

Milk Dispenser for Variable Fat Content

by

Julie E. Henion

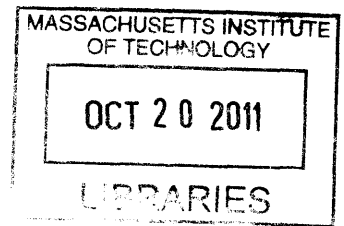
Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of

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ABSTRACT

This thesis describes the development of a new milk dispenser product that is designed to dispense milk with varying levels of milk fat content. The product contains two tanks of milk, one containing skim and one containing whole. The user can rotate a dial to select which type of milk they want (skim, 1%, 2%, whole) and the product is able to mix the skim and whole milk at the appropriate ratio to dispense the desired type of milk.

A prototype was developed that uses two, gallon-size milk jugs, each attached to a flexible tube at the cap interface. The flexible tubes pass through a ratio selection mechanism that the user can rotate to select the desired type of milk. The mechanism compresses the tubes to achieve the appropriate ratio, and finally the tubes pass on through to a dispensing valve.

The prototype was tested using clear water in one tank, and colored water in the other to visually observe how well the product mixes. The final prototype was able to mix quite appropriate ratios with sufficient precision in milk fat ratios.

Thesis Supervisor: David Wallace
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Introduction

1.1 Idea

The idea for this product came out of the kitchen of an undergraduate MIT living group, French House. An elected officer called the food steward is responsible for ordering food to keep the kitchen in stock, including four kinds of milk (skim, 1%, 2%, and whole) to appease the varying tastes of the members of the house.

The scene begins late one typical mid-semester evening. Several members of the house are working tirelessly on their problem sets in the French House dining room. One member decides to take a study break and grab a few cookies and milk. The student opens the fridge to find five gallons of milk, but among the five gallons, there is not a gallon of 1% milk, the student's milk preference. The student proceeds to complain to the food steward, who is already stressed, that there is "no milk in the house" and we need to buy more. This is the moment that the idea to mix different types of milk to create an intermediate type was born.

The product concept in its original form was some sort of large tank with compartments for both skim milk and whole milk. The user selects which type of milk they would like, and some sort of internal mixing device mixes the milk to the correct ratio, delivering it to the user. Figure 1 shows the original concept sketch as drawn for 2.009, MIT's senior product design class.

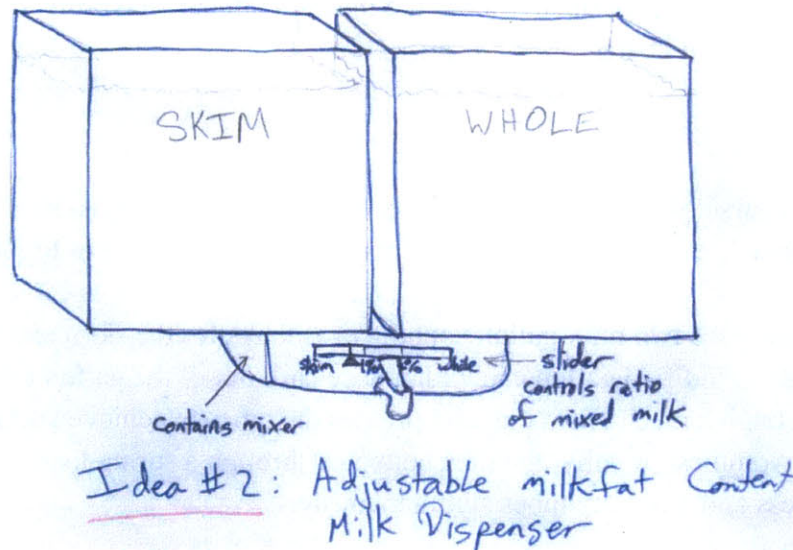


Figure 1: Initial Concept Sketch

1.2 Need

This product benefits both the milk purchaser and the consumer. On the purchaser side, there is a time savings in determining exactly which milk to buy. They only have to keep two types

of milk in stock instead of four. Also, there is a reduced chance of milk going bad since without the product there might be a kind that is less popular and sitting around for a long time, but with this product, the whole and skim milk will be used up twice as fast and much less likely to go bad. It is also more cost efficient to buy a gallon of each skim and whole milk than a half gallon of four types of milk, since the unit price of milk is smaller when you buy larger quantities. (For more information about milk pricing, see section 1.5.2)

In addition to the benefits that the purchaser sees, the consumer benefits by always having the exact type of milk that they prefer available to them. With all these benefits for the purchaser and consumer, it's clear to see why there is a need for the product.

1.3 Thesis Goals

At the beginning of the semester, I set an ambitious timeline to complete the project. The goals were to:

- Investigate the product concept and its need in today's market.
- Develop sketch model prototypes to confirm
- Test sketch model with users to get feedback
- Build a second mockup prototype improving upon the flaws of the first
- Test this prototype with users

See *Appendix A: Scheduling* for details about the plan to complete the project during a single semester, including a Gantt chart.

1.4 Summary

During the course of the semester I was successfully able to build a mockup prototype and test it with users to get their feedback. The final prototype is shown in Figure 2.

The prototype uses two milk gallon containers as tanks for the skim and whole milk. The milk travels through a modified gallon cap with a hose barb out of the gallon into a flexible tube. The tube passes through a mechanism that compresses the tubes to achieve variable ratio flow rates between the two tubes. Finally, the tubes both pass through a spring loaded valve, which is designed to compress and seal both tubes simultaneously.

To test the product, one tank was filled with clear water, while the other tank was filled with water colored with food coloring. The shade of blue of dispensed shows whether or not the product successfully mixes in varying ratios.

Though the prototype had issues with sealing in three locations (at the interface between the gallon jug and hose attachment, inside the ratio adjustment mechanism, and at the dispensing

valve), it served as a successful proof of concept prototype and we were able to get good data from users about what features they wanted to see and what direction the product should go.

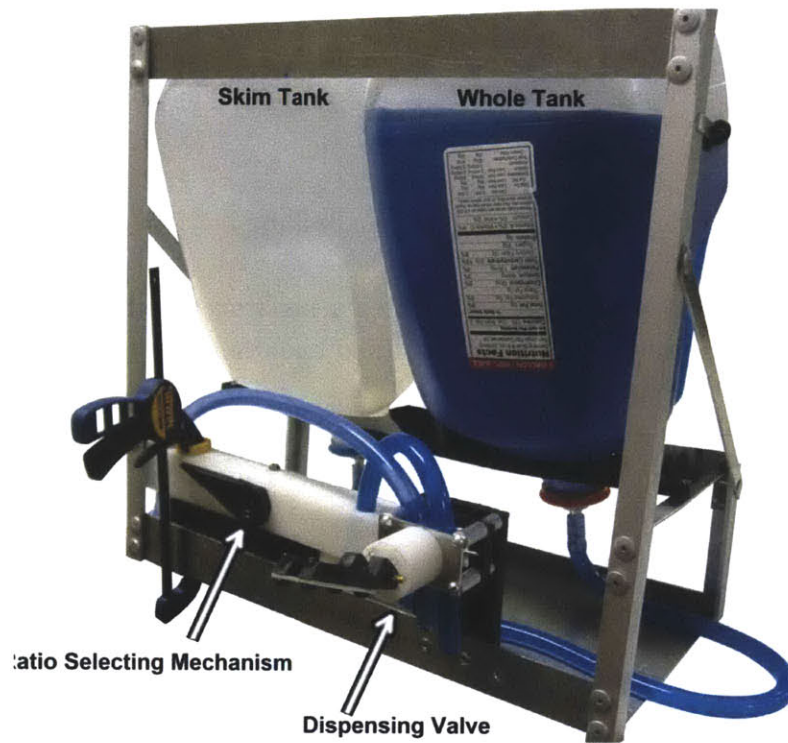


Figure 2: Photo of the final Prototype of the Milk Dispenser. The image shows clear water in the skim tank and blue water in the whole tank, for the purposes of visually determining how well the ratio mixing was working.

