. Fick, Associate Professor at the University of Wisconsin – Platteville. A special recognition is also given to our instructor, Dr. Jessica P. M. Fick and our faculty mentor, Dr. Kyle Horne, Assistant Professor at the University of Wisconsin – Platteville for their invaluable guidance throughout this project.

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[10] N. P. Israni, "Compact appliance for making flat edibles". US Patent US8820221B2, 02 09 2014.

Appendices

Appendix A: Source code

The source code for the Cookie Lab project is in a GitHub repository. This was done to allow multiple team members to simultaneously collaborate on the code as well as to track progress and revert any mistakes. It is recommended that future teams clone this repository and start their own for new development.

The repository was created with an MIT license “A short and simple permissive license with conditions only requiring preservation of copyright and license notices. Licensed works, modifications, and larger works may be distributed under different terms and without source code.”

https://github.com/CalvinBrice/UW-Platteville-CookieLab-Spring-2019

Appendix B: Work instructions

Work instructions for the project may also be found in the GitHub repository.

Appendix C: BOM

The Bill of Materials and item cost is listed below

Date	**Vendor**	**Item**	**Quantity**	**Cost per item**	**Total Cost**
2/18/2019	Amazon	Digital scale	1	$ 12.59	$ 18.58
2/20/2019	Amazon	Plastic Beaker Set	1	$ 5.48	$ 11.47
3/15/2019	Amazon	Power HD HD-1501MG High Torque MG Servo	2	$ 18.99	$ 37.98
3/15/2019	Amazon	Fishing Line 150Yd 100lb	1	$ 14.95	$ 14.95
3/15/2019	Amazon	Hamilton Beach 62682RZ Hand Mixer	1	$ 14.99	$ 14.99
3/15/2019	Amazon	Stepper Motor Nema 17 (Pack of 3)	1	$ 34.99	$ 34.99
3/15/2019	Amazon	T8 Lead Screw Kit	1	$ 16.69	$ 16.69

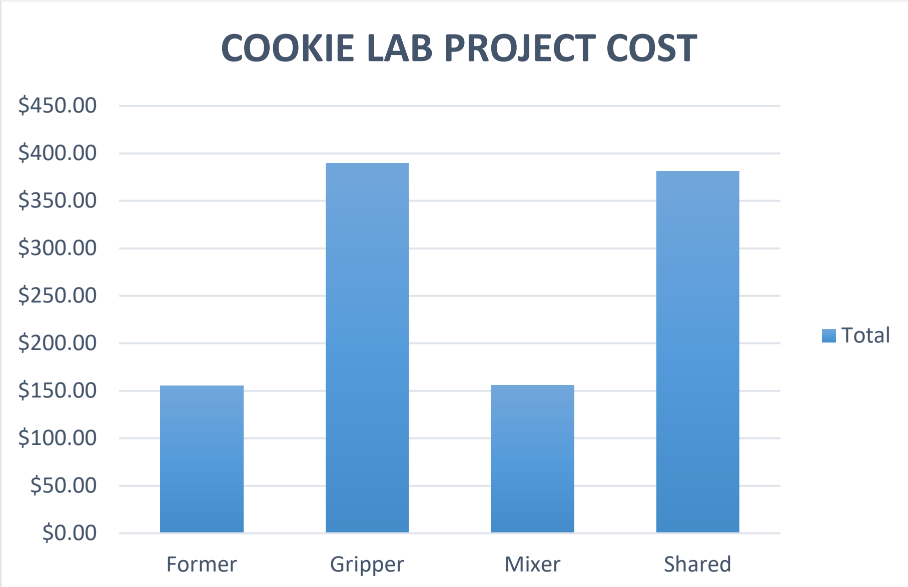
3/15/2019	Amazon	Arduino Uno R3	1	$ 16.99	$ 16.99
3/15/2019	Amazon	Motor Driver Shield	1	$ 5.39	$ 5.39
3/15/2019	Amazon	8020® Bolt Assembly	1	$ 8.99	$ 8.99
3/15/2019	McMaster-Carr	T-Slotted Framing	1	$ 23.57	$ 23.57
3/15/2019	McMaster-Carr	Tapered Heat-Set Inserts for Plastic	1	$ 10.82	$ 10.82
3/15/2019	McMaster-Carr	Black-Oxide Alloy Steel Hex Drive Flat Head Screw	1	$ 8.26	$ 8.26
3/21/2019	SteelMart	Stainless Steel/Aluminum Stock	1	$ 113.00	$ 113.00
3/22/2019	Amazon	Mechanical Endstop Limit Switch	1	$ 10.99	$ 10.99
3/22/2019	Amazon	Motor High Torque	2	$ 19.79	$ 39.58
3/26/2019	Amazon	Servo extenders	1	$ 6.99	$ 6.99
3/26/2019	Amazon	Servo Y-splitters	1	$ 6.99	$ 6.99
3/26/2019	Amazon	Vytaflex 30 Urethane	1	$ 36.35	$ 36.35
3/26/2019	Openbuildspartstore	V-Slot® NEMA 23 Linear Actuator Bundle (Lead Screw)	1	$ 129.99	$ 129.99
3/26/2019	Openbuildspartstore	NEMA 23 Stepper Motor	1	$ 27.99	$ 42.19
3/26/2019	Amazon	DC 24V 300RPM Gear Motor	1	$ 15.49	$ 15.49
3/26/2019	Amazon	DC 12V 50RPM Gear Motor	1	$ 15.49	$ 15.49
3/29/2019	McMaster-Carr	Ø1/4”, L1-1/2”, 8-32 zinc-plated female standoff	5	$ 1.31	$ 6.55
3/29/2019	McMaster-Carr	Torsion spring, 0.340” OD, 0.028” wire diameter	1	$ 4.63	$ 4.63
3/29/2019	McMaster-Carr	8-32, L3/4” countersunk bolt	1	$ 6.62	$ 6.62

