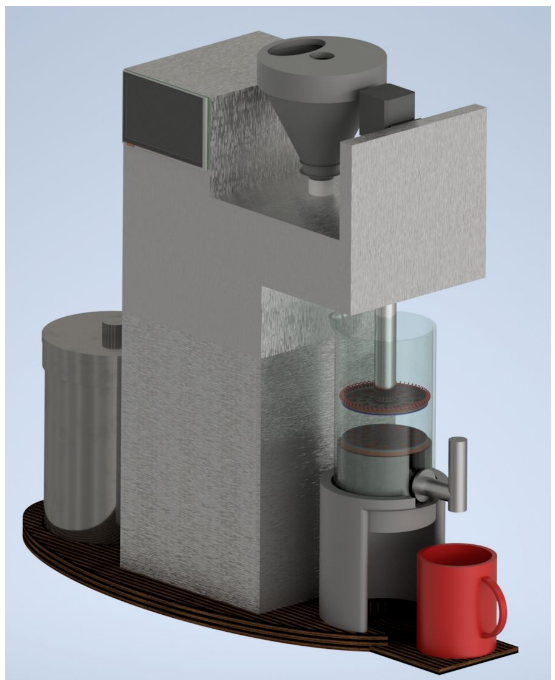
24-671 Electromechanical System Design
Automatic French Press Machine

Final Report



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Group 4 (Team Caffeine)

Libby Armon
Kushagra Varshneya
David Oke
Christian Teixeira

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Executive Summary

With the recent advent of different kinds of automatic coffee makers, it's clear the at-home coffee market is burgeoning. Fulfilling the needs of the average consumer, competitors such as Keurig and Nespresso have flooded the market with standard pod coffee makers providing the exact same experience time and time again. On the other end of the spectrum, pricey complex espresso makers, such as the Breville Barista, allow for coffee drinkers to make almost any kind of coffee imaginable but comes with a hefty price tag of 1000$ not to mention all of the maintenance required to keep it running. Thus, the automatic coffee market needs an affordable but customizable option to fulfill the middle of the road consumers needs. With an Automatic French press, we could meet the customer segments and deliver an elevated coffee experience.

In the end, our final design consisted of 6 subsystems: water heater, pump, grounds dispenser, press, spigot, and user interface. Initially, the consumer would enter there coffee brewing preferences, such as temperature, strength, and serving size. Once the microcontroller has received the brew settings it would turn the heater on until the water has reached the desired temperature. Once this is complete a peristaltic pump, and a helical screw grounds dispenser will begin operating in an alternating sequence, dispensing both the water and the grounds into the brewing chamber. As soon as the number of cycles needed to deliver the intended amount of water and grounds is complete the press will begin to slowly squeeze the grounds while the steep. Finally, the consumer will be able to open the spigot and dispense as much coffee as they desire.

In the end, this design was able to fulfill the customer needs we identified, although not perfectly. Overall, our intended order of operations worked and was able to create a customizable brew of coffee but it was unable to be consistent. With the integration of so many subsystems, tight tolerances were needed to ensure all ingredients could cleanly be delivered to the brew chamber. Sadly in practice, this was difficult to perform without industry-standard manufacturing practices. However, issues such as these are common for prototypes and could be addressed with a large scale production operation utilizing six sigma and lean practices. Thus, with a little more development, this product can be made into a successful consumer-grade automatic coffee maker.

Problem Definition

Problem description

The market space for automated coffee solutions is vast and includes households as well as office workspaces seeking to boost employee morale. Usual automatic coffee makers can only produce one version or several similar versions of a cup of coffee. Aficionados prefer to have control over proportions and material to customize for their taste needs which can be easily done with a french press. Sadly there are essentially no automatic french press machines that are feasible for household consumers to purchase. Therefore, a large market gap exists for an automatic french press that is affordable enough for the average (cup of) joe.

Primary competitors

In terms of our competitors, we face no direct competition for a product with our planned functionality and pricing. However, other automatic coffee brewing solutions do exist. For instance, Keurig, and Nespresso are examples of indirect competitors. Their products serve the people who prefer fast low effort coffee. On the other end of the spectrum, automatic espresso machines, such as the Breville Barista, offer a more complete experience for the most serious of coffee lovers. Products such as these cost upwards of 1000$ putting them out of reach for the average consumer. All in all, most of our product's competition is indirect due to other comparable products fulfilling the needs of different market segments.

Assumptions

When using the automated french press its is assumed that the user has access to a power source, water and coffee grounds. The eventual user of our product will be expected to maintain the water in the tank, and the grounds in the container for daily use. From time to time, the final user will also have to remove and clean the brewing chamber, bean container, and various nozzles. In terms of constraints, our product is designed for personal use in any ordinary kitchen, constraining the size of our final product to something that would fit on an ordinary countertop. On top of this, components of our french press have to be removable for easy cleanup. Finally, our most important constraint has to be price. Making a product for household consumers requires the price not be too high, however, due to our better performance than Keurig type coffee makers our price can be more than their typical offering.

Stakeholders and Customer Needs

Stakeholder Identification

As identified previously, we have defined our major stakeholders as coffee consumers, businesses, and niche coffee growers. Coffee consumers and niche coffee growers would directly benefit from our product: consumers will have more choice in and customizability in terms of their experience, and niche coffee growers will be able to sell their product to people with our product. Businesses can benefit from our product as it can save them money on their coffee-related expenses.

Customer Needs

External Outreach

View our Surveys & Responses: [Customer Survey Responses]

There were several key results we took away from our customer needs surveys. Our customers wanted low cost, variety, and pre-grounded coffee. These coupled with other small takeaways helped us form perspectives on what our customers would appreciate.

As evident by the survey results, the cost was an overwhelming problem in responses with 93% of surveyors in one survey saying it's their least favorite thing about getting coffee outside of the home. Consequently, we strived to build a french press that was affordable in the long term and also provided variability in brewing. Although there is an upfront cost, by our estimations, consumers can recuperate the cost within 3 months.

Another takeaway from the surveys was the need for variety in brewing. Variety in coffee is what drives consumers to get coffee outside their homes. Homemade drip coffee although convenient lacks the variability you can get at coffee shops like Starbucks or La Prima. You can't brew the coffee to your own preferences and although Keurig exists, they don't produce fresh coffee which tastes far better. To help satisfy this need, we added variability to our brewing.

The 3rd takeaway we discovered which couples well with the previous two and came as a surprise to us was the preference for pre-ground coffee over coffee beans. Initially, we had planned to incorporate a grinder in our system to make freshly ground coffee. Although having a grinder would have enhanced variability, it would also have greatly increased system complexity, design, and cost. So when we discovered the majority of consumers don't mind pre-ground coffee, it came as a win-win to us. We were able to still satisfy our customer's needs and also narrow the scope and complexity of our project. As a result, we decided not to include a grinder in our system even though originally we felt it was a great idea which goes to show the importance of researching and verifying customer needs.

Organization & Classification

From the customer surveys as well as internal team discussions, we were able to generate a list of needs we felt would incorporate customer requests and what we felt was achievable by the final Design Expo:

Table 1: Customer Needs

Category	S.No.	Need
Drink Making	1	Ability to Customize
	2	Control over Coffee Temperature
	3	Control over Press
	4	Control over Proportions
	5	No need to refill water for every cup
User Interaction	6	Easy Cleaning
	7	Good UI
	8	Quiet while Processing
	9	Good Looking
	10	Low Preparation Time
	11	Ease of Use
Safety	12	Safe Moving Parts
General	13	Lightweight
	14	Small Size
	15	Low Cost
Maintenance/ Cleaning	16	Sanitary Storage and Handling

Drink making: Drink making encompasses all the needs in variability that consumers want control over like coffee temperature and the amount of pressing time. We felt these were important because they were all available with a traditional french press and so we don't want to limit the capabilities of the french press; just automate them.

UI: (User interface) takes into account the problem defined by us and the desire of the consumer for automation. Our machine should require as little as possible human help to function. At a lower level, this includes a simple preference selection system (i.e temp, brew time & concentration), automatic press, aesthetically pleasing, and non-disruptive (i.e. low noise).