Background

2.1 Milk Processing Techniques

Milk, undergoes several processes between the time it is collected from the cow and the time that it is packaged. Of particular interest to this project is the separation of the fat from the skim milk.

1. Collection- Cows are milked using vacuum milking machines. The milk is cooled and transported to a milk processing plant.
2. **Separation- The milk is passed through a separator, which separates the milk into cream and skim milk. The cream is added back to the skim milk to produce milk with different fat contents.**
3. Fortification- A process which adds Vitamins A and D to the milk.
4. Pasteurization- The milk is heated to 161 degrees Fahrenheit for fifteen seconds to kill the bacteria.
5. Homogenization- The homogenization process reduces the size of the fat molecules in the milk to prevent the cream from separating from the skim milk.
6. Packaging- Finally the milk is pumped into either paper cartons or plastic bottles and sealed. [8]

For the purposes of this project, it is important to know the fat content in different types of milk. Table 1 shows the fat content per cup of each of the seven milk products that were investigated during the course of the project. These numbers were taken from the nutrition facts from several different brands of milk. From those brands that I investigated (Garellick Farms, Hood, Shaws, Shopper's Value) all the brands had the same amount of milk fat in the same type of milk. The table below shows the number of grams of fat per cup in each of the seven milk products.

Table 1: Fat Content in Milk Products

Type	Fat per cup
Skim	0g
1%	2.57g
2%	5g
Whole	8g
Half and Half	21g
Light Cream	40g
Heavy Cream	80g

The original idea for the product involved mixing skim and whole milk to get anything in between, but it is also possible to use various types of cream instead. The user could then get any type of milk up to the highest level of cream. It is interesting to note that the fat content in the milk is a whole order of magnitude less than that of heavy cream. If heavy cream is used to mix into skim, you need much less of it, and the amount that gets mixed in has to be very precise, since a small difference in the amount of heavy cream could mean a one or two percent difference in milk fat. This difference is about the same as the difference between each of the milk types, which is an unacceptably large difference, which is why the dispensing of a heavier cream would have to be very precise. Figure 3 shows graphically to scale the milk fat contents of each of the seven products.

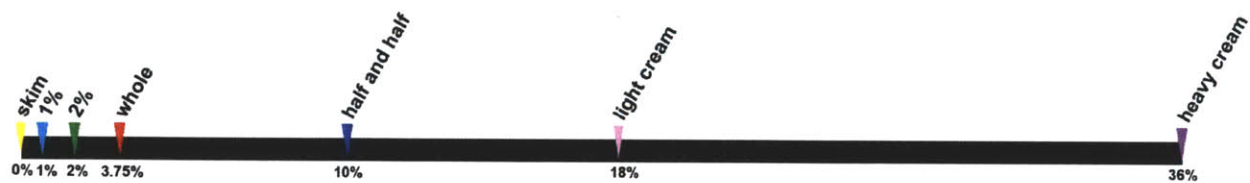


Figure 3: Graphical Comparison of Milk fat Content

2.2 Prior Patents

The original patent searches were focused primarily on types of milk dispensers that have been invented. I was searching for dispensers that had been designed to be used on either a commercial or residential scale, since industrial milk processing occurs on a much larger scale than what I'm looking at, and will use very different processes.

Among the patents, three different types of mechanisms came up, none of which were the same concept as this product. The first type included milk and beverage dispensers that have focus on some sort of new dispensing or valve technology. The variable milk dispenser doesn't claim to develop a new type of valve, so these patents don't stand in my way. The second type of patents found in the search were beverage mixers containing a single tank. These were primarily for beverages that could separate if not stirred, which is also not related to my product idea. Finally, there were many patents related to methods of measuring, metering, or dispensing milk, but they were all focused on processing raw milk from the cow rather than milk from the supermarket, and they were designed for an industrial scale.

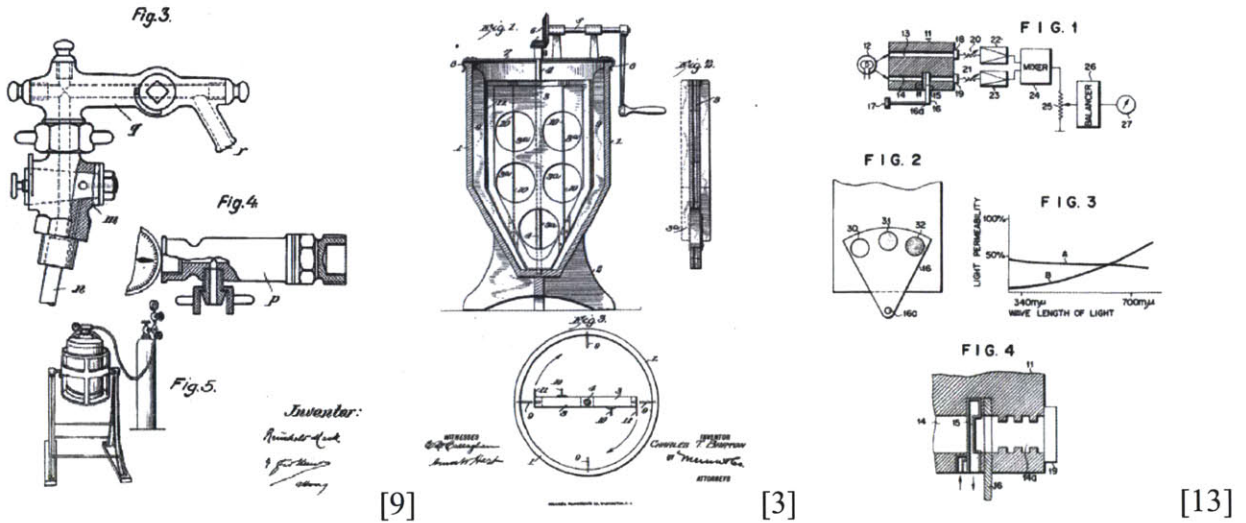


Figure 4: Images from patents for milk processing or dispensing. From Left to Right, the images show patents of (1) a valve used on a milk dispenser, (2) a device which is used to mix a beverage in a single tank, and (3) a device designed to separate milk by fat content using light properties

The innovation in this product is the decision to mixed to types of fully processed milk and using some sort of device that adjusts the ratio flow between the two types.