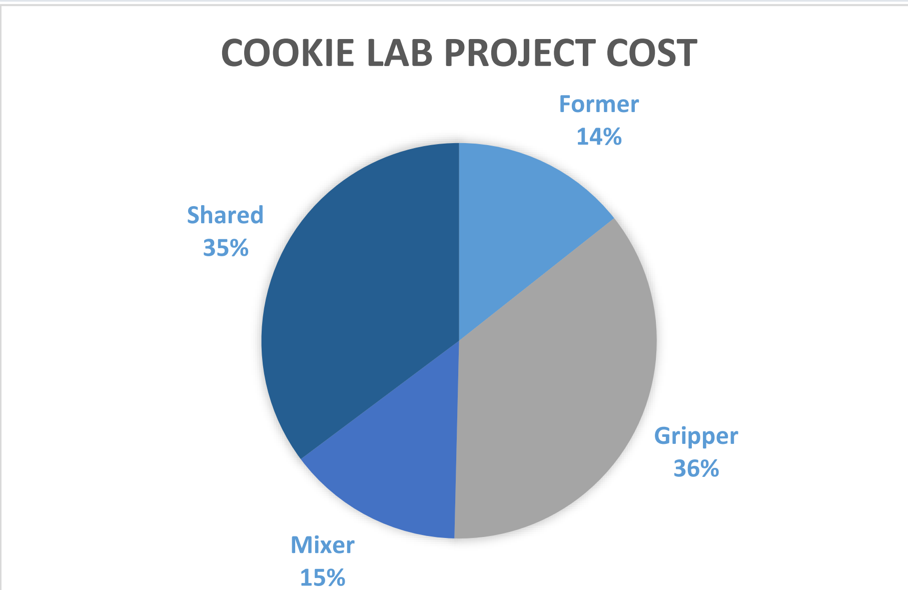
3/29/2019	McMaster-Carr	3" Turntable	2	$2.29	$ 4.58
3/29/2019	Amazon	NEMA 23 Stepper Motor Driver	1	$ 39.95	$ 39.95
3/29/2019	Amazon	12V Power supply	1	$ 20.99	$ 20.99
3/29/2019	Amazon	Arduino Uno Motor Shield	1	$ 11.99	$ 11.99
3/29/2019	Amazon	Fused power switch	1	$ 6.99	$ 6.99
3/29/2019	Amazon	Timing belt and pulleys	1	$ 13.99	$ 13.99
3/29/2019	Amazon	Cable wrap	1	$ 8.99	$ 8.99
3/29/2019	McMaster-Carr	4" Turntable	2	$ 3.11	$ 6.22
4/5/2019	McMaster-Carr	Sleeve Bearing Carriage for T-Slotted Framing	2	$ 43.51	$ 87.02
4/12/2019	Amazon	Buck converter (voltage step down, 8 pack)	1	$ 10.99	$ 10.99
4/12/2019	Amazon	20kg Servo	1	$ 13.29	$ 13.29
4/12/2019	Amazon	24V Power supply	1	$ 20.61	$ 20.61
4/15/2019	Heiser	Extension Cord	1	$ 9.99	$ 9.99
4/15/2019	Heiser	Plug Strip	1	$ 14.99	$ 14.99
4/15/2019	Heiser	Fasteners	4	$ 0.28	$ 1.12
4/15/2019	Heiser	Fasteners	4	$ 0.33	$ 1.32
4/15/2019	Heiser	Fasteners	4	$ 0.10	$ 0.40
4/15/2019	Heiser	Clear tote w/lid	1	$ 3.59	$ 3.59
4/17/2019	Amazon	Adjust-A-Cup	1	$ 12.71	$ 18.70
4/19/2019	Amazon	FS-20W 20KG Servos	2	$ 13.29	$ 26.58
4/24/2019	Amazon	Arduino Uno Motor Shield	1	$ 11.99	$ 17.98