Safety: Safety is a requirement determined internally. Since we are dealing with liquids and food that people digest, we have to ensure all our components are food grade to avoid contamination and health risks. We also have mechanical and thermal risks like spinning motors and hot fluids that we need to ensure function properly and safely.

General: Also as general requirements, we want a light-weight and small volume project. As engineers, we want to optimize everything we build and that goes for our french press. Since surface area on kitchen countertops is limited we don't want to take up more space than is required.
Maintenance: And finally, if time permits, we intend to implement a self-cleaning system to improve the maintenance and sustainability of the whole system.

Target Specifications

Mapping of Customer Needs to Metrics

Table 2: Needs to Specs Matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18
N1																		
N2																		
N3																		
N4																		
N5																		
N6																		
N7																		
N8																		
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Competitive Analysis

Table 3: Competitors

Product, Price and Market Availability	Operating Principles	Key Functional Elements	Potential Drawbacks
Keurig $100 Available for Purchase	• Environment: Household and office • Speed: 40 second coffee • Variety: Unlimited options	• Wide variety of options in pods • Detached water tank	• Powdered milk • Limited brew style
Nespresso Latte Maker $400 Available for Purchase	• Environment: Household and office • Speed: 40 second coffee • Variety: Cappuccino, latte and espresso	• Fresh Milk tank • Detachable water tank • Efficient capsules	• Need to fill milk container • Limited coffee style • Must purchase Nespresso Capsules
Automated Coffee Maker $4800 Available from commercial retail sites	• Environment: Cafe, office or hotel • Speed: 30 second coffee • Variety: 8 options	• Easy button interface • Efficient capsules • Rated at 80 espressos/hr • Grinds beans fresh • No training for baristas	• Relatively large 13*11*36.5” • Costly

The above table shows the similar products that are available on the market for consumer use. These products range from $100 - $5000. Even with the plethora of products available on the market, there are very limited automated french press machines available. We aim to target this niche market with our product.

Target Specifications

Table 4: Technical Specifications

Metric #	Need #	Metric	Units	Importance	Marginal Values	Ideal Values	Keurig	Automated Coffee Maker
1	16	Cost	$	5	200	100	100	4800
2	11	Brew Time	minutes	5	5	4	0.66	0.5
3	11	Setup Time	seconds	5	15	10	10	10
4	7, 15	Footprint Size	Sq. ft.	3	3	2	1	2
5	8, 10	Good UI	Subjective	3	-	-	-	-
6	2	Brew Temperature	degree Celsius	5	93	93	-	-
7	1, 3	Ability to Control Compression	Binary	5	yes	yes	N/A	N/A
8	1, 4	Ability to Control Final Grind Size	Binary	5	yes	yes	N/A	N/A
9	1, 5	Precision	ml	5	15	5	-	-
10	7, 17	# Parts to be Removed	#	3	8	0	1	-
11	7, 14	Weight	lbs	3	8	5	-	-
12	6	Tank capacity	L	3	1	1	1	1
13	10	Aesthetics	Subjective	3	-	-	-	-
14	9	Sound Level	dB	3	50	30	-	-
15	1	Ability to Customize Drinks	Binary	3	yes	yes	yes	yes
16	1	Ability to Queue Drinks	Binary	1	no	yes	no	-
17	13	Food-rated Parts	Binary	5	yes	yes	yes	yes
18	13	Secured Moving Parts	Binary	5	yes	yes	yes	yes

Concept Generation

Functional Decomposition

Figure 1 `: Functional Decomposition

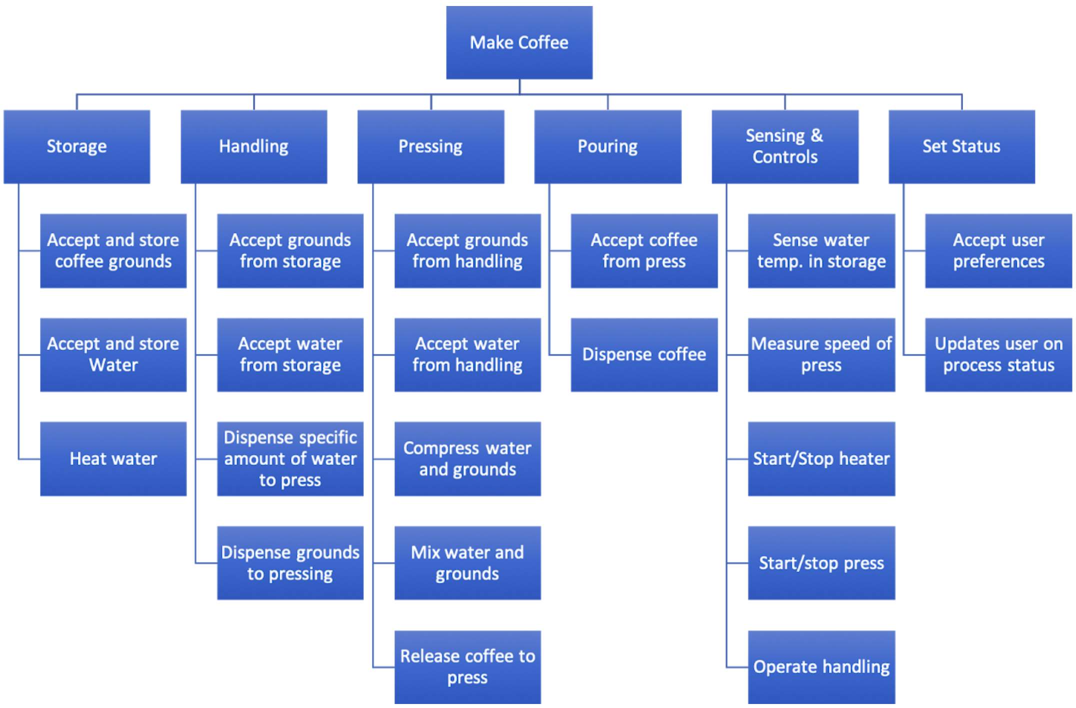
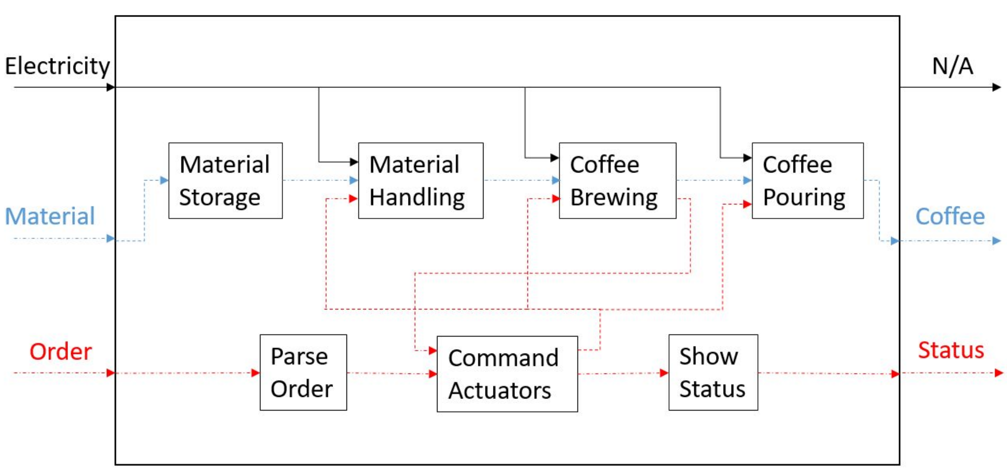


Figure 2: Flow Decomposition



Above are our functional and flow decomposition trees that outline how we break down the functional process of taking coffee grounds, water, and user input to automatically dispensing a cup of fresh coffee.

Storage: We first have our storage function which is where we accept materials from the user. In this function, we heat the water to the specified temperature given in another function and move the material on to the handling function.

Handling: Handling acts as the intermediary between storage and the pressing system. Physically, this function will consist of some variation of a transport system (i.e gravity dispenser, helical screw, and/or pump). Initially, such a function may seem fairly trivial but after some analysis, the ability of the system to move components is essential to its success. If one transport location fails, the whole system fails. That's why it was essential to us that we considered the most effective way to implement our handling system.