One patent stood out as the closest to the product idea. Images of the patent from the patent document are shown in Figure 5.

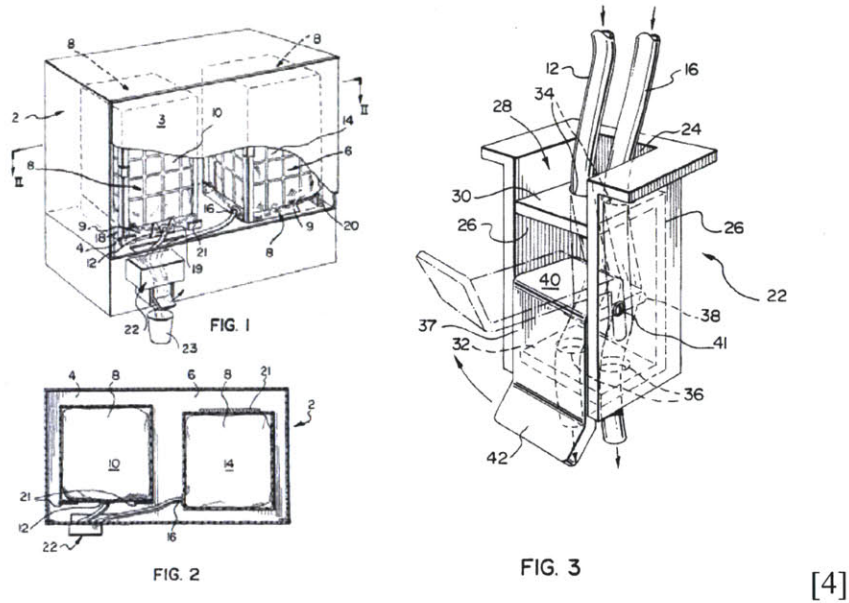


Figure 5: US Patent Number 4,651,898. Designed to mix equal ratios of real milk and powdered milk to save money.

This product uses a similar concept of two tanks with flexible tubes for holding different types of milk, and dispensing them directly from the pair of tubes into a container. There are two important differences between my product and the patented product. First, and most importantly, the patented design does not adjust the ratio between the two tubes. There is a fixed ratio between the two tanks, likely to be 50/50 if the two tubes are the same size. Second, the patented design is supposed to be used to mix regular milk and powdered milk, rather than milk with different amounts of fat.

2.3 Benchmarking

I primarily investigated different types of beverage dispensers when benchmarking for this project. There are no products that I could find that mix two different beverages together during dispensing, so I investigated regular dispensers that are designed to dispense a single type of beverage at a time. The products shown in Figure 6 illustrate the types of products available for beverage dispensing.



Figure 6: Several Beverage Dispensing Products investigated for benchmarking purposes.

Notice that there seem to be two classes of products, the first being commercial scale products, and the second being residential scale products. The top row of figure 6 shows the dispensers designed for the commercial scale. These products include some sort of refrigeration unit and stand on their own. The price reflects the larger scale they are expected to be used on, with prices upwards of \$1000 for each of the products. The bottom row shows three products that are for a residential scale, with a milk dispenser on the left, and two Brita water dispensers

on the right. Prices for these generally fall between \$20 and \$50, which is a reasonable price that a home buyer can be expected to pay.

For this product, I narrowed it down to three different possible form factors from the products shown above. The first is the Silver King refrigerated countertop dispenser on the top right of Figure 6. The other two potential form factors are the Brita pitcher and dispenser. These two are similar, but one is designed to stay in the fridge all the time, and one is smaller so it's designed to be a little bit more portable.

2.4 Market

2.4.1 Target Market

There are a variety of possible markets that the product could be marketed toward, but as a customer base for the purposes of this project, I worked closely with the group that inspired the project in the first place, MIT's French House.

If the product were to be taken to market, it would have three possible market sizes to target. The first would be a to target families or other groups of people of similar size. According to census data, there are approximately 115 million families in the United States, a very large population to target. If the product were aimed toward this market, it is likely that it would take a form similar to other products aimed at this market such as the Brita filter water tanks that are aimed at families. While this is a large market, the product price should be as low as possible, since families don't want to pay top dollar for a product like this.

A second possible market is a mid-sized market. This includes living groups of 20-30 people, smaller restaurants, bakeries, coffee shops, etc. In 2005, the number of the coffee shops in the United States was approximately 21,500, while the number of bakeries and other snack shops was about 38,000. This product has a smaller market in quantity of potential buyers, but many of the customers would be willing to pay more than in the case of the family market. [2]

The third market type to potentially aim the product at is a more commercial setting, such as large restaurants and dining halls. The product in this case would be modeled closer to the Silver King dispensers shown above, since these dispensers are designed to be used by large numbers of people to dispense large quantities of milk per day. Silver King milk dispensers sell for anywhere between \$1200 for a single valve variety and \$1650 for the triple valve type of machine. There are approximately 2200 four year colleges in the US, so if each one of them has an estimated average of three dining halls on campus, that is 6600 dining halls that could be equipped with these milk dispensers. In addition, there are about 220,000 full service restaurants in the United States that might use the dispenser, though depending on the type of restaurant, the

dispenser might be kept in the back of the restaurant, or in the front where the customers could take milk themselves. [2]

2.4.2 Pricing Considerations

To examine possible cost effectiveness or savings of the product, I took a closer look at the prices of milk and cream, up to heavy cream. Table 2 shows the minimum and maximum pricing of the milk products that I recorded during the semester. Note the sharp increase of price as you get above the regular milk and enter the cream region. Another interesting thing to note is that skim, 1%, 2% and whole milk all have the same unit price, despite different amounts of milk.

Table 2: Prices of various milk products as of February 2011 in the Boston Area

Type	Volumes Sold	Min Unit Price / gal.	Max Unit Price	Average Unit Price
Skim	1 qt. - 1 gal	3.99	5.96	4.70
1%	1 qt. - 1 gal	3.99	5.96	4.70
2%	1 qt. - 1 gal	3.99	5.96	4.70
Whole	1 qt. - 1 gal	3.99	5.96	4.70
Half and Half	1 pt - 1/2 gal	8.60	15.76	12.13
Light Cream	1 pt - 1/2 gal	13.56	19.12	16.34
Heavy Cream	1pt - 1 qt	23.12	27.96	25.13

Figure 7 graphically shows the trends in unit pricing of milk versus fat content. Oddly, Heavy Cream got more expensive per unit volume when purchased in larger quantities, but this might be also due to small numbers of data points.

