GNG 1103B
Engineering Design

Project Deliverable J: Final Report

Swiss Chard Machine
Hydroponics B5

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Abstract

Group B5 of GNG1103 Engineering Design of the Fall Term 2018 used the engineering design process to develop a hydroponics system for a greenhouse that was made for an Aboriginal community in La Domaine, Quebec, Canada. This report thoroughly explains the process of designing, constructing and testing while highlighting the constraints and challenges that were faced. It is explained in detail the results of the design project, providing documentation about the design process and solution, showing the required research and assumptions that justify the final solution as being the best or most appropriate one.

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Introduction

This project was developed for the Barriere Lake First Nations community in La Domaine, QC. This community is home to around fifty people living in a remote area that is one and a half hours away from the nearest town of Maniwaki, QC. Their location has no access to running water or electricity. Although their camp is located near a lake, the lake water is polluted with mercury and is not filtered. As a result, their main water source is to collect water from a spring. Their camp is built on an airport strip and the landscape consists of very fine sand and mixed forest. Also, during the winter time, this community receives large amounts of snowfall and temperature can drop below -30 degrees Celsius. Therefore, due to their lack of fresh water, poor landscape and severe temperatures, they can not cultivate their own fresh produce.

The team applied the engineering design thinking process of **empathize, define, ideate, prototype and test** to create a hydroponics system capable of sustaining the needs Barriere Lake First Nations community year round. This project highlights the process of designing and the constraints that were faced.

Empathize - Needs Identification

Customer Needs

The first client meeting was an interview with the client, Monique. This allowed us to empathize with the client to understand their problems, constraints and needs. The group was able to gather the information and separate them into five distinct categories which were **cost, build quality, modularity, ease of use/maintenance and space efficiency**. Afterwards, the team interpreted the customer needs into design criteria which explains what the system has to do in order to meet the customer needs. Doing this allowed us to rank the importance of each customer need with 1 being the most important and 5 being the least important. The following table describes the customer needs, design criteria and rank of priority:

Table 1: Customer needs, design criteria and rank of priority.

Priority	**Customer Needs**	**Design Criteria**
1	Greenhouse must be usable all year round to grow fruits and vegetables	The System must be able to operate and sustain plant life in temperatures ranging from -40 degrees C to around 30 degrees C.
5	Animals may eat crops or damage the greenhouse	The Hydroponics system shall be designed for it to be difficult for animals to eat the crops or damage the system.

4	The community has about 50 people. Trips to grocery stores are long and costly, and access to fresh vegetables is limited in the winter. The client needs easy access to fresh fruits and vegetables	The Greenhouse and Hydroponic system must be space-efficient and able to grow enough fruits and vegetables to support a community of 50.
3	Flexible to grow different kinds of plants	The system shall support several kinds of plants at the same time. Hardy vegetables like potatoes, swiss chard and various herbs.
2	Ease of operation and maintenance	The system shall be designed such that someone with no experience with hydroponics can, with proper instructions, maintain and operate the system.

Define - Problem Statement and Design Criteria

Problem Statement

Empathizing with the client allowed us to define a problem statement that explained the problem that needed to be solved, and constraints that have to be met based off of the needs of the client. The formulated problem statement was:

Limited access to fresh fruits and vegetables has resulted in the need for a Hydroponics System that is capable of growing fruits and vegetables in temperatures ranging from -40 degrees C to 30 degrees C, is easy to operate and maintain, and can support the 50 members of the community.

Design Criteria & Constraints

Table 2: Customer Needs, Translated Design Criteria, Order of Ranking

Ranking	Customer Needs	Design Criteria
1	Greenhouse must be usable all year round to grow fruits and vegetables	Durability Lasts for all-seasons (degC)

2	Ease of operation and maintenance	Simple Controls (min) Minimal Maintenance Cost ($)
3	Flexible to grow different kinds of plants	Variety of Crops
4	The community has about 50 people. Trips to grocery stores are long and costly, and access to fresh vegetables is limited in the winter	Dimensions (m) Can grow enough crops
5	Animals may eat crops or damage the greenhouse	Shape of system Protection against predators

Functional Requirements

- Able to grow a variety of crops to sustain the needs of 50 people
- Simple controls (min)

Table 3: EDS Functional Requirements

Number	Design Specifications (Functional Requirements)	Relation (=, <, >)	Value	Units	Verification Method
1	To be able to grow plants	=	yes	n/a	Test
2	Automatic watering system	=	yes	n/a	Test
3	Easy to use and maintain	=	yes	n/a	Test
4	Able to support good volumes of crop	>	50	people	Analysis, test
5	Can support multiple types of plants	=	yes	n/a	Analysis, test

Non-Functional Requirements

- Durability/Product Life
- Aesthetics
- Protection against corrosion and sunlight
- Protection against predators
- Ease of operations

Table 4: EDS Non-Functional Requirements

Number	Design Specifications (Non-Functional Requirements)	Relation (=, <, >)	Value	Units	Verification Method
1	Durable/Animal proof	=	yes	n/a	Test
2	Ease of use	=	yes	n/a	Test

Constraints

- Dimension (Length x Width x Height)
- Cost ($)
- Operating Conditions (°C)

Table 5: EDS Constraints

Number	Design Specifications (Constraints)	Relation (=, <, >)	Value	Units	Verification Method
1	Cost	<=	100	$CAD	Analysis
2	Size when deployed	<	60'' x 36''	inches	Analysis
3	Operating Conditions	=	> -30	degC	Test

Benchmarking

Table 6: Benchmarking Hydroponics Systems
(Green = 3, Yellow = 2, Red = 1)

Specifications	Hydroponics System		
	Miracle-Gro AeroGarden Sprout with Gourmet Herb Seed Pod K	**SuperPonics 16 Hydroponic Grow System**	**Hydroponic Site Grow Kit Garden Vegetable Planting System Kit + opaque 20L water reservoir**
System Cost ($) (4)	$89.99 CAD	$450	$159(Kit) + approx $20 = $179
Weight (kg) (1)	1.5kg	5kg	8.5kg
Dimensions (2)	11” x 11” x 6”	29’’ x 22’’ x 12’’	38’’ x 39’’ x 28’’
Ease of Use (7)	Prompts user when to water, add nutrients, etc. Requires little to no knowledge of plants.	Requires knowledge of plants. User must adjust to each plant type.	Requires knowledge of plants. Roots grow into pipes, making plant changes difficult.
Types of Crops (3)	Small Herbs Only (Basil, Thyme, Dill) Unable to plant fruits or vegetables	3 inch potting cups. Can plant small-medium sized fruits and vegetables.	Small Herbs, Small Fruits/Vegetables, or Saplings of larger plants before transplanting
Build Quality & Maintenance (5)	Easy assembly and simple maintenance. Comes with easy to follow instructions.	Easy assembly, but requires occasional cleaning	Easy assembly but it is not a kit solution so it will be longer to assemble. Difficult to maintain.
Planting Capacity (6)	Up to 3 plants at a time	Up to 16 small-medium plants	72 1.2 inch planting holes.
Total	**66**	**55**	**47**

* 1 = Less important and 7 = Most important

Ideate - Design Concepts

Concept Generation

By using the problem statement, benchmarking and list of prioritized design criteria, we then developed conceptual designs for our hydroponics system. After analyzing and discussing our different ideas, we were to decide on a final design that incorporated the best features of our different designs.