Pressing: Next and most importantly in the functional tree is pressing. Pressing takes in the heated water and coffee grounds from the handling system through a specified procedure. From there on, the press function compresses and mixes the water and coffee grounds together. The function for variability in the press takes place under the sensing and controls branch so, from a higher level, the pressing function is only meant to accept, press and release the results to the pouring function. We separated the computation and "thinking" aspects into S&C

Pouring: The pouring function is fairly straightforward in that it accepts the prepared coffee from the press. After this, it automatically dispenses the coffee into a container specified by the user (i.e cup or mug).

Sensing & Controls (S&C): Unlike the previously mentioned functions which occur consecutively, the S&C function happens concurrently with all the others. This function acts as the brain of the coffee maker; coordinating other functions in a timely and systematic manner. It's responsible for taking sensor data from the system such as the water temperature or speed of the press, comparing that data with the user's preferences, and adjusting accordingly. It provides the actuator commands to the motors and also the voltage to the water heater.

Set Status: Finally there's the set status function that interacts with the user. It allows them to specify their brew preferences and also displays how far along the process the french press is.

All of these functions coupled together encompass the whole coffee-making process and we believe outline clearly how we get from point A with materials and user input to point B, a nice hot cup of Joe.

Concept Generation Activities

With a functional tree and understanding of the key consumer needs we need to satisfy, we began developing ideas. With a bounty of other comparable products, we took a great amount of inspiration from existing products. For example, the water heater tank is based on a common design feature of many automatic coffee machines. Placing the water heater tank in the back prevents the user from injuring themselves through touching the near-boiling water. Furthermore, keeping the tank low to the ground help ensure stability and safety as the product as a whole. Additionally, our conical grounds dispenser was inspired by a culinary sugar dispenser. Due to the grounds' nature to clump, something like a helical screw is needed to make sure that the grounds are always receiving a force to push them along. Similar products can be seen in professional bakeries across the world as they use similar helical screw set up to ensure an even dusting of powdered sugar. On the other hand, not all of our subsystems are redesigned existing products or copied from similar designs. For example, we designed a self-cleaning spout, coming out of the grounds dispenser, that will be rinsed with each use. To accomplish this we connected the pipes from both the grounds and water delivery to flow down the same pathway so if any grounds are stuck in the passage hot water will be able to wash it out. All in all, we took inspiration from external sources and even used some simple designs to help keep the cost low of our prototype, but our coolest features are products of our own internal concept generation which will hopefully lead to an amazing prototype.

Classifications & Combinations

Table 5: Sub-Function Level Concept Generation

Sub-Function	Category
Water Heater	Electric Coil Gas Microwave
Dry Ingredient Flow	Gravity + Valve Helical Screw Paddle Fed
Wet Ingredient Flow	Centrifugal Pump Peristaltic Pump Gravity + Valve
Storage	Stationary Bins Carousel
Press	Rack & Pinion Linear Actuator Hydraulic Pneumatic
Dispensing	Pitcher Valve/Spigot

We took all our different subsystem concept ideas and bundled them into separate sub-function categories. The main sub-functions we determined were water heating, dry ingredient flow, wet ingredient flow, storage, press, and dispensing. Each one of these serves as an independent module and acts as a black box to all the other sub-functions. Other functions have no dependency on how other works; they're only dependent on what one another produces. This way, the choice of one module has no direct impact on another module. Building our system in a modular manner enables us to decompose our overall problem definition into smaller and more digestible tasks and lets us optimize our design by combining our best ideas.

Table 5: Full Concept Generation

Options	Water Heater	Dry Ingredient Flow	Wet Ingredient Flow	Storage	Press	Dispensing
1	Electric Coil	Gravity + valve	Gravity + valve	Stationary bins	Linear Actuator	Pitcher
2	Electric coil	Pump Valve	Peristaltic Pump	Carousel	Hydraulic	Valve/spigot
3	Gas	Gravity + Valve	Gravity + valve	Stationary bins	Pneumatic	Pitcher
4	Microwave	Helical Screw	Centrifugal Pump	Carousel	Hydraulic	Valve/spigot
5	Microwave	Gravity + Valve	Gravity + Valve	Stationary bins	Rack & pin	Pitcher
6	Electric Coil	Helical Screw	Centrifugal Pump	Carousel	Rack & pin	Valve/spigot
7	Electric Coil	Helical Screw	Peristaltic Pump	Stationary Bins	Linear Actuator	Spigot
8	Electric Coil	Gravity + Valve	Peristaltic Pump	Stationary Bins	Linear Actuator	Valve/spigot

Options	Water Heater	Dry Ingredient Flow	Wet Ingredient Flow	Storage	Press	Dispensing
9	Electric Coil	Helical Screw	Gravity + valve	Stationary bins	Linear Actuator	Pitcher
10	Gas	Helical Screw	Peristaltic Pump	Carousel	Hydraulic	Valve/spigot
11	Gas	Paddle Fed	Peristaltic Pump	Carousel	Pneumatic	Pitcher
12	Microwave	Helical Screw	Centrifugal Pump	Stationary Bins	Hydraulic	Valve/spigot
13	Microwave	Helical Screw	Peristaltic Pump	Stationary bins	Rack & pin	Pitcher
14	Microwave	Gravity + Valve	Centrifugal Pump	Carousel	Hydraulic	Valve/spigot
15	Gas	Gravity + Valve	Gravity + Valve	Stationary Bins	Pneumatic	Pitcher
16	Electric Coil	Paddle Fed	Gravity + valve	Carousel	Hydraulic	Valve/spigot

From there, we generated a concept matrix with 16 different combinations of sub-functions. Although 16 does not encompass all possible permutations, we had a general idea of what ideas we felt would work best and rather than go through 100 concepts permutations, we went with 16.

Concept Selection

Concept Selection Process

Table 6: Pugh Matrix

Selection Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Designer needs																
Minimal complexity	1	-1	0	-1	-1	0	1	-1	0	0	0	-1	-1	-1	-1	-1
System integration	1	0	1	-1	1	-1	0	1	-1	1	-1	0	0	-1	1	0
Customer needs																
Variability	0	1	1	0	-1	1	1	1	1	0	0	1	0	0	0	1
Cost	0	0	-1	0	0	0	1	0	-1	-1	-1	-1	0	-1	-1	1
Small size	-1	0	0	0	1	1	0	0	0	1	-1	1	1	1	1	1
Total	1	0	1	-2	0	1	3	1	-1	1	-3	1	0	-2	0	2

Table 7: Weighted Pugh Matrix

Selection Criteria	Weight	1	3	6	7	8	10	12	16
Designer needs									
Minimal complexity	3x	3	0	0	3	-3	0	-3	-3
System integration	2x	2	2	-2	0	2	2	0	0
Customer needs									
Variability	1x	0	1	1	1	1	0	1	1
Cost	3x	0	-3	0	3	0	-3	-3	3
Small size	3x	-3	0	3	0	0	3	2	3
Total	_____	-1	0	2	7	0	2	-4	4

Assessment & Justification

We generated a Pugh chart to help us systematically determine the best combination of sub-functions from our concept bundling. The set of criteria used in the pugh was simplicity, system integration, variability, cost, and compactness. The design best meeting the needs specified was concept 7: electric coil, peristaltic pump, helical screw, linear actuator, stationary bins, and spigot. When coming up with the final design we had to account for potential problems like clumping of oily grounds, difficulty to remove pitcher and need for modularity.

The water heating method was a simpler system for the coffee maker. The prime concerns were size, simplicity, and timeliness. Using a microwave is not efficient. Conduction plates can be slow. Electric coils, however, are simple, cheap and can compactly fit into the water chamber.

For coffee ground transport we initially considered moving grounds with gravity and having them fall through a funnel directly into the chamber. This method, however simple, had lots of space for failure due to the fact that better coffee grounds are oily and clump together very easily. This would render a passive system like gravity useless and so we went ahead with a motorized helical screw.