Milk Product Unit Pricing vs. Volume

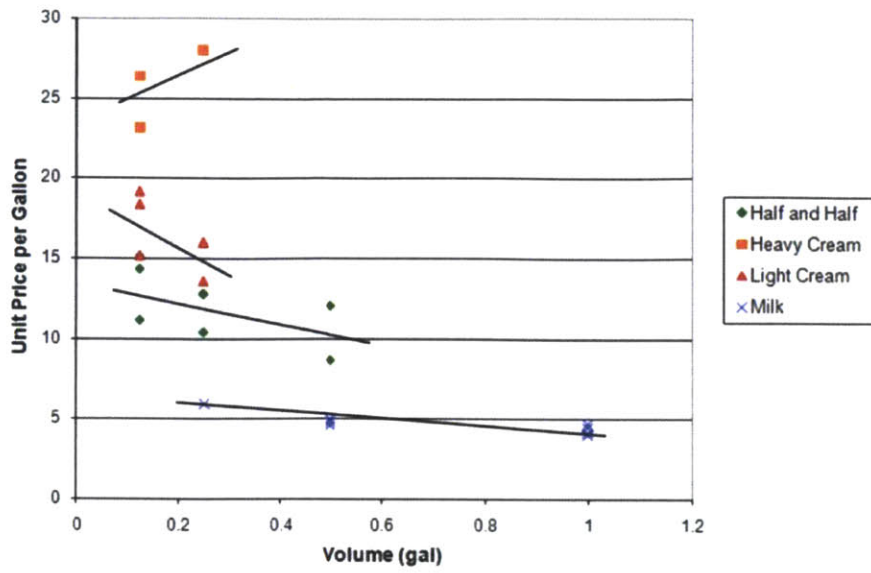


Figure 7: Graph of Unit Price of Milk vs. Volume of Container sold

Ideas and Development

3.1 Directions

With the development of any product, there are a variety of possibly directions that the designer can take the product. It's no different for this milk dispenser.

The primary concern for this product was the form factor. I mentioned earlier that the three possible form factors for the product include a standalone refrigerated unit, a dispenser tank that is always kept in the fridge, and a pitcher.

Another decision about the product's functionality is about what type of milk/cream to mix skim with. The original idea involved simply mixing skim and whole, but there is also the possibility of using a higher cream so you can use less of it, thus allowing the device to be more space efficient. Table 3 shows the exact amount of various types of cream that would have to be mixed with skim to create milk of different types. Note that accuracy is very important if using cream to mix with skim since in some cases a half a teaspoon of cream can mean the difference between two types of milk.

Table 3: Mixing Milk and Cream - Necessary Ratios

Type	Fat per cup	Mixing with Heavy Cream			Mixing with Light Cream			Mixing with Half and Half		
		Tbsp cream	%skim	%cream	Tbsp cream	%skim	%cream	Tbsp cream	%skim	%cream
Skim	0g	0	100	0	0	100	0	0	100	0
1%	2.57g	0.514	96.79	3.21	1.03	93.57	6.43	1.96	87.77	12.23
2%	5g	1	93.75	6.25	2	87.5	12.5	3.8	76.2	23.8
Whole	8g	1.6	90	10	3.2	80	20	6.09	62	38
Half and Half	21g	4.2	73.75	26.25	8.4	47.5	52.5	16	0	100
Light Cream	40g	8	50	50	16	0	100			
Heavy Cream	80g	16	0	100						

A third direction for the product is directly related to the ratio adjustment mechanism. It could be either discrete or continuous. In the discrete case, the user would only be able to select standard milk types (skim, 1%, 2%, whole) while a continuous mechanism allows the user to choose a ratio anywhere between skim and whole.

These three are the primary decisions that needed to be made before design could begin. These decisions were made by discussing with users what they expected from the product and how they envisioned interacting with it.

3.2 User Feedback

Throughout the course of the semester, I have been interacting with customers to gain insight into how they might interact with the product and what features they find most useful. A survey was conducted early on in the semester of a majority of the people who live in French House to get their input about the product. The survey was focused on two things, the first being to understand the milk drinking habits of the customers, and the second being to actually get customer feedback about high level design choices such as form factor and usability.

The first key to understanding the customers' needs is to understand their milk preferences. For a product like this to have value, there should be several people who are very picky about their milk choices, and not agree on which types of milk to drink. If everyone was open to drinking all kinds of milk, there would be no value in having this product since you could appease everyone by simply keeping one type of milk in stock. Table 4 shows the milk consumption habits of thirteen members of the MIT French House. You can see that there are people who prefer every type of milk, though people tend to prefer one extreme over the other.

Table 4: Milk Drinking Habits of thirteen potential customers. Green indicates preferred type of milk, Yellow indicates willingness to drink that type, and red indicates refusal to drink that type

	Skim	1%	2%	Whole
1	Green	Yellow	Yellow	Yellow
2	Red	Yellow	Yellow	Green
3	Yellow	Yellow	Green	Yellow
4	Yellow	Yellow	Yellow	Green
5	Red	Red	Yellow	Green
6	Yellow	Green	Yellow	Yellow
7	Yellow	Yellow	Green	Yellow
8	Red	Red	Red	Green
9	Green	Yellow	Red	Red
10	Green	Red	Red	Red
11	Green	Yellow	Yellow	Yellow
12	Green	Red	Red	Red
13	Red	Yellow	Yellow	Green

The next thing discussed with the customers was the form factor of the product. After discussion of the three possible form factors that the product could take on, I asked each of them to decide which they thought would work the best and be most effective. The overwhelming majority chose the large tank unit that would live in the fridge at all times.

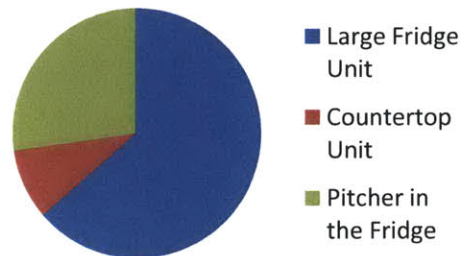


Figure 8: Customer Input on Product Form Factor

I asked the customers about whether or not they would find it useful to mix a higher cream with skim instead of whole milk, and the overwhelming response was that they very rarely purchase cream. A few responded that they purchase half and half for their coffee sometimes, but even they didn't feel that being able to dispense half and half from the product was particularly useful.

With respect to the continuous vs. discrete dispensing question, customers generally felt that it would be a cool feature, but is not necessary. Others thought that it is one way for the product to differentiate itself in the market, since you can't get custom milk fat percentage milk at the supermarket.

3.3 Selecting a Direction

The design of the milk dispenser was broken down into five separate mechanisms that would need to be designed and built to complete a working prototype of the product.

- Attachment to Milk Jug
- Mechanism to get milk out
 - Ratio Adjustor
 - Mixing Mechanism
 - Dispensing Mechanism

The first thing the milk encounters as it leaves the gallon jug is the interface to the flexible hose. There are not too many possible directions that this could go in. I decided to use the standard snap on milk cap since they are already proven to fit any standard gallon of milk.