Main Conceptual Design

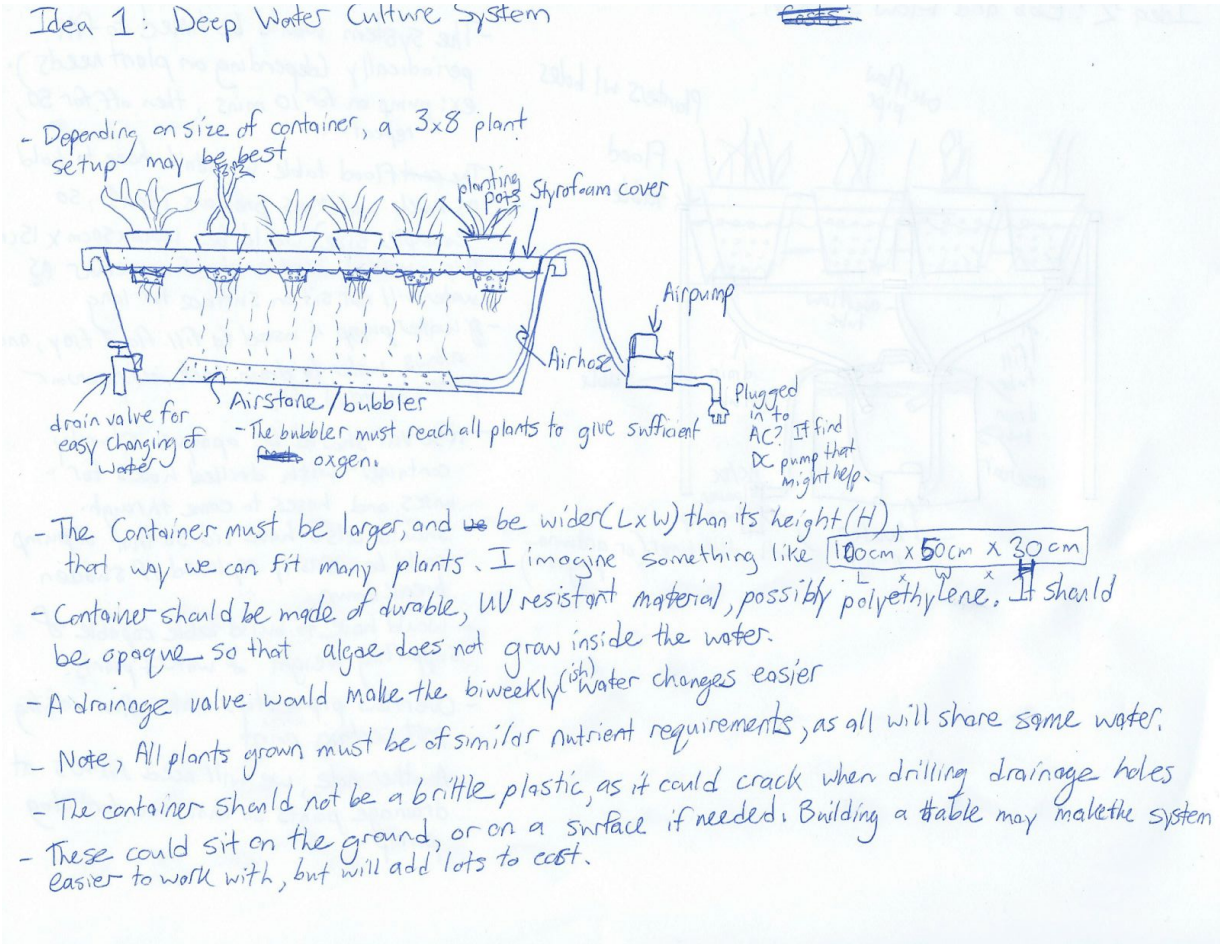

Figure 1: Daniel Grainger's main conceptual design #1

Secondary Conceptual Designs

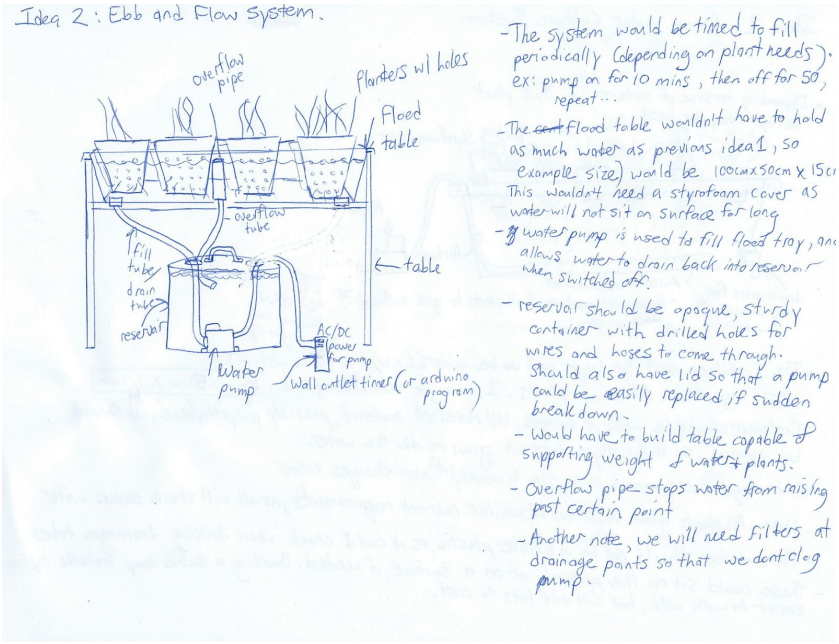

Figure 2: Daniel Graingers conceptual design #2

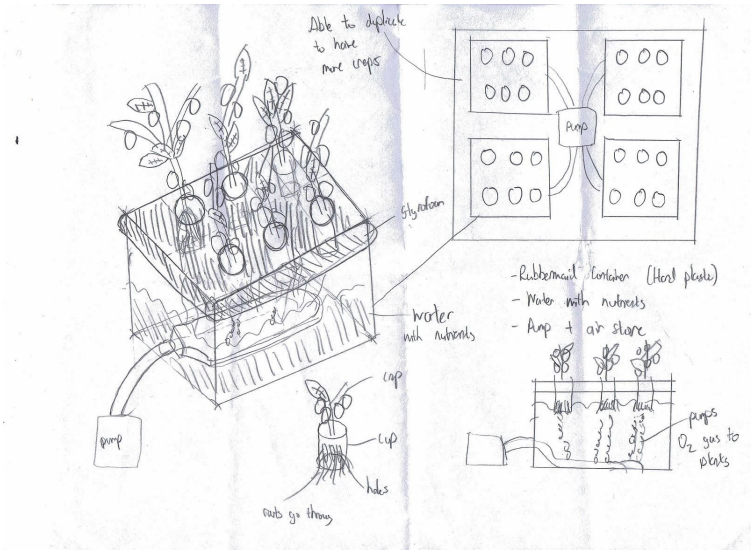

Figure 3: Andre Alvarez's conceptual design #1

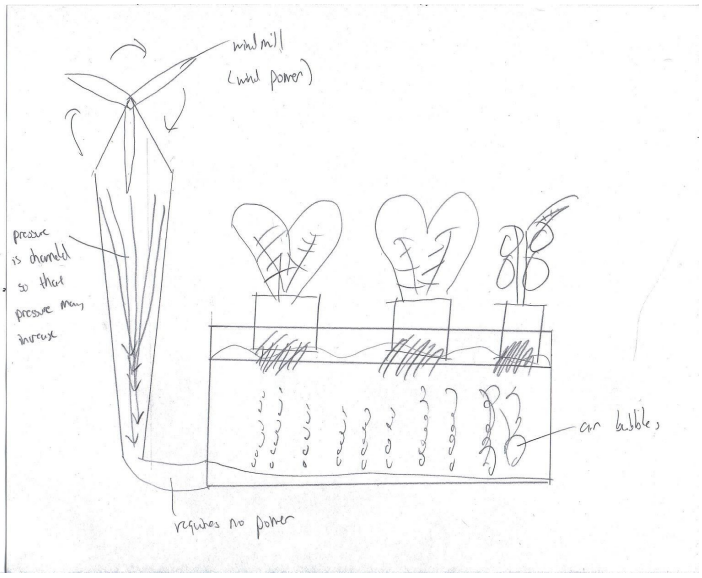

Figure 4: Andre Alvarez's second conceptual design #2

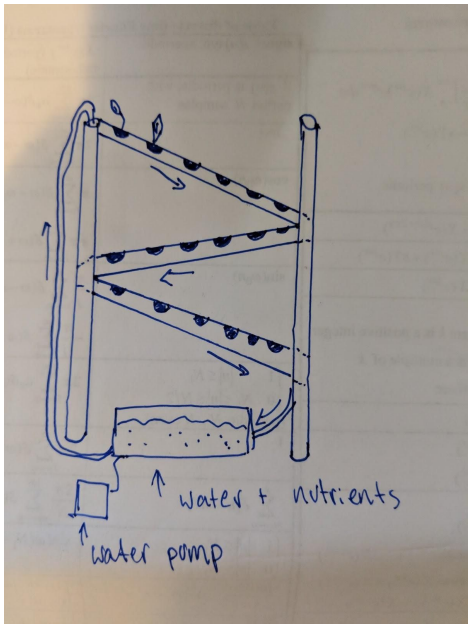

Figure 5: Haozhou Huang's conceptual design

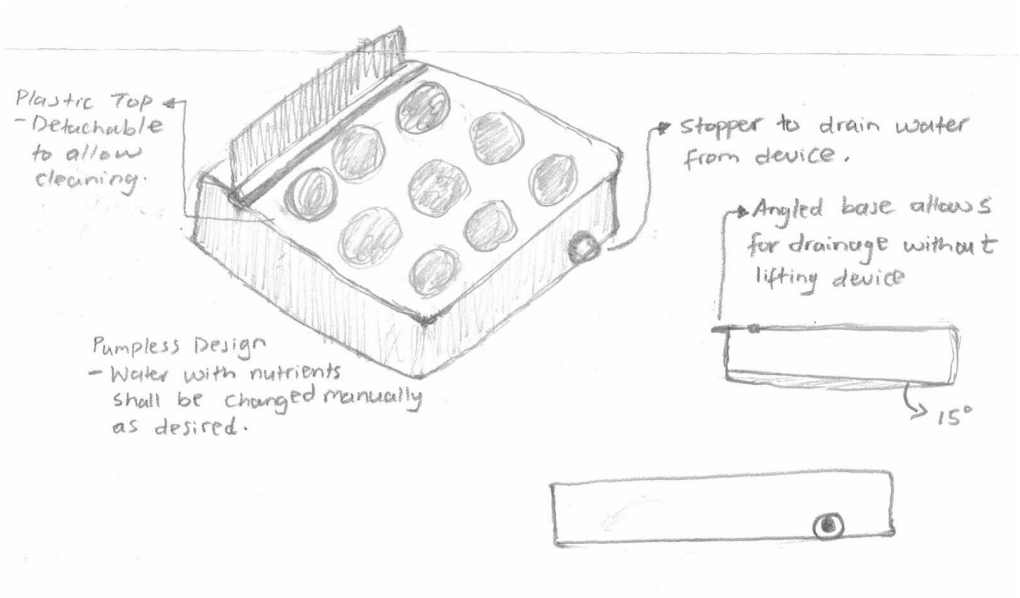

Figure 6: Prince Nimoh's conceptual design #1

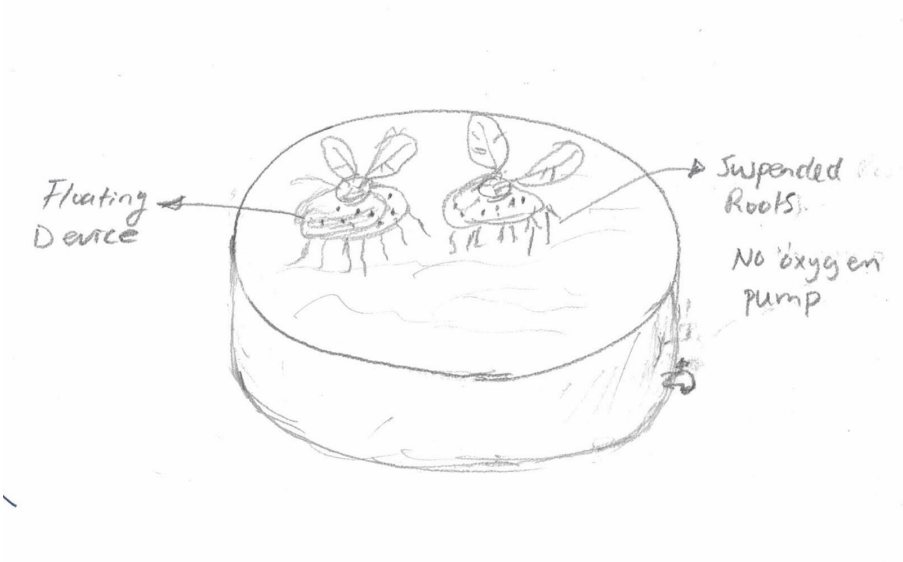

Figure 7: Prince Nimoh's conceptual design #2

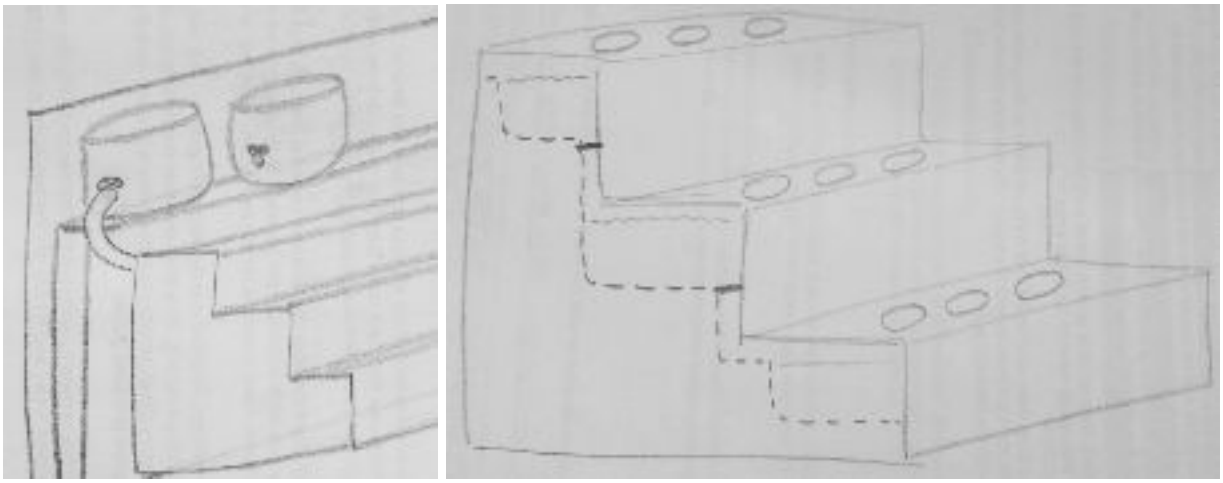

Figure 8: Carolina Ortiz's conceptual design #1

Concept Analysis & Selection

Our design criteria determined several needs for our system. The $100 budget was the primary limiting factor. After considering the information obtained from the client meeting, and the goal of the overall project, it was concluded the the dimensions of our system needed to be scaled to the dimensions of the greenhouse project that was being run by another group. Before the dimensions of the greenhouse were known, we tentatively agreed that our system had to be less than 60 in long by 36 in wide. Ease of use, low maintenance, and the capability to grow large volumes and variety of plants was of paramount importance, so we evaluated all of the concepts to determine which may best meet these criteria.