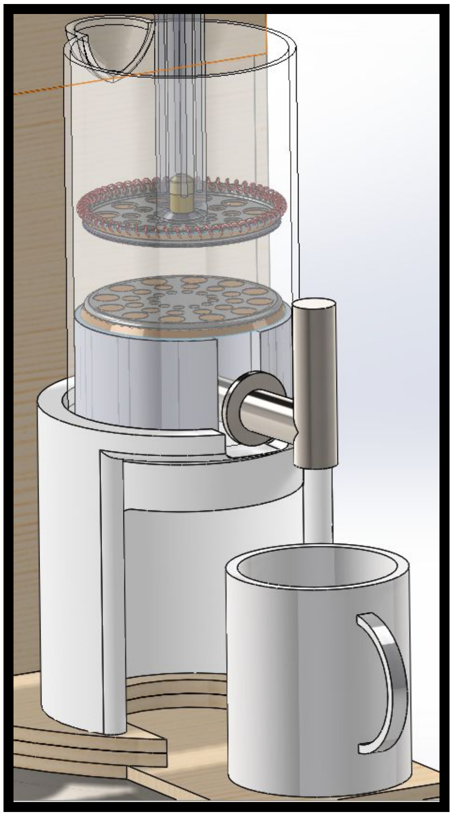
We had a similar debate on water transport; whether it is better done actively or passively with gravity. Ultimately the choice was made for a peristaltic pump due to decreased complexity compared to other pumps rated at boiling temps. The water is being pumped rather than gravity fed since placing the hot water above the beaker leaves room for thermodynamic error and poses safety risks to the users since they may touch the tank. Instead with the pumped method, the water can be placed below the user on level ground where it can be heated safely. This design decision kept complexity low and increased the opportunity for tight, modularized design. The water pitcher will be cleaned with patty removal and water flushing. The water tank should be kept separate due to heating and leakage issues so there will be an active pump rather than using gravity.

The pressing of grounds was also a difficult design choice considering its impact on potential customer lead variability, size of the system, cost, and complexity. The choice was between rack and pin, pneumatic, hydraulic and linearly actuated pressing mechanisms. Ultimately the immediate access to a linear actuator coupled by the large torque offered by a stepper motor made it the best choice.

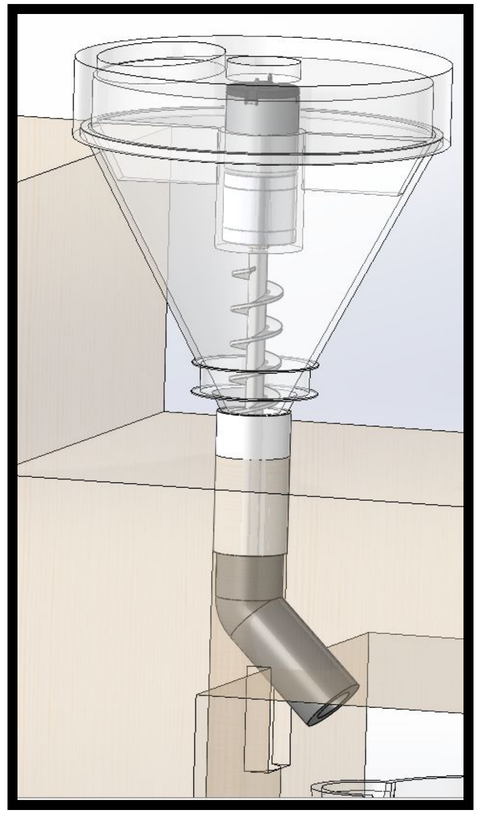
Dispensing the coffee was a system that could easily add complexity to the system so we decided on a spigot which is a familiar mechanism to most consumers.

The final design choice was routed in meeting consumer requests in the best way possible while existing within the realm of our budget and reasonable project scope.