The fit was even tested by using the snap on caps on the gallons of milk that usually use a screw on cap and it was discovered that they are still compatible. It is important that the cap and hose interface seal very well. Figure 9 shows a few concept sketches from my design notebook

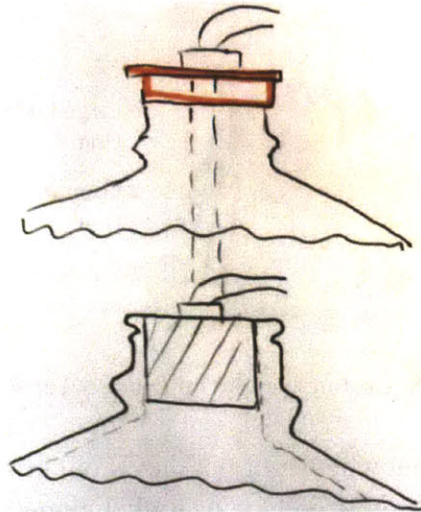


Figure 9: Milk Jug attachment concepts

The next key design decision was about how to get milk out of the tanks and moving toward the next mechanism. There are two possible ways to do it, one which involves using a pump of some sort to transport the milk, and the other taking advantage of gravity to move the milk. Taking advantage of gravity seems like a natural choice, but there are some concerns about how well that work. One of the biggest concerns is that there would be variable pressure at the exit of the tubes as the tank empties. This difference in pressure might significantly change the flow rate of the milk as it exits the tube. Also, the height of the overall unit and the placement of the outlet valve are dictated by the fact that the milk will only flow downward. A peristaltic pump would solve these problems, but at the same time, the pump would be more complicated and more expensive. It would also need electrical power, or require the user to turn it.

To decide which direction to move forward on the milk feed mechanism, I set up a Pugh chart (shown in Figure 10). It was between four different options, including either a servo powered or hand powered peristaltic pump, or two arrangements of gravity feed. One uses shallow pans, while the other makes use of a large height difference between the level of the jug. The idea behind these two concepts is that the pressure difference between a full and empty milk jug wouldn't create a large pressure difference at the outlet.

	① Servo Powered Peristaltic	② Hand Cranked Peristaltic	③ shallow pan Gravity Feed	④ Tall gravity feed
Usability	0	—	0	0
Reliability	0	0	—	—
Ease of Manufacture Machinability	0	0	+	+
Space	0	0		—
Cost	0	+	+	+
Power	0	+	++	++
Maintenance	0	0	—	+
Total	0	+1	+1	+2

Figure 10: Pugh chart of potential mechanisms to get milk out of the jug

While each of the four designs is a valid one, they all have a fundamental flaw, so it is necessary to select a design in which the flaw detracts from functionality the least. The motor powered pump would require electricity. For a fridge unit, there is not an option of plugging into an outlet. If it had a battery, that is a big usability issue. The user should not have to remember to charge their milk dispenser.

In the case of the gravity feed, the shallow pan one faces maintenance issues. If you can't use a standard milk gallon jug, that means you are continuously filling up these shallow tanks with milk. Remnants of old milk in the tank could produce bacteria that causes the milk to go bad or the consumer to get sick. From a usability standpoint, cleaning these tanks every week or so is a major inconvenience to the user. While the tall gravity feed would work, this option faces a lot of trouble in fitting into a fridge. Space is at a premium, and shelves generally do not have all that much space between them, so this type of unit would not be able to fit into a fridge very well. Of all of the designs, I decided to implement the tall gravity feed design since it is the simplest to build for a first prototype.

The next mechanism is the ratio adjustment mechanism. The only high level design decision on this mechanism is whether the ratio selection should be continuous or discrete. To decide this, customer feedback about the issue was taken into account. Users felt that while continuous dispensing would be a cool feature, it's not particularly necessary, so it should not be a primary focus. If a continuous design turns out to be the simplest and most reliable solution, then the unit will have a continuous ratio adjustment.

Initially, I had thought that the mixing device would have to be a moderately complicated internal assembly to ensure that the two types of milk thoroughly mix. Most of the ideas focused on inducing turbulent flow somehow between the two streams. However, after some simple bench level testing, it was discovered that the turbulence of the milk hitting the bottom of the cup is sufficient to mix the milk without any trouble, so the need to build a mixing device was eliminated.

Since the simplest way for the two types of milk to mix is for them to simply mix in the glass, this dictates that the two streams separately exit the outlet valve. Ideally, the valve would seal both tubes at the same time and open both tubes to full diameter so as not to affect the compressive ratio between the tubes that is controlled further upstream at the ratio adjustment mechanism.

In addition to thinking about each of the mechanisms inside the product, it was necessary to decide whether to mix skim with whole milk or some type of cream. I did a price analysis of how much more or less expensive the mixed version would be in comparison to a purchased version. Because milk is the cheapest of the dairy products, it seems that mixing with anything other than whole milk is not cost effective, but rather highly ineffective. The prices are anywhere from 10-60% more expensive than the purchased counterparts. This is the primary reason that the final product was selected to use skim and whole, rather than skim and cream.

Table 5: Price Comparison of Milk mixed with cream vs. Milk directly from the store.

Type	Unmixed	Mixed w/ heavy cream	Mixed w/ light cream	Mixed w/ Half and Half
Skim	4.70	4.70 +0%	4.70 +0%	4.70 +0%
1%	4.70	5.36 +13.96%	5.45 +15.91%	5.61 +19.35%
2%	4.70	5.98 +27.17%	6.16 +30.96%	6.47 +37.64%
Whole	4.70	6.74 +43.47%	7.03 +49.53%	7.53 +60.22%
Half and Half	12.13	15.54 +28.13%	14.34 +18.22%	12.13 +0%
Light Cream	16.34	20.74 +26.90%	16.34 +0%	
Heavy Cream	25.13	25.13 +0%		

3.4 Design Process

The key mechanism in the product is the ratio selection mechanism. Several potential ideas came up in the design of the ratio selector. Many of the initial concept ideas involved

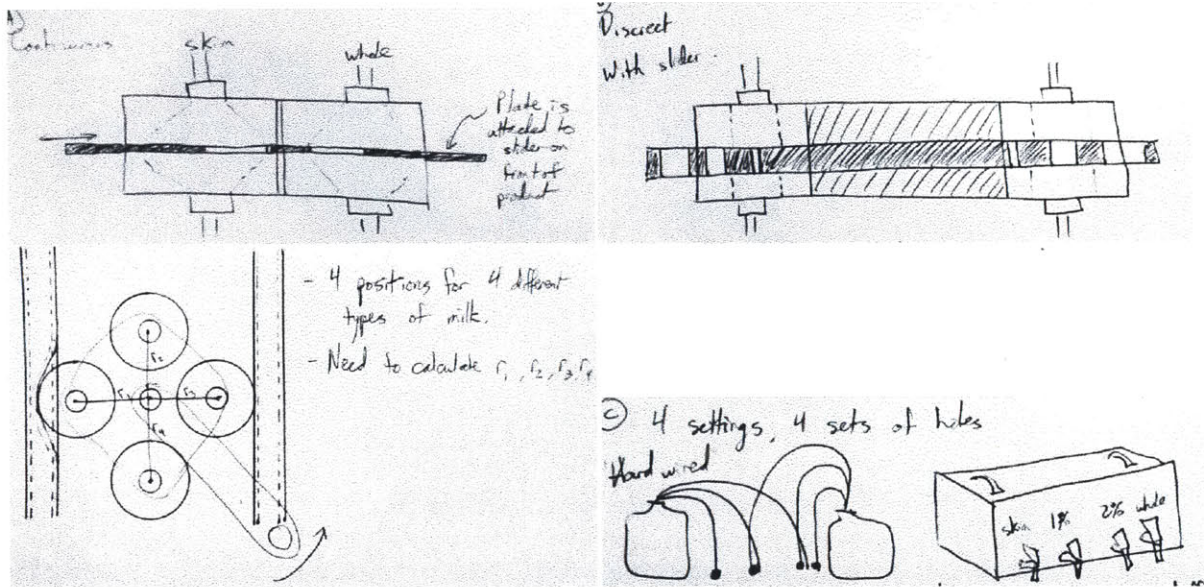


Figure 11: Ratio Adjustment Mechanism concept sketches.