It was decided that Daniel's Concept 1 meet those criteria for several reasons. Firstly, the system would only have one moving part, an Air Pump. Having one main mechanical point of failure ensures that critical failures are unlikely. Furthermore, since a large water reservoir was to be used to hold the plants, a pump failure would not result in rapid death of the plants. The water would provide enough oxygen to the roots for about one day after a pump failure. The system would be easy to use as all the plants would sit in cups that are reachable and easy to change. A drainage valve was also proposed as a way to empty the water from the system with ease. Lastly, the dimensions of the container would allow many small to medium size plants to be grown at once. Other designs were also considered.

Andre's design is another version of a deep water culture system very similar to Daniel's concept 1 where the roots of the plants are submerged under water and an airstone pump oxygenates the plants by pumping air bubbles to the surface of the water. Unlike Daniel's design, this system is designed to hold fewer, but larger plants. By having less plant cups, there is more room for the plants to grow, thus this system is capable of growing medium sized plants such as lettuce, tomatoes and swiss chard.

Additionally, Andre's and Daniel's first concept are both very cost-effective and can be easily scaled up. As shown in the sketch, each container can be duplicated to form multiple hydroponics systems. Four containers are drawn that are all linked to a central pump that is able to power four air stones at once. By doing this, it can minimize the amount of air pumps that are required and power would only have to run to that single air pump.