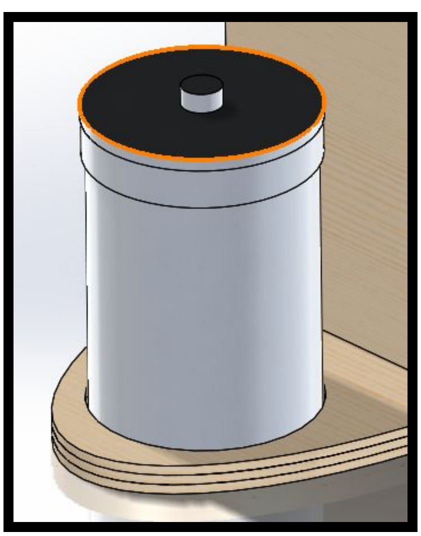
Detailed Models



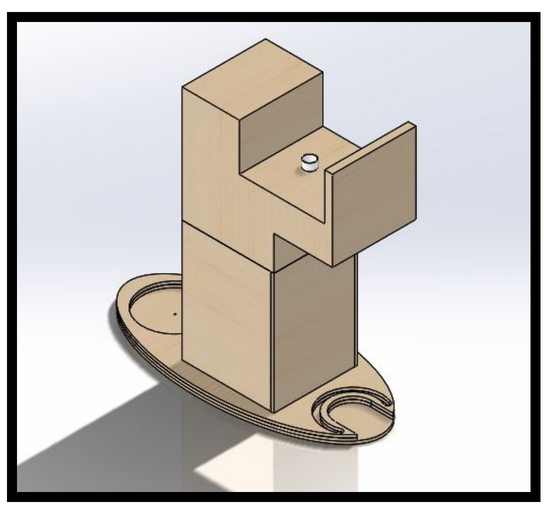
Spigot



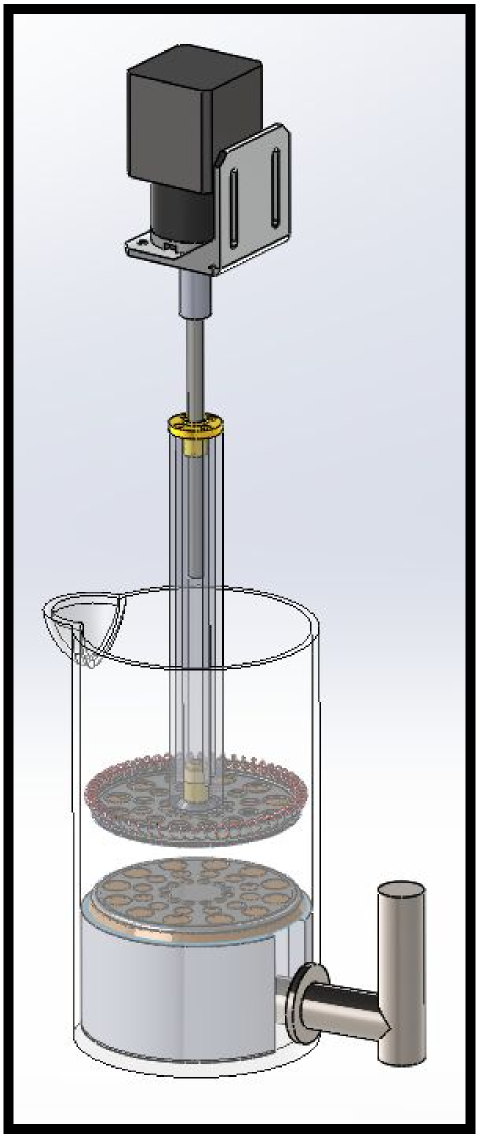
Grounds Dispenser



Heater



Body



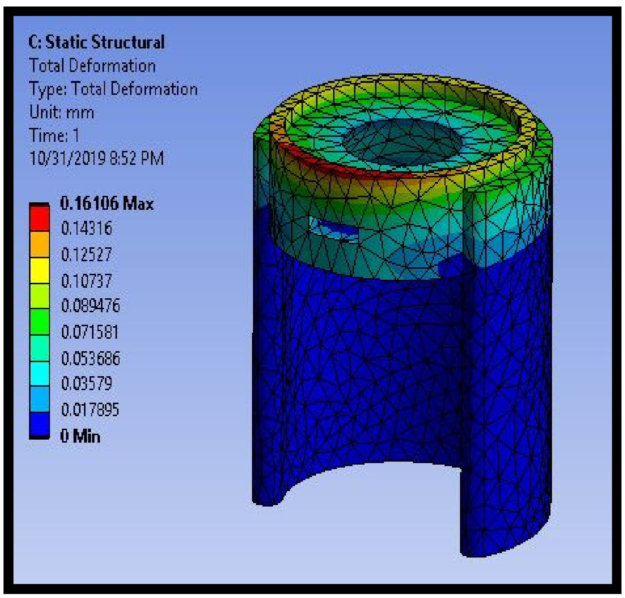
Press & Double Mesh

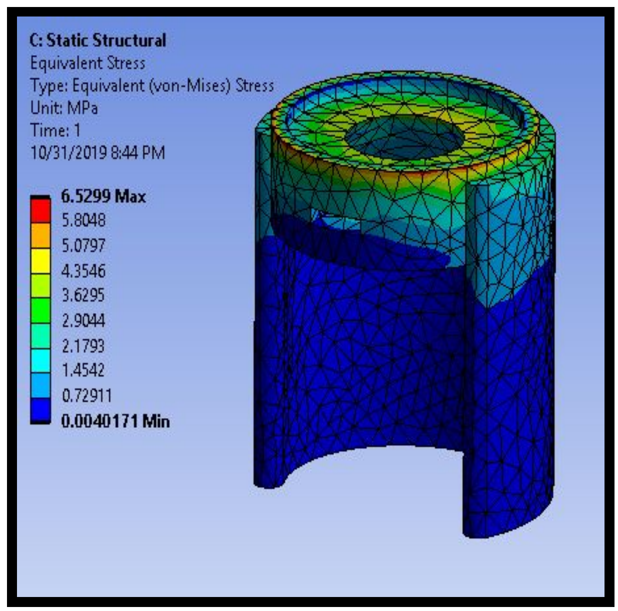
Detailed Design & Engineering Analysis

Details of Engineering analysis and calculations conducted

The following Finite Element studies were set up to measure the stresses in the system and whether they'll cause failure in our system.

Carafe Support FEA

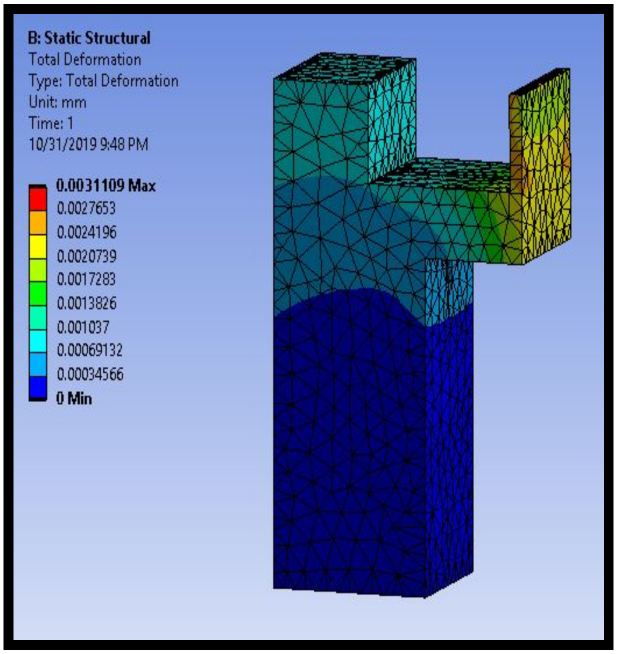


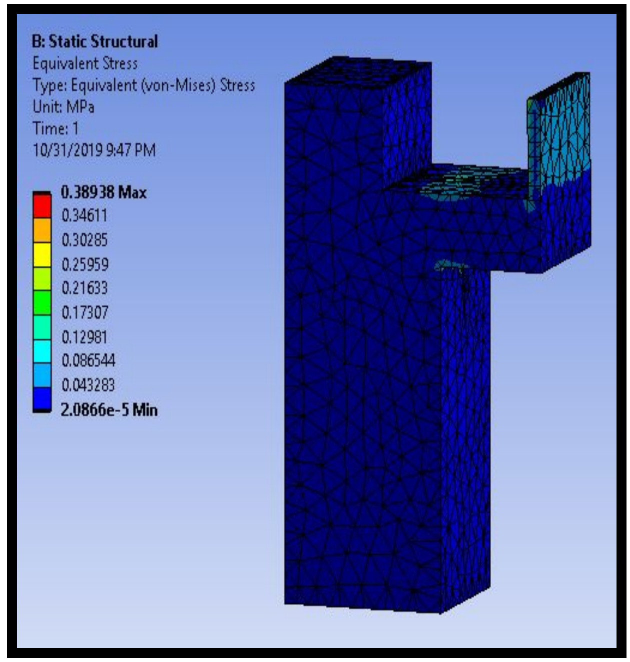


Setup:
A thermal study was set up. The base was given a temperature of 45 °C (insulating sheet between carafe and stand) and a natural convection state was set up for the body. These thermal stresses were pre-loaded into a new static structural study. The body was fixed at the bottom as a rigid support. The weight of the carafe system with the max force applied by the linear actuator was modeled as 100 N. Material for study purposes was taken as ABS and a mesh size of 10 mm was taken.

Result:
The max stresses are 6.5 MPa and max deflection is 0.162 mm. The values are very small with respect to the dimensions of our system and our system will easily handle the load. There is an additional opportunity for us to print the ABS stand with a non-100% infill, thus saving on printing costs and keeping the project under budget.

Body FEA





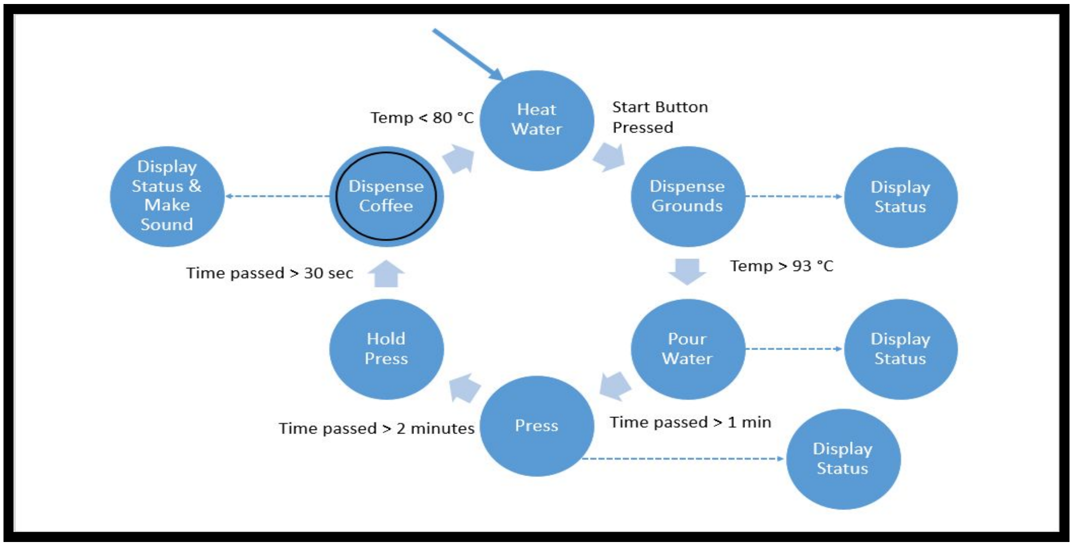
Setup:

A static structural study was set up. The body was fixed at the bottom as a rigid support. Two loads were taken, the weight of the ground dispenser system as 70 N and motor mount reaction force as 17 N. Material for study purposes was taken as Birchwood and a mesh size of 10 mm was taken.

Result:

The max stresses are 0.39 MPa and max deflection is 0.0031 mm. The values are very small with respect to the dimensions of our system and we can easily conclude that our system will handle the load.

Finite State Machine



Heat Water: We heat the water to the specified temperature determined by the user. The user must initiate the process by inputting their preferences and pressing the start button.

Dispense Grounds: As the water is heated up, the grounds are dispensed through the grounds dispenser that leads to the press.