4/30/2019	McMaster-Carr	Spring Tab Drop-in Fastener	20	$ 1.46	$ 34.35
4/30/2019	Amazon	Push measuring cups	2	$ 12.71	$ 25.42
5/2/2019	Amazon	12V Nema 17 Stepper Motor	1	$ 17.59	$ 23.58
Total					**$ 1,082.16**

Appendix D: Final budget

Category	Cost
Former	**155.42**
Robotic arm	**389.73**
Mixer	**155.9**
Shared	**381.11**
Grand Total	**1082.16**





Appendix E: Forming Mechanism

This mechanism was removed from the machine as a drop cookie does not need a specific shape and the mechanism as designed did not reliably produce a ball. The paragraphs below were removed from the report but retained for informational purposes

The spiral disk method, **Error! Reference source not found.**, was discovered through research a nd quickly showed potential for the project. The dough ball is placed into the center of a spiral shaped wall on top of a rotating disc. The dough is forced around the wall as it clings to the disc and as it rotates is shaped into a cookie ball. The design itself is mechanically simple and easy to manufacture while introducing engineering concepts such as centrifugal force, motors, and friction. This design is visually intriguing and easy to highlight with lights as well as mechanically easy to manufacture and clean. The mechanism can be designed to consist of large, geometrically simple pieces that are durable, open (allowing sanitation), and allow full visibility of the dough to showcase manufacturing. Flour can be introduced into the system to minimize dough stick and ease the rolling process with no effect of cookie taste or harming baking qualities. Exact design and production are currently in the development stage and this method is intended to appear in the final product.

Figure 29: Spiral Disc Concept shown with extruder and cutoff mechanism. This extrusion method will be mimicked by the push bottom measuring cup and wire

The transferring dough of the dough must integrate smoothly with the forming module to effectively produce a cookie. Cookie dough tends to stick to the container that it is mixed in. The initial concept of removing the dough from the mixing container was to introduce a rotating wire shape. This shape would mimic the form of the mixing container cross section and rotate to effectively scrape the dough from the surface of the container. When inverted this design would allow the dough to take advantage of gravity and separate from the container. A wire, using minimum surface area, when compared to a fin or scoop, would allow most of the dough to fall cleanly from the container into the forming mechanism. This mechanism, although effective, involves many moving, complex parts and limited time did not permit the implementation of this method.

The dough ball should be placed on a final cookie sheet in ordered to be baked into a cookie. Using the current method of forming, the dough would be rolled into a ball. This ball can be easily directed into a variety of retrieval mechanisms. Currently the intended design is to output a dough ball in method like a gum-ball machine. The dough ball rolls into a retrieval pocket where it can be retrieved at a specified location and be manually placed onto a cookie sheet for baking. This would allow the user to experience direct contact with a product that they have designed and enhance the connection that they have to the processes involved, taking their inputs and using mechanical processes to produce something tangible and personal.

The forming mechanism works very well when small amounts of dough are used. While designing, an error in calculation caused the pitch of the spiral to be too small. Time and financial constraints did not permit the re-machining of the spirals this semester. In future iterations of the mechanism, the spiral pitch could be increased so that a ball of dough 1.5” diameter can easily fit through the channel with extra clearance. This may increase the required size of the rotating disk. The current base should be able to accommodate the increase in dimensions and the existing guard ring can be bored out to fit the larger disk. The fixture plate that was used to create the forming mechanism plates can still be used to produce more pieces and is stored in the Ottensman Hall machine shop. If the spiral disks are to be re-machined, it is advised to machine one solid piece rather than create multiple plates to be stacked. This will improve the assembly time and prevent buildup of flour between the plates.