Daniel's Concept 2 was evaluated by the group, and did not seem to be as effective a solution because it includes a pump, a table, an additional reservoir, and other small additions that would add significantly to the project costs. However, this system would be able to grow many plants, and would be easy to use and maintain.

Andre's concept 2 was evaluated by the group, and did not seem to be an effective solution because the addition of a windmill provided more cons than pros. For example, using it is a big risk because it relies solely on wind power, therefore, if there is no wind, there will be no power for the system. In addition, it adds extra costs to the budget and can be very hard to maintain and build. Three of the designs were then chosen to be benchmarked.

Table 7: Benchmarking Conceptual Designs **(Green = 3, Yellow = 2, Red = 1)**

Specifications	**Concept design**		
	DANIEL X1	**ANDRE X1**	**PRINCE X1**
System Cost ($) (4)	~ $90 - $100	~ $80 - $90	~ $70 - $80
Weight (kg) (1)	~ 6.5 kg	~ 5 kg	~ 5 kg
Dimensions (2)	(100 x 50 x 30) cm	(70 x 50 x 50) cm	(80 x 80 x 25) cm
Ease of Use (7)	Easy to use and user friendly. Can be dismantled for easy cleaning.	User friendly. Operation of device is self explanatory.	Simple to use but requires small amounts manual labour to fill device with water weekly.
Types of Crops (3)	Leafy crops (Lettuce, Celery, Kale etc.)	Thin-leaved crops (Spinach, Mizuno, Radicchio, etc.)	Bulky crops (Cabbage, Radish, Carrots, Cassava, etc.)