Pour water: Next in the state machine is the preparation of the materials to be pressed. Once the temperature sensor reads 93°C, it triggers the peristaltic pump to move the heated water through the system and to the press. As the water is dispensed into the press, it pushes any leftover coffee grounds that may have stuck to the grounds dispenser tubing. This also allows the coffee and hot water to mix before they are pressed.

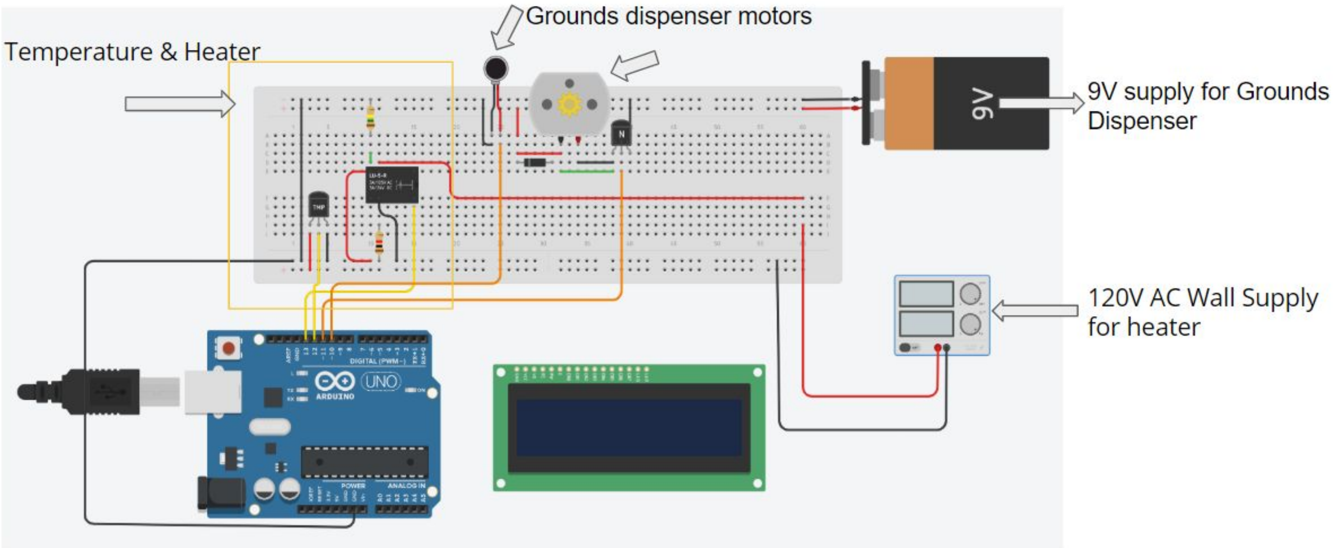
Press: The press begins once the pump is done pumping water. A timer is used to trigger and stop the pump. It runs the pump for an amount of time proportional to the brew size requested by the user. Once that is done, the Press begins to move down, compressing the coffee and water together at a slow speed.

Hold Press: After a certain amount of time has passed of pressing which is determined by the user's specified brew strength, the press holds its current position. This is just an additional step in how french press coffee is made that is also determined initially by the user.

Dispense: Once a certain time has passed, the coffee is ready to be dispensed to the user below. Unlike the previous states, this state is triggered by the user rather than a timer.

Display Status: Meanwhile, as all these states are triggered and occur, an update is sent to the user using a display status. This allows the user to take note of what is going on externally.

Circuit Diagram



Above is the final prototype circuit diagram.

Unlike prototype 1, it includes a greater voltage supply for the heater and also vibrational motors that work within the grounds dispenser. The majority of the components such as the motor and heater purchased operate automatically when provided a high voltage that the Arduino cannot supply. So in order to control these components using the Arduino, we implemented several relay switches and BJT Transistors. These switches and transistors allow us to control these high voltage devices with the Arduino while still being able to give them the different voltage supplies that they need to work.

The temperature heater, for now, is our only sensor and works through a voltage divider of a 4.7KΩ resistor. Arduino and a sensor library handle all the signal conditioning needed to get accurate readings from the sensor simplifying the circuit but also complicating the code architecture.

Not included in this diagram are the connections for the LCD Display to the Arduino that will provide updates to the user and also the circuitry for the stepper motor and driver due to the limitations of tinkerCAD.

FMEA

Function/ Component	Failure mode	Effects	S	Cause	O	Controls	D	RPN
Water Heater	Burning	Fire	8	Wires/ Inadequate heat isolation	6	Easy manual off and using existing pre-tested heater	4	192
Dry Ingredient Flow	Leakage and clogs	No grounds in the coffee	5	Oil in grounds	4	Vibration motors	3	60
Wet Ingredients Flow	Leakage	Electronics being shorted	8	Poor seal	3	Barbed Hoses	5	120
Storage	Helical Screw	Clogs	4	Oil in grounds	4	Vibration Motors	5	80
Press	Alignment	Catching on Carafe	6	Incorrect placement of Carafe	4	Mechanical lip to place carafe	4	96
Dispensing	Clog	Slow Stream	2	Grounds slipping below the mesh	2	Secondary mesh on the dispenser	4	16

The possibility of misalignment in the lip was addressed mechanically with a placeholder for the carafe. Although the piece fit relatively ok there were little alignment constraints to keep the PVC tube from interfering with the press. The risk of grounds clogging up was also reduced via vibration motors that were placed strategically and via channeling the water through the PVC tube. The risks pertaining to the water heater were reduced significantly by using a consumer water heater.

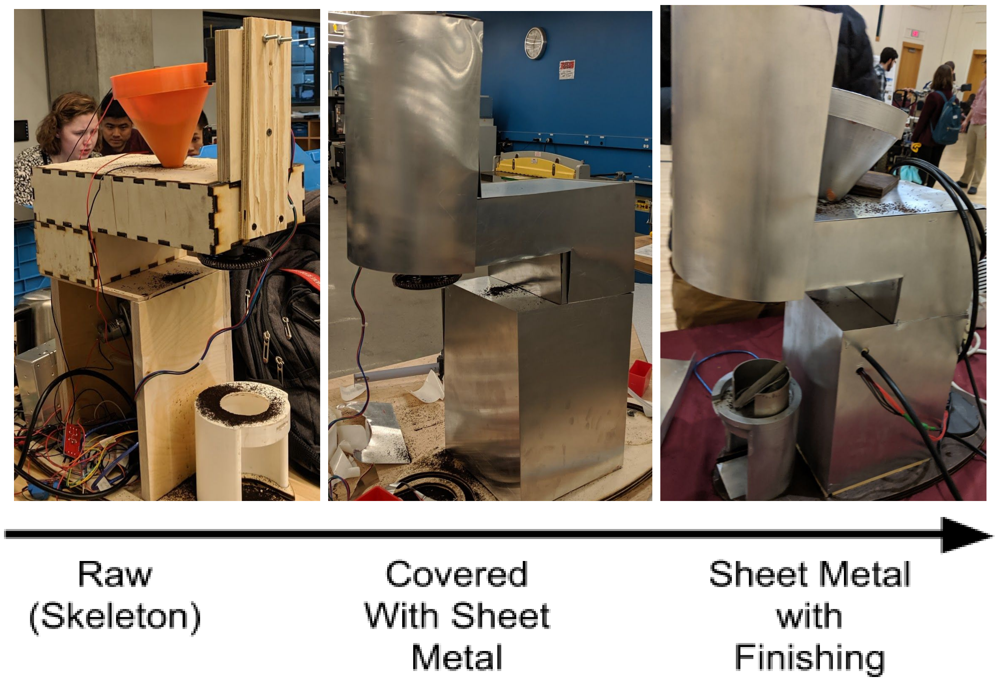
Manufacturing and Assembly Techniques

BOM

Part Name	**Cost**	**Quantity**	**Total**
12V, 1/2' solenoid valve	$39.99	1	$39.99
Arduino Mega	$29.00	1	$29.00
Breadboard wires	$6.98	1	$6.98
French Press	$50.99	1	$50.99
Water heater	$5.94	1	$5.94
Stepper Motor	$13.99	1	$13.99
Water temp. sensor	$9.95	1	$9.95
Stepper Motor bracket	$10.99	1	$10.99
Brass Hose barbs	$3.08	3	$9.24
DC Power Supply	$18.95	1	$18.95
Road Pro Electric Heater	$13.11	1	$13.11
12V Adapter	$6.95	1	$6.95
AC Power Cord	$8.22	1	$8.22
30 gauge wire	$12.99	1	$12.99
12v to 9v stepdown	$7.99	1	$7.99
1L Water Kettle	$20.99	1	$20.99
Coarse Ground Coffee	$15.49	1	$15.49
Wood & Sheet Metal	$70	-total-	$70
3D Printing	$100	-total-	$100
Adafruit Touchscreen	$40.00	1	$40.00
30A Relay	$9.89	1	$9.89

The total budget used is $ 501.65.