In Figure 11, the top two images show devices with a sliding plate with holes. Depending on the relative size of the holes in each chamber, the ratio is adjusted. The bottom left uses a rotating piece to compress the tubes to different amounts. The bottom right doesn't need any moving components. The relative diameter of the hoses attached to each of the four outlet valves determines the ratio between the two. The top two seem like they would have a lot of trouble properly sealing, and they would also be difficult to manufacture. The two frontrunner ideas were compressing the tubes or having a passive system with four dispensing valves. Each of these are fairly simple and easy to build.

Table 6: Required ratios of Skim and Whole to achieve other types of milk.

Mixing Percentages	Skim	1%	2%	Whole
Skim	100%	68%	37%	0%
Whole	0%	32%	63%	100%

I continued investigating the concept of compressing the tubes by varying amounts to achieve the ratio. Based on the calculated required ratios between the two tanks as shown in Table 6, the I worked out the geometry of how much the tubes should be compressed to achieve the desired ratios. Figure 12 shows cross sectional area geometry for different amounts of tube compression.

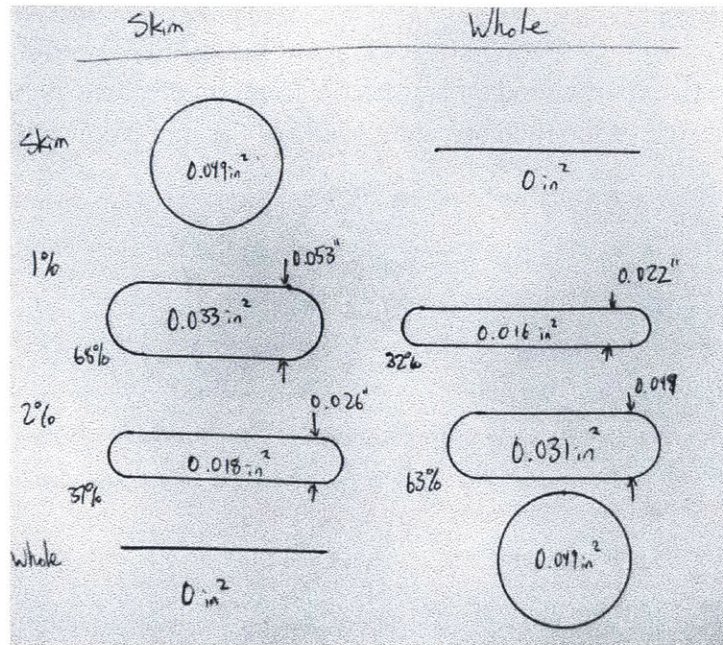


Figure 12: Tube Compression - Area ratios

The tube compression concept continued being developed, and evolved from a rotating wheel with rollers into a lever arm concept. If pivoted at the middle, then when tilted one direction, the skim tube would be compressed leaving the whole milk tube open and vice versa. The biggest advantage to this design is that the compression ratios of the tubes are mechanically linked by a single part. It's a simple, elegant solution. The mechanism is actuated using a screw through a barrel nut near the pivot point. A 180 degree rotation of the 1/4-20 screw results in a 0.025" translation. With a lever arm approximately ten times longer than the distance between the barrel nut and the pivot point, we can achieve the required 0.259".

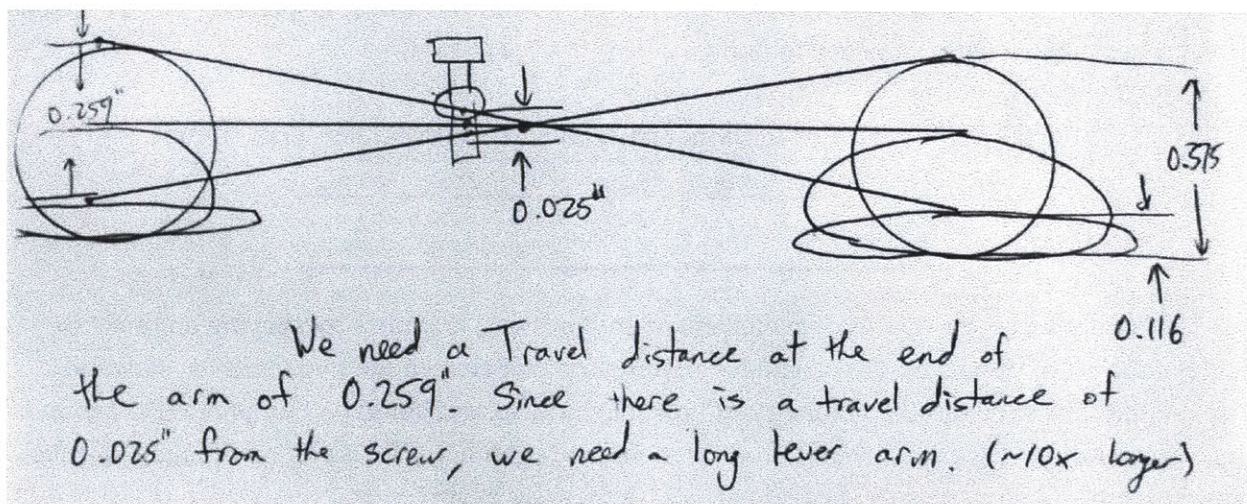


Figure 13: Ratio Adjustment Lever Arm Mechanism Concept Sketch

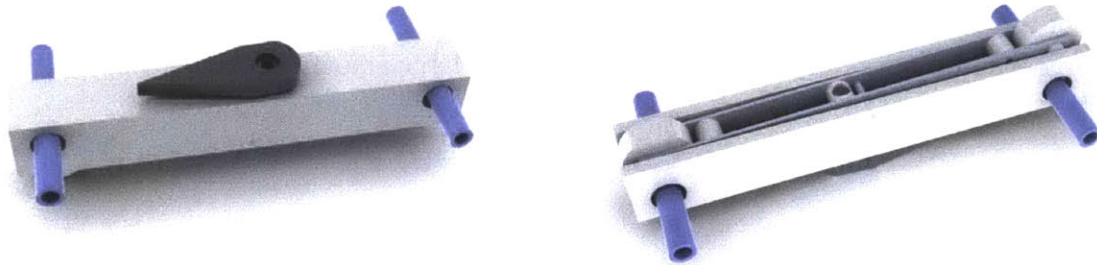


Figure 14: Solidworks Renders of Ratio Selector Design

Two Solidworks renders of the ratio selection mechanism are shown in Figure 14. The lever arm has two Delrin rollers at each end that act as tube compressors. The screw adjusts the lever arm by translating the barrel nut. Also, a plastic selection arrow is pressed onto the screw head so that the user can rotate it to select which type of milk they want.