Build Quality & Maintenance (5)	Robust and Built to last. Requires occasional cleaning if algae begins to bloom.	Tough and sturdy. Requires occasional cleaning if algae appears.	Light but Rugged. Requires frequent change of water due to lack of oxygen pump.
Planting Capacity (6)	18 Bountiful leafy crops.	6 Nutritious crops and spices.	12 Healthy crops.
Total	**83**	**58**	**52**

* 1 = Less important and 7 = Most important

After consulting all the concepts, the team decided that a deep water culture system was the ideal solution for the hydroponics system. DWC is one of the easiest ways to produce crops hydroponically as it requires minimal maintenance and prior knowledge. The roots of the plants are submerged in the water and an airstone pump oxygenates the plants by pumping air bubbles to the surface. This airstone is powered by a central pump. The only required maintenance would be to change the water every week, to add more nutrients into the water and to occasionally scrub the containers clean to prevent a build up of algae. For these reasons, Daniel's concept 1 was chosen as the main design of the hydroponics system because it met the most number of design criteria and is the ideal solution for the problem due to its easy to use deep water culture system, its minimal maintenance, and low cost.

Prototype - Project Plans and Prototypes

List of Tasks

GANTT CHART

	Task Mod	Task Name	Duration	Start	Finish	Resource Names
1		Build Prototype I	1 day	Thu 18-10-18	Thu 18-10-18	Andre,Daniel ,Kian,Stuart
2		Finalize list of parts	3 days	Thu 18-10-18	Sun 18-10-21	Andre,Carolina ,Daniel ,Hazozhou,Kian,Prince,Stuart
3		Order Parts Online	1 day	Mon 18-10-22	Mon 18-10-22	Hazozhou
4		Make solidworks prototype	9 days	Mon 18-10-22	Thu 18-11-01	Hazozhou
5		Test Airstones & Pump/Preparing Tubing & Container	1 day	Thu 18-11-01	Thu 18-11-01	Carolina ,Prince,Andre,Daniel ,Stuart
6		Gather client feedback	1 day	Fri 18-11-02	Fri 18-11-02	Group
7		Purchase Styrofoam & Planting Pots	2 days	Fri 18-11-02	Mon 18-11-05	Andre
8		Cutting Holes for Cups/Finalize Plan for Heating/Draining	3 days	Thu 18-11-08	Sat 18-11-10	Andre,Daniel ,Kian,Stuart
9		Purchase Heating Components/Drainage Valve/Rain Barrel	5 days	Thu 18-11-08	Wed 18-11-14	Andre
10		Set up Drainage system/Heating Components/Rain Barrel	1 day	Thu 18-11-15	Thu 18-11-15	Carolina ,Hazozhou,Prince
11		Perform tests for Water flow and bubbles/complete unfinished parts	1 day	Thu 18-11-15	Thu 18-11-15	Andre,Daniel ,Kian,Stuart
12		Finalize the Build	8 days	Fri 18-11-16	Tue 18-11-27	Group
13		Review Presentation for Design Day/In-Class	3 days	Wed 18-11-21	Sat 18-11-24	Group,Andre,Carolina ,Kian,Prince,Stuart
14		Design/Construct Platforms for Reservoir & System	1 day	Sat 18-11-24	Sat 18-11-24	Group,Andre,Daniel ,Carolina
15		Connect Greenhouse Gutters to Water Reservoir/Overflow Tube	1 day	Sat 18-11-24	Sat 18-11-24	Kian,Hazozhou,Prince,Stuart
16		Purchase Heating Lamp Fixture	1 day	Sun 18-11-25	Sun 18-11-25	Daniel
17		Assemble System in the Greenhouse	4 days	Mon 18-11-26	Thu 18-11-29	Group
18		Design Day (Build must be Finished)	1 day	Thu 18-11-29	Thu 18-11-29	Group

Figure 9: List of Tasks

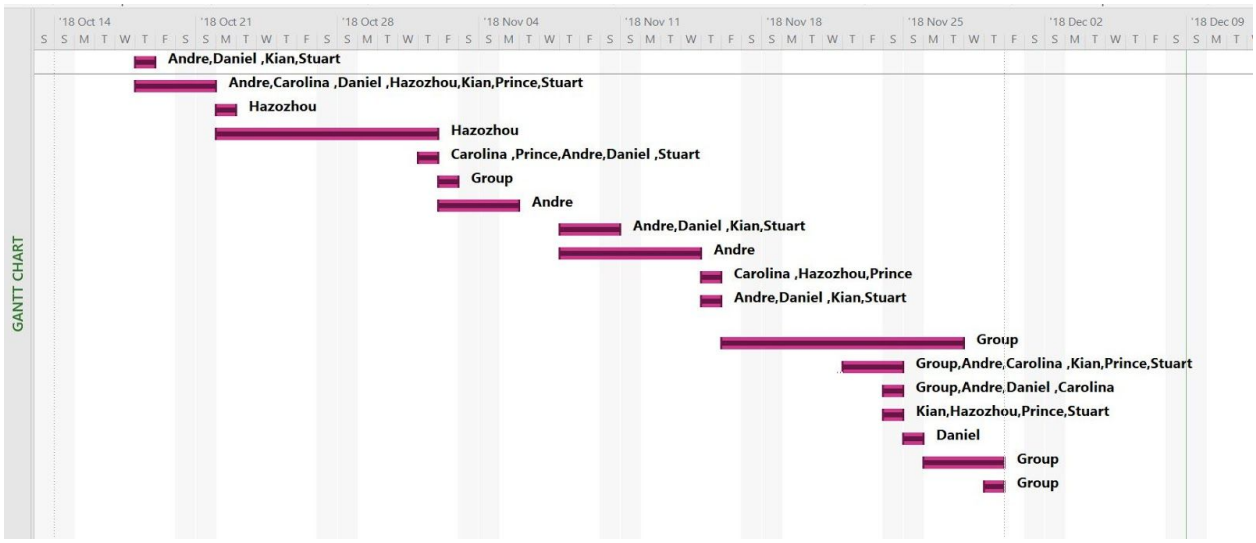

Figure 10: Gantt Chart

Prototype

Prototype I

The purpose of the first prototype was to take our conceptual designs and turn them into a physical representation. This provided insight on the scale and dimensions of the system, and to gauge whether the system is feasible.