Main body manufacturing



One of the challenges in our design we were not sure how to address was the fabrication of the main body. We had a nice and dimensionally accurate CAD model that correctly incorporated all our subsystems together. However, building and assembling such a unique structure that was also aesthetically pleasing and cheap was a problem. We couldn't 3D print or CNC the structure due to the absurdly large cost and print time. We couldn't build it out of metal because the material cost would have put us over budget and the time spent milling would have taken away from other meaningful work we needed to do. Our solution to this problem was to fabricate the structure out of pieces of plywood. For prototype 2 which was our functionality test, we found free available wood in Tech Spark and using laser cutters and drop saw, created 2D profiles. Then we assembled these 2D profiles using wood glue and wood screws. We were able to maintain the structural integrity we needed, minimize the material cost to $0, and get accurate dimensioning for our subsystems. To improve the presentability for our final prototype, we covered our structure with thin aluminum sheets that we cut out. This provided a better aesthetic view for the user than the wood and was also painless to implement. (the process used to cover the part is in the appendices)

Subsystem manufacturing

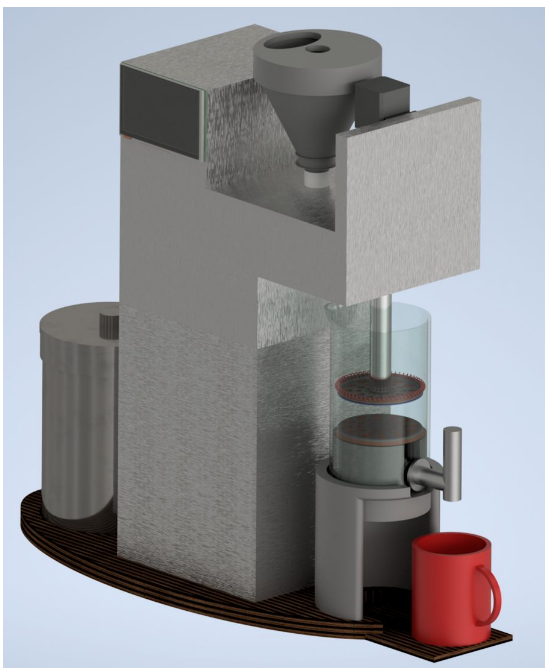
For our different subsystems, we 3D printed our grounds dispenser, carafe holder, and linear actuator parts. These geometries were small enough to print but too complex to manufacture through conventional means (i.e milling, lathing, laser-cut, saw etc). The rest of our components like the carafe, heater, motor, and electronics were purchased and then assembled based on our CAD model.

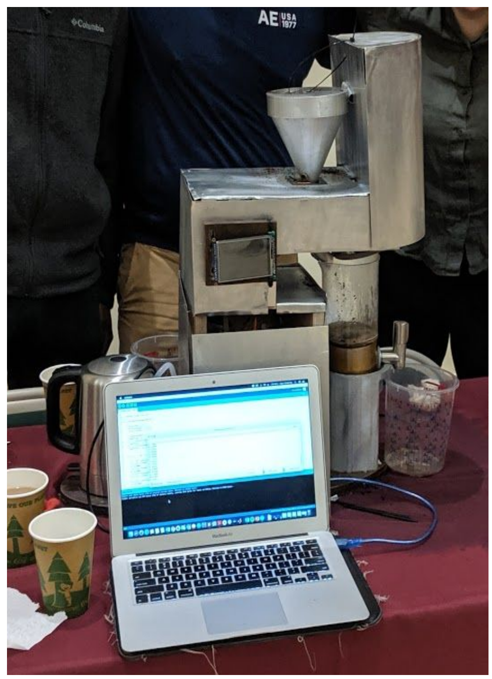
Mass Production

For the purposes of mass production, we would switch to a plastic body and have the body injection molded in pieces. The plastic body will have threads inbuilt for us to mount our electronics and other components. We would also use a custom PCB which would have our code and all the required connections.

Final Prototype Description

Demonstration of Design





Full system video demonstration:
https://drive.google.com/file/d/1CY1-2xE-76RqIJKxqXK1BuhBCcLc5trG/view?usp=sharing

Testing and Results

The way we designed our system allowed us to verify the functionality of the whole system by verifying each sub-function separately. We conducted tests on each subsystem separately in prototype 1 and tested the system as a whole in subsequent prototypes and the results of those tests are discussed below:

Water Heater

We implemented and tested a 12V heater initially. What we took away from our tests is that although a 12V heater is convenient and safe, 120W does not supply enough heating power. We would like to heat up our water in under 5 minutes as supposed to 20 minutes unless we would not meet our target specifications. As a result of all of these takeaways. we decided to purchase a 10x more powerful heater that came with thermal insulation, an integrated heater container, and an easily detachable container to refill the water. We also purchased a 30A relay to handle the high current and large voltages from the water kettle.

We re-ran our heating tests with the new and improved water kettle and compared the data to that of our previous heater test.

Figure 2: Heating test with new water kettle

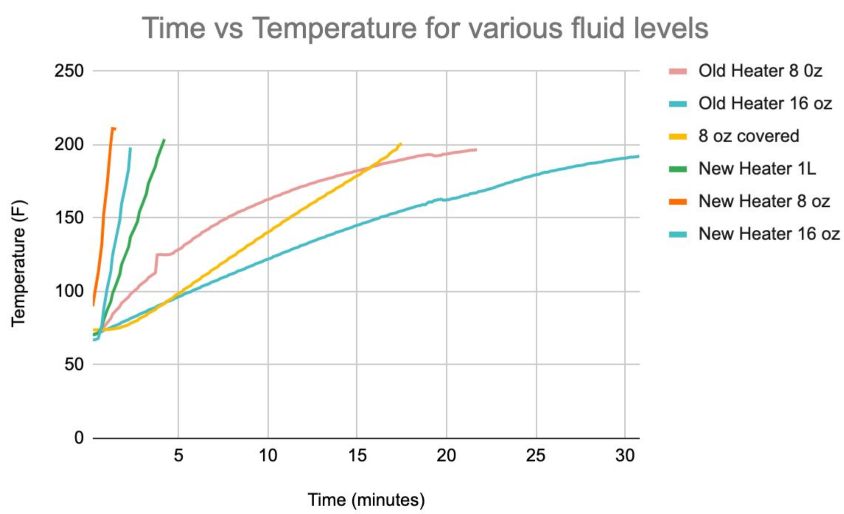
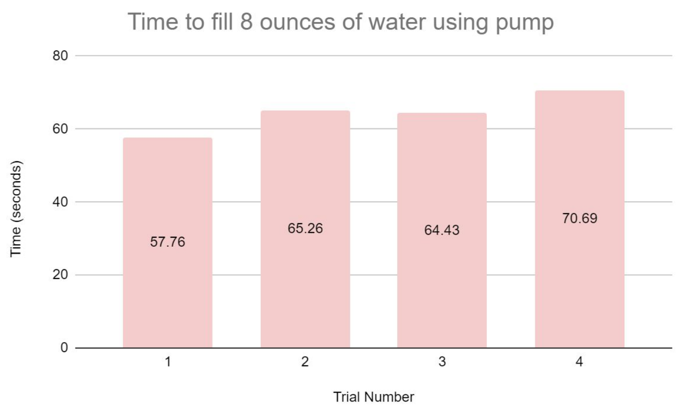