3.5 Build Process

The first small assembly I built was the hose attachment to the milk gallon, since without this, there is no easy way to feed the milk through the ratio device or dispensing valve. I settled on a Delrin piece that fits inside a standard milk cap with an O-ring in between it and the cap itself to seal. The hose barb screws into a threaded hole in the Delrin piece. See Figure 15.

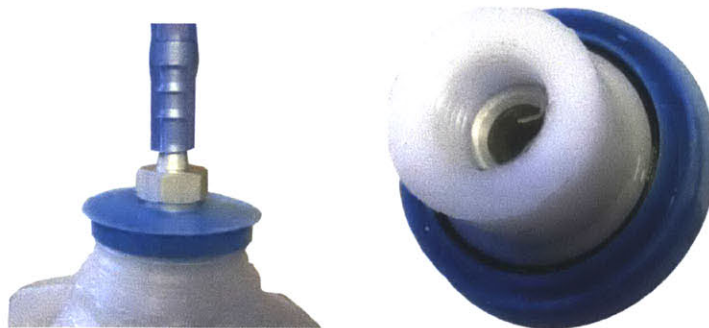


Figure 15: Hose Barb Attachment to Milk Cap

Initially, one of the attachment pieces had issues with sealing in between the Delrin piece and the cap, but that wasn't something that hot glue couldn't fix.

The second mechanism I built was the ratio adjustment mechanism. It makes use of the lever arms I discussed earlier in the design section. An odd bug that was experienced with this device was that the screw needed to be rotated twice as much as originally designed. This is

happening for two reasons. The first is that there is probably some sort of backlash between the barrel nut and the lever arm. Since it is so close to the pivot point, a small amount of backlash means a large difference at the end of each lever arm. The second is that I may have underestimated the amount of "squish" that is required to compress the tube completely to the point of preventing all flow. It's easy for it to be compressed almost all the way, but there are small corners at the sides of the tube that remain until a large amount of force is applied to the tube.

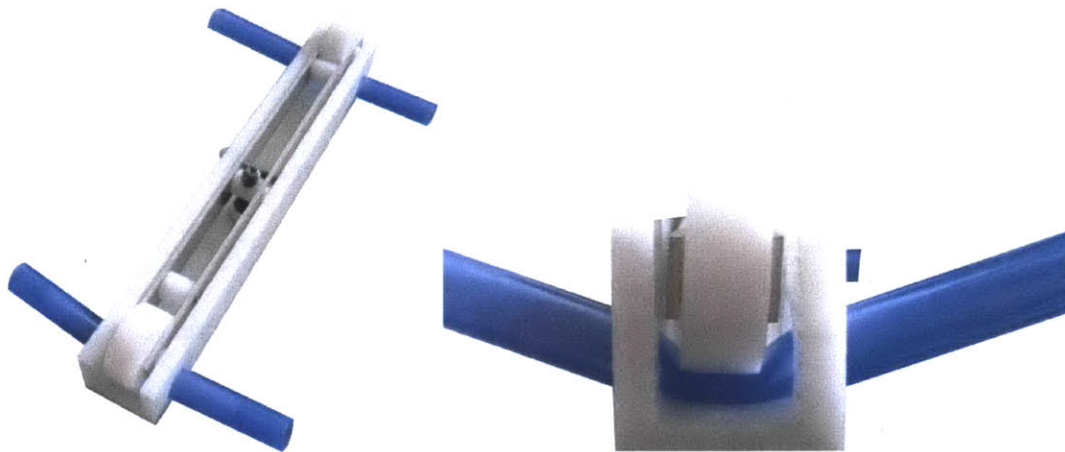


Figure 16: Ratio Adjustment Mechanism

Next, I built the structure for the milk jugs to be held in. The final sub-assembly to be made was the dispensing valve itself. For time reasons on the first version, I used an off the shelf dispensing valve as shown in Figure 17. The valve itself worked really well, but you can see that since the two tanks are connected at the block behind the valve, the colored water was able to flow into the other tank, which is a highly undesirable effect. Eventually, the two gallons would equalize, and all the milk dispensed from the unit would be 2% milk.



Figure 17: First full assembly of the milk machine. Notice the backflow of the colored water into the clear water tank.

To solve this issue, I proceeded to build my own valve which clamps both tubes at the same time. In addition to preventing backflow, this design would improve maintenance, since the only parts the user would have to clean are the tubes themselves, rather than the tubes, mixing chamber, and output valve.

Figure 18 shows the new valve design that I built. It uses the same principles as the off-the-shelf valve. The tubes are clamped in the resting state by a spring. The user presses on a lever arm to release the spring and open the tubes for dispensing. In the case of this particular design, the mixing occurs in the user's glass rather than inside the milk machine. Bench level testing indicated that the turbulence upon hitting the glass is sufficient to mix the milk, so long as the tubes are close enough together. If the tubes are far apart, the turbulent effects of hitting the glass don't occur near each other, and mixing is not as complete. The tubes in the valve are directly next to each other, so this was not a problem.

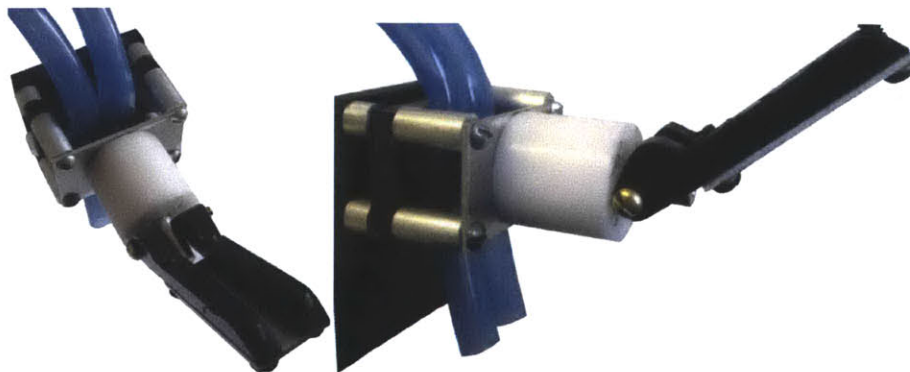


Figure 18: Close-up images of valve assembly

Results

4.1 Final Design

The prototype of the product is shown in Figure 19. The full assembly includes the two tanks, hose barb milk caps, flexible rubber tubing, ratio selection mechanism, dispensing valve and the outer support structure.