Figure 11: Prototype I Top View

Figure 12: Prototype I Side View

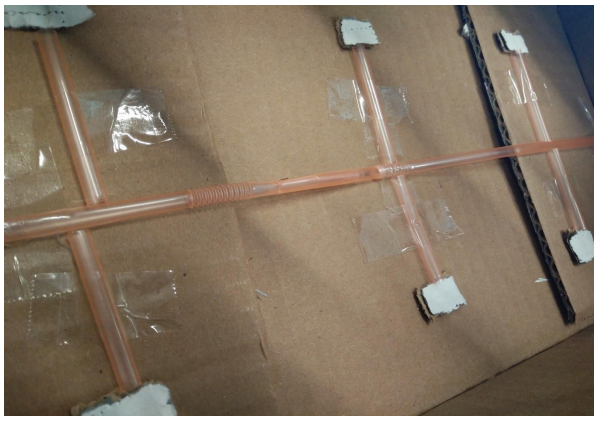

Figure 13: Prototype I Inner View

Figure 14: Prototype I Cup View

Figure 15: Prototype I with Cups

Customer Feedback & Refinements for Prototype I

Due to the simple, no moving parts design of our first prototype, there are not many ways that one can test the prototype for functionality. The prototype did provide a 3D representation of our system, as opposed to the 2D representation of our design sketches from the previous deliverable. We were given an idea of the scale of the solution and where certain components of the system, such as the air stones and planting pots, had to be relative to other parts of the system.

The simple design did help foster discussion about what would be required for the fully functional, full-scale solution. Firstly, it was noted that the air pump would have to be raised above the water level so that water does not drain in reverse through the air hose and destroy the pump. Another design feature that was discussed were the air stones. In our first prototype we had 6 air stones. Seeing as our conceptual design suggested between 18-24 plants, it would require lots of tubing and air stones if our full design was to have an airstone per plant. It was discussed that fewer large air stones could simplify design.

Our first prototype was a low comprehensive physical prototype. Because of the lack of working mechanisms, it was hard to test functionality for our final prototype. However, this prototype allowed us to have a better picture of what our final prototype would represent, and was a catalyst to discussion about future challenges that we may face with our design.

Prototype II

The purpose of the second prototype was to test the most critical aspect of the project. For a Deep Water Culture System, having oxygenated water is crucial to the speed of growth, and the healthiness of plants. The Air Pump and Air Stones are the two system components that are pivotal to the operation of our system, so it was decided to test these components first.

Furthermore, a Solidworks model of our system was to be developed to aid in our client's understanding of our design, as well as give us a visual reference to help guide the rest of our project. The solidworks model is a basic 3D model of a visualization of our hydroponics project. It is not a fully defined representation of our final project but it does include our planting pots, drainage system, and airstones.

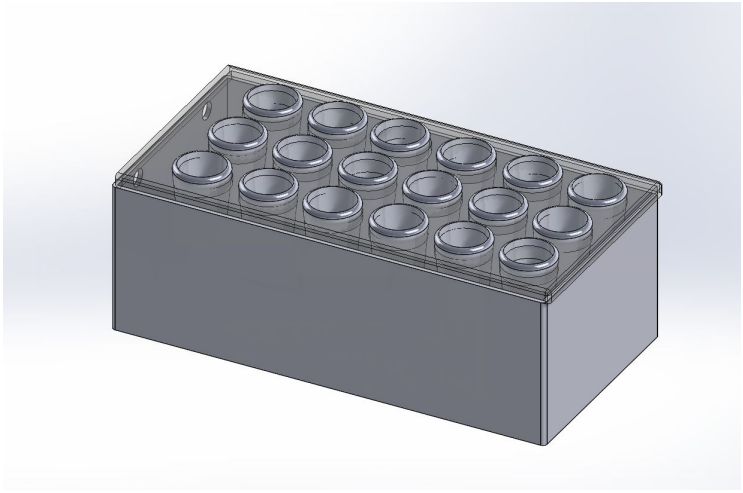

Figure 16: Prototype II Side View

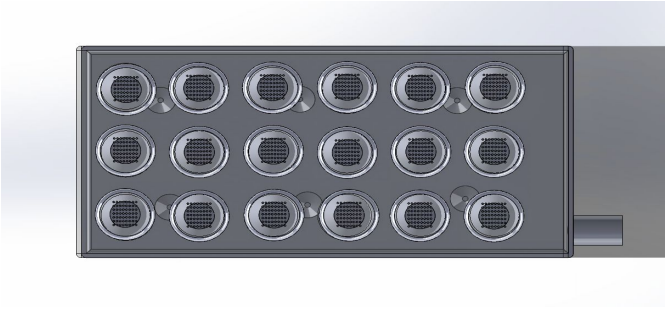

Figure 17: Prototype II Top Down View

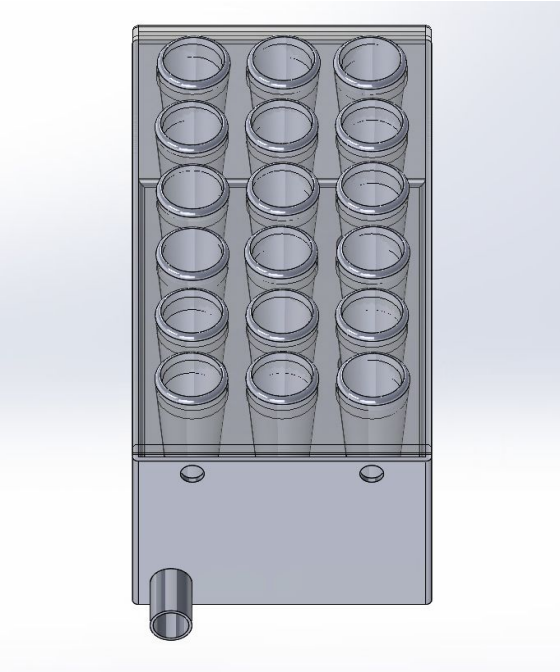

Figure 18: Prototype II Front View

Test Plan & Results for Prototype II

Goal:

Purchase an Air Pump and Air Stones, then determine whether they will effectively aerate the growing solution.

Process:

1. Research Air Pumps and determine what will be needed for our system with regards to power consumption, pump strength, and build quality.
2. Research Air Stones to find out what shape, size, and type of Air Stone would best match the size of our reservoir, the budget constraints of the project. Build quality and reliability must also be taken into account.
3. Purchase the selected components.
4. Assemble the Pump and Air Stones in the Reservoir and turn on to ensure all work as expected.