Table 2: Old heater vs New Heater

Old Heater		**New Heater**	
Amount	**Heating time [93 °C]**	**Amount**	**Heating time [93 °C]**
8 oz. covered	17 min	8 oz.	1.5 min
8 oz.	22 min	16 oz.	2.3 min
16 oz.	32 min	1.1L	4.1 min

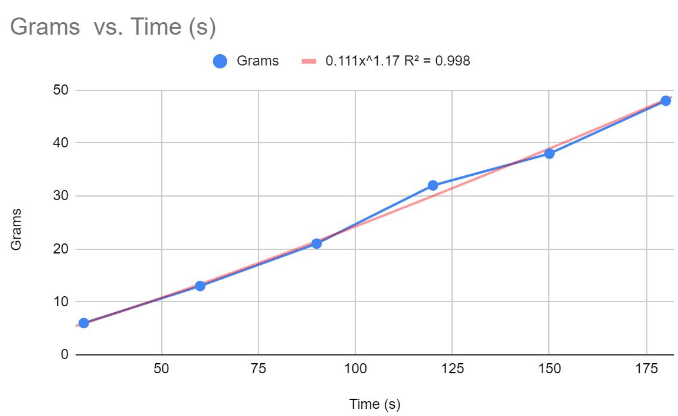
Peristaltic Pump

For the peristaltic pump, we found the average time to pump 8 oz. of water was ~1 minute which keeps us on track with our target brew time of 3-5 minutes. As a consequence of these results, we planned to implement the same pump in our prototype 2 and also our final prototype. We installed the pumps and tubing securely on our housing; something we did not do in prototype 1.



Grounds Dispenser System

As for the grounds dispenser system, we initially ran into some blockage with the coffee grounds sticking and clumping together. However, with the design modification of additional vibrational motors, we were able to resolve this issue. This resulted in a grounds dispensary that could efficiently and dependably supply enough coffee grounds to the press system for different brew sizes. The pump also puts water in the same tube further restricting the grounds from being clogged up.



Press & Linear Actuator

The stepper motor for the press was mounted on the system properly and a force analysis was conducted to measure the max force put by the press on the carafe. The max force was found out to be 12N, which is good enough for our press operation and the stresses on the system.

Final Prototype

For the final prototype, we combined all our findings to create the perfect french press machine. The data we collected was implemented in our code for smooth operation. The final prototype was then tested at different settings to check if the product is doing what we need it to do with the user input. The brew time for an 8 oz cup is 3 minutes from scratch, and it could be faster if we only heat up the required water instead of the whole kettle.

Conclusions

What we learned

Some of our key takeaways from this project were the importance of preliminary design, manufacturability, and scope.

Looking back on our final prototype, we feel that more time could have been spent not just making our system work, but making our system work well. Our project planning and steps we took from the initial design to a final prototype allowed us to produce a functional system at the end. However, we experienced a lot of final system integration problems such as aesthetics, UI, wire bundling and subsystem functionality that we didn't anticipate. These were all problems we did not address thoroughly in our preliminary design that came up at the end. If we had concrete solutions early on in our design phase rather than pushing them off until the end, we would have produced a more successful product.

Another key takeaway from this class was the importance of manufacturability. The CAD model of our main body was very clear and simple but was very difficult to build and make presentable. We optimized its design to hold all our subsystems but pushed off how we would manufacture it until the end. This proved not to be the best choice in the end during our final preparations. So it's important not to just design systems and parts from a design perspective but also from a manufacturability perspective as well.

Our final takeaway was the importance of scope selection. Professor Bergbreiter touched upon the importance of selecting a reasonable scope for our projects because we should be realistic about what it is we can achieve in a semester. This turned out to be very important for us, especially being a 4 person team. If we broadened our scope by adding additional components like milk storage or a grinder, we would have likely been overwhelmed and unsuccessful. However, by simplifying our task and narrowing our scope to something we were capable of doing, we produced a functional prototype in the end.

What we would do differently

The final prototype successfully met the requirements to dispense customizable french press coffee that was drinkable. Although difficult, all the parts that came in contact with the coffee and water were food grade and durable. The exterior of the coffee maker was redone to match the first prototype design which had a curved top. Initially, this design seems unachievable, but by rethinking the parts a cosmetic solution was reached. Sheet metal with brushed effect helped meet the initial constraint to design something aesthetic that resembled a kitchen appliance.

The User Interface and reliability of the machine fell short in the final deliverable, as well as the integration of autonomous cleaning. The UI initially was an Arduino touch screen with various customization settings as well as active updates on the status of the machine. Unfortunately, when transferring the screen onto the body of the coffee maker the part stopped working. Accordingly, the UI was changed to a prompted user input on a laptop. This solution was far from ideal and resulted in unreliable results as the code was changed just prior to the expo. The computer prompted input did meet the constraints of having a customizable brew. What we would have done differently is either test out the touch screen earlier in the semester or used a simpler user interface such as an LCD with push buttons.

The cleaning cycle of the coffee machine was also never implemented due to a set back once the original carafe broke. Although unfortunate that a part broke it was obvious that the timeline constructed was not followed since time was not available to account for this mistake. If the project were done again time would be allotted for accidents and the Gantt chart would be adhered to more closely.

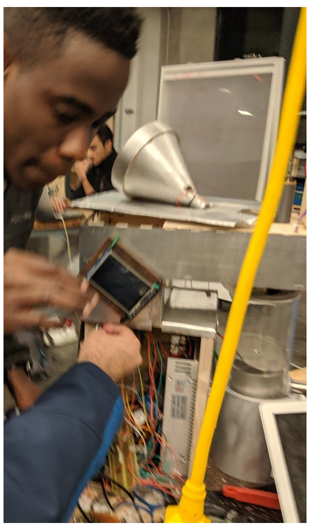
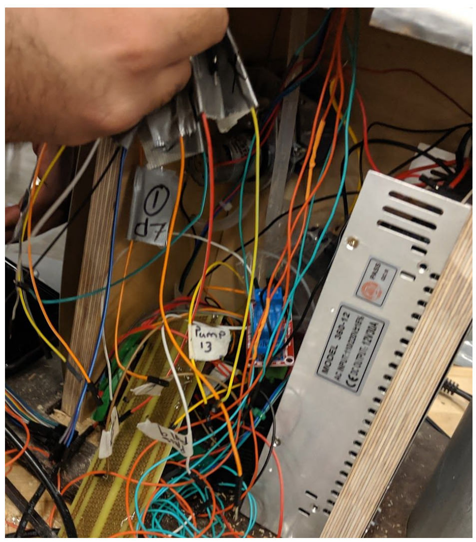
With continued investment in the project, there would be a functioning touch screen UI, cleaning cycle, electronics isolation from metal, better wire management and a more stable way to hold the carafe.

Appendices

Exterior Design

The exterior of the coffee machine was adapted from Prototype 2 to resemble conventional kitchen equipment and increase aesthetic likeability. To improve appearance 6061 aluminum was cut and bent around the skeleton of the coffee maker (made of wood) and secured in place with folds and metal staples. The aluminum was then finished with a wire brush and fine-grit sandpaper to give it the appearance of stainless steel

User Interface

Designed Settings :

Size	8 oz	16 oz	24 oz
Temp	93 C	95 C	98 C
Press	Fast (strong brew)	Medium	Slow (weak Brew)

The user interface was originally designed with touch screen input using the above table. Touch screen is more intuitive for people now and makes providing system feedback seamless. As the water heats, pump fills the carafe, and press engages the user is constantly updated on the status of the operation. The touch screen in actuality stopped working once attached to the coffee machine, however prior to combining the UI and body, we received positive feedback on the interface. Since the screen stopped working the UI was changed to a prompted user input in the Arduino command window, where a person could enter the settings for their coffee.

Arduino Code:

https://drive.google.com/file/d/18RmAdDh5TO-zGhZKRWOrsQdWQG75U6v0/view?usp=sharing