Figure 19: Picture of the final prototype. The tanks contain colored and clear water for observing mixing

4.2 Testing

On the final prototype, I tested with a tank of colored water and a tank of clear water representing whole and skim milk. This way, you can use the color of the water to tell visually relative ratios of the two liquids that are dispensed.

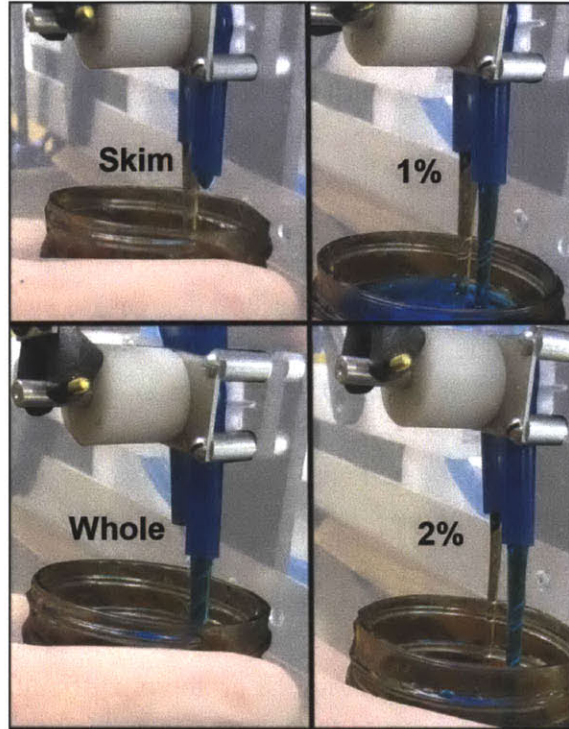


Figure 20: Dispensing of four different kinds of milk. Stream size clearly shows which type of milk is being dispensed.



Figure 21: Glasses containing water dispensed by the prototype. Glasses contain (from left to right) simulated Whole, 2%, 1% and Skim

Figures 20 and 21 show that the prototype is quite successful at adjusting the ratios. The colored water gets progressively lighter. It is worth noting that the "skim" glass is not entirely clear, which it should be. This happened for two reasons. The first is that there is a section of tube after the ratio adjustment mechanism which captures some whole milk and that volume will be dispensed even if the user selects skim. Also, the sealing in the ratio adjustment mechanism could use some work, so even when skim was selected, a small amount of whole was coming through.

4.3 User Feedback

I continued working with members of the MIT French House when testing the product. I gave them the product to try both dispensing and loading gallons of milk into the prototype. In general users found dispensing very intuitive, but loading the milk tedious and difficult.

With respect to the ratio selection mechanism, users found it simple to use, though a few people expressed that it required too much motion (360 degrees) to switch from skim milk to whole milk. When asked how much of a range people thought it should have, responses ranged from 60 degrees to 180 degrees. Perhaps 120 degrees is a good value for the next prototype.

The dispensing valve was modeled after a standard water cooler spring valve mechanism, and users found it easy to understand how it works, though they were disconcerted that the one I had built had some issues with leakage. In fact, this was the primary concern expressed by the users when asked what they thought about the prototype.

Users found loading the milk tanks into the prototype difficult. For one thing, the milk jugs need to have a small hole (at the top of the jug as oriented in the product) to relieve the negative pressure that is created when milk is dispensed. The prototype didn't have any mechanism that would pierce the jug, but the final product would ideally have this feature. Because this feature was missing, small amounts of water were leaking out of those relief holes during loading. Another annoying issue with loading occurred when the tubes bent or became crimped. If there was a kink in the tube, the flow rate was significantly reduced. There should be some intuitive and repeatable way for the tube to be routed such that this is not a problem.

Other customer input was about aesthetics and added functionality. Two suggestions that I received about the look of the product were that it should have a nice looking outer shell instead of the barebones frame that I built for this first prototype. Another user said the product should be pink.

As far as added functionality, several people had suggestions of adding different things into the milk as well, specifically chocolate or strawberry syrup. One user even suggested that the product add food coloring to the milk as a fun feature.

Discussion and Future Development

5.1 Product Vision

5.1.1 Next Prototype

Based on customer feedback and my own testing, there are a few key low level issues that would need to be addressed in the next prototype. The number one issue to fix is the leakage of the milk at the three problem areas (Jug/hose interface / Sealing in Ratio Mechanism / Sealing at dispense valve). The first is a fairly simple fix, involving finding O-rings that create a little tighter seal inside the jug cap. The second requires a slightly different geometry of the rollers. Currently, the mechanism uses 1/2" wide rollers to compress the tubes. This large area requires a lot of force to compress, so the rollers could easily be made to go to a point, which will be much easier to compress the tubes and get a tight seal. The third can be solved in a similar way to the second. The surface area that clamps the tubes should be minimized so it doesn't take as much force to compress the tubes. Also, a stronger spring could be used in the valve to keep the tubes compressed.

In addition to solving leakage, the next prototype should focus more closely on the enclosure since much of the functionality has already been proven to work. In addition to the enclosure shape and form factor, care should be taken to make the prototype as small as possible, especially if it is expected to be stored in a fridge.

As far as usability concerns go, the first simple issue is to modify the ratio mechanism selector so that the user doesn't have to rotate it a full 360 degrees to go between skim and whole milk. A much more reasonable range is 180 degrees. This can be achieved by using a coarser threaded screw, or even a double or triple helix screw, so that the same amount of rotation of the screw results in a larger translational motion of the mechanism.

These are the most pressing concerns and the ones that would most likely be addressed in the next prototype.

5.1.2 Future Iterations

Looking beyond the next prototype, more research into the market would have to be done to determine exactly which market is most lucrative to target. I suspect that a commercial scale product that could be used in dining halls and restaurants would be the best direction for this product to go eventually. This would emulate the model of the Silver King milk dispensers I mentioned earlier (*Section 2.3: Benchmarking*).

There are many possible features that could be implemented in the product eventually, ranging from measured dispensing to adding flavored syrup to the milk (i.e. chocolate syrup, strawberry syrup, etc.)

5.3 Conclusion

Over the course of the semester, a successful proof of concept prototype of the variable fat content milk dispenser was designed and built. The prototype contained two tanks hooked up to flexible hose that was compressed to variable amounts to adjust the ratio between the two streams. Though it had issues with leakage in some locations, the key mechanism of the prototype, which is the milk fat ratio selection mechanism, proved successful.

Future work in the area of this product should be focused around improving sealing at every interface where milk flows. The product could also benefit from a non-drip outlet valve design. Other improvements for the next prototype include a focus on form factor and minimizing the space that the product takes up. Also, the ratio selection mechanism should be optimized such that the user doesn't have to rotate it quite as much to switch between skim and whole milk.

If the product were to be further developed, more detailed research should be conducted in the area of the market to determine whether a commercial or residential market would be more lucrative to target. The product would be significantly larger if it were to be used by dining halls or restaurants rather than families.

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