Results

We knew that the solar panels provided for the project have a maximum power output of 260W. We knew that heating for the greenhouse would use up the majority of the power that the panels could supply, so we focused on searching for low power pumps. A 4W pump with 2 tubing connector outlets was found. User reviews demonstrated that the pump had enough power for more than 4 Air Stones. As a bonus, this pump also came with two small disc Air Stones, some tubing, a check valve to prevent flow back into the pump, and a T-connector to connect two Air Stones to one tube. The pump was also inexpensive and small, and appeared to meet our needs best.

Air Stones come in many styles, shapes, and sizes. Our search was narrowed down to two 8 inch Air Stone Cylinders, four 4 inch rectangles, or four 1.6 inch discs. Reviews for the 8 inch Cylinders were mostly positive, with some people stating that they needed a higher power pump than what was specified in order to get any bubbles out of it. Due to the limited power of our chosen pump, smaller Air Stones appeared to be the better option. The 4 inch rectangles were a great value, however some user reviews stated that the stones would leak air at the connection point. Other reviewers said that the stones quickly lost ability to create bubbles after a few months. The 4 pack of 1.6 inch had very positive reviews, but their small size left some uncertainty as to whether they could output enough bubbles to properly oxygenate the growing solution. The 4 pack of 1.6 inch stones were chosen.

After purchasing the Pump and Air Stones, and scavenging a reservoir and extra tubing from a past group's project, we began to assemble our system. The reservoir was partially filled with water, and the Air Stones were submerged for about an hour before use. The tubing was cut to size and two T-connectors were used to connect four of the Air Stones. The Pump was plugged in, and bubbles emanated from two of the Air Stones. A small hole was found in one of the pieces of tubing, so that piece was swapped out for another. No more leaks remained, and all of the Air Stones were deemed functional.

Customer Feedback & Refinements for Prototype II

By testing the Air Pump and Air Stones first, and developing a 3D model of our project, some of the uncertainty and risk associated with our project has been nullified. The assembly of the second prototype instilled confidence in the Pump and Air Stones. The 3D model gave members of the group a clearer understanding of what the final system may look like, and will help guide our next prototype and future progress. By iterating on the progress we have made with our second prototype, we are confident that our design is achievable.

Prototype III

After showing our updated prototype to our client, we received helpful feedback on how to work on our final prototype. After discussing our prototype II and our plan on what to include for our hydroponics system, our client gave us feedback and approved us to start on the final prototype.

Test Plan & Results for Prototype III

Goal:
To Continue construction of the Hydroponics system using items already purchased, as well as decide on the method of implementation of the heating and water collection systems.

Process:

1. Purchase styrofoam insulation lid for Water Reservoir
2. Cut holes for the planting cups to rest in. Hole Diameter must be chosen to maximize the number of planting cups while remaining structurally strong.

3. Continue research on greenhouse heating systems, and deciding on the proper solution(s) for our project.
4. Decide on the criteria for the water storage reservoir.
5. Find 3D-printable alternative to costly drainage valve.

Results

Insulation styrofoam was chosen as the lid of our Hydroponics system because it is more rigid than most traditional packing styrofoams, has some UV resistance, and floats. This buoyancy property will allow the plants to rise and lower with the changing water level in the reservoir. If the plants consume water quickly, this will allow the plants to always have access to water, regardless of whether or not the water level has been adjusted frequently.

It was decided to use plastic drinking cups as our planting pots because alternatives from stores were much more expensive, and we could not find the sizes needed at a reasonable price. The cups are easy to replace, and a good size for the small to medium sized plants that we are aiming to grow with our system. The size of cups chosen allowed us to find a balance between the size of plants, the number of plants, and the spacing between each plant that we think will match the needs of our clients.

The circles have a diameter of 8cm. This is less than the actual 9.3cm diameter of the cups. This allows the cups to sit above the styrofoam, allowing for more material to be left for structural purposes, while still maintaining the same number of planting pots. The ridged design of the cup also helps keep the cup in place.

Figure 19: Prototype III Styrofoam with Holes

Figure 20: Prototype III Cross-Section of Styrofoam Sheet & Cups

Customer Feedback & Refinements for Prototype III

The next goal to be reached for this prototype was to decide on the heating system. The constraints on possible heating solutions were very limiting. Not only were we able to budget approximately $50 towards the heating system, but we also had to contend with the 260W maximum power output of the solar panel, as well as the limitations of the included battery. Conventional space-heaters had 500W and greater power requirements, so we had to find alternatives. It was decided that a plant-focused heating solution would be necessary. It was decided that a 50W aquarium heater, and a 100W heat lamp would be our best option. The aquarium heater ensures that the water in the reservoir doesn't reach freezing temperatures, while the heat lamp will be hung above the system and heat the air around the plants.

On top of electrically based heating systems, some other methods can be employed to heat the greenhouse. By filling water bottles with water, painting them with matte black paint, and positioning them around the greenhouse, solar energy can be absorbed into the water during hours of sunlight. The energy is then released during the night. Furthermore, our rain collection barrel and Water Reservoir can also act as thermal masses.

The next aspect of the project to be decided for this prototype was that of the water storage system. Criteria decided on was that the volume of the container must be greater than that of the Hydroponic System water reservoir so that the system could be completely re-filled at once. The barrel would also have to be made of a soft plastic so that drainage holes could be drilled into the side without cracking. Lastly, if a black barrel was to be found, that would help the water storage double as a thermal mass for heating.

Lastly, a cheaper solution for adapting our water storage system and water reservoir for pumpless drainage than the solutions described in the deliverable E parts list had to be found. A 3D model was found that appears to offer the same functionality of the previous solution. Time will have to be alloted to print out the adapter and valve to ensure that they will meet the needs of our system.

By finding a suitable product and material for the lid of our Hydroponics system, as well making the cutouts for the planting cups and testing the fit, we were able to confirm that our system is able to hold a suitable number of plants for the client. The choice to use the plastic drinking cups from our original prototype as planting pots ensure we were able to meet our budget specifications, without compromising the quality, reliability and maintenance level of our system. Selecting a 50W aquarium heater (as opposed to our previous idea of a conventional space heater) for heating the water inside the system allowed us to stay within the 260W maximum output of the solar panels, and using a 100W heating lamp helps maintain a warm temperature in the air surrounding the plants. The implementation of both these heating solutions allowed us to fulfill our client's need for keeping crops alive in temperatures as low as −40℃. Finding the water bottle heating method for keeping the greenhouse warm, along with the possibility of utilizing the rain collection bottle and water reservoir as heating agents. The results of this prototype were used to iterate and guide our project to completion.

Test - Testing and Final Analysis

Cost Estimate

With the main prototypes completed, and significant portion of our systems components purchased or decided on, we put together a cost estimate graph to give us an idea of the remaining costs associated with completing our project.

Table 8: Cost Estimate

Item	**Cost**
102L HDX Black Box	$12.99
Polyethylene Tubing, 3/16 Inch Inside Diameter X 5/16 Inch Outside Diameter X 10 Ft Coil	$5.28
2 Drainage Valves	$7.00
170L Water Reservoir	$104.99

(2x3's and 2x4's) Wood to build platform	$42.00 ($3.50 Each)
Blue Plastic Cups	$5.57
Styrofoam Project Panel (2ftx2ft)	$8.48 (tax incl.)
4 Pawfly Airstone Bubblers	$11.99
4W Pawfly Air Bubbler	$20.80
100W Heating Lamp	$19.55
50W Water Heater	$19.00
Heating Lamp Dome	$10.00
Cost Estimate	**$267.65**
Tax Estimate	**$34.79**
Total Cost	**$302.44**

Final Development

After Prototype III was completed several adjustments were made to our design. Firstly, the water collection reservoir discussed in the prototype II section was to be decided on. Searching for large water reservoirs or rain barrels online and in stores provided a bleak view of the costs associated with such barrels. Our search was narrowed by the fact that the water reservoir was to have a volume larger than the 102L container we had already procured for our Hydroponics System and for prices below $20. A large cut in half barrel that was left by a previous engineering design group was found outside of Colonel By. It was filled with ice and rocks, but had a Spigot already in the bottom and fit the dimensions required. The barrel was drained and cleaned and outfitted with a valve and tubing to act as water collection reservoir for our system.

The heat lamp and water heater that were decided on for Prototype III arrived and could be tested. The clamp lamp fixture that was found from a previous year's project did not have a ceramic or heat resistant fixture, and thus could not be used to hold our heat lamp. A clamp lamp with a ceramic fixture was found online for $10, much lower than the $30 price associated with buying it new on Amazon. The heat lamp and water heater were both tested.

We also realized that in order to stop the cold from leaching into our system from the flooring, and to allow a gravity based system refilling method, that we would need to build platforms for the system and the water reservoir. Budget was not quickly allocated towards the wood to build the platforms as we knew that the greenhouse groups would have some leftover after building their structures. Once the greenhouses were nearing completion, two platforms were designed and built with the remaining wood.

Project Pictures

Figure 21: System Side View

Figure 22: System Top View

Figure 23: System Front View

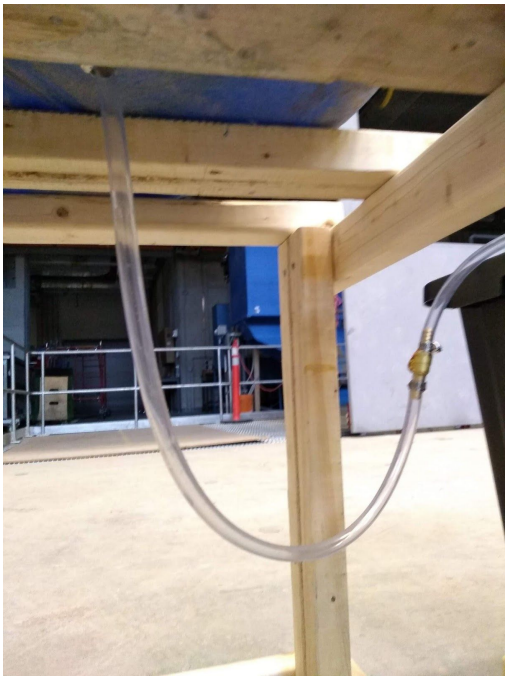

Figure 24: Connection Between Water Reservoir & System

Figure 25: System Back View

Total Amount Spent

Due to the items found from past year's projects, and plenty of research into finding cost effective solutions, the actual total costs associated with the project were much lower than the estimated cost.

Table 9: Final Cost

Item	**Cost**
102L HDX Black Box	FREE
Polyethylene Tubing, 3/16 Inch Inside Diameter X 5/16 Inch Outside Diameter X 10 Ft Coil	FREE
2 Drainage Valves	FREE
Water Reservoir	FREE
(2x3's and 2x4's) Wood to build platform	FREE
Blue Plastic Cups	FREE
Styrofoam Project Panel (2ftx2ft)	$8.48 (tax incl.)
4 Pawfly Airstone Bubblers	$11.99
4W Pawfly Air Bubbler	$20.80
100W Heating Lamp	$19.55
50W Water Heater	$19.00
Heating Lamp Dome	$10.00
Total Cost	**$89.82**

Conclusions and Recommendations

Challenges Faced

- Budget constraints: As noticed in the list of cost of materials we used, some of them were provided. We saved money by having access to past year's projects and finding free materials. Had we not been able to find all of these free materials, we would have had to make compromises on other areas of the project. Furthermore, the budget restricted us from higher quality planting cups and styrofoam lid.
- Heating constraints: Although system has a localized heating solution consisting of a water heater and a heat lamp, these solutions would not be able to heat the entire greenhouse through cold nights. Our solution is believed to be effective considering the budget and power constraints, however with more money a more effective heating solution could be purchased.
- Time constraints: By the end of the project period, our design could have still been improved with more time. We could have bought or made a more robust drainage valve for the hydroponics system.

Lessons Learned

We learned how to work with a real client and how to apply the design thinking methodology to a real problem in order to come up with a solution that satisfies the needs of the client. We learned about the importance of time management and how a project plan helps a lot. Since all the members of the team had different schedules, finding spaces where everybody was available to work was crucial for the development of the product. Those spaces needed to be efficient, so having a project plan helped to keep us on track and know what to do in each session.

Areas to Improve and Future Refinements

With increased time and budget, several refinements could be made to our design. Some of these refinements could include:

- Better planting cups
- Better heating for greenhouse + new solar panels and larger battery
- Could make pop-can solar heater as an effective electricity-free heating solution
- More robust drainage valve for Hydroponics Water Reservoir
- More powerful Air Pump and larger Air Stones
- Fitted lid for rain collection barrel (to stop algae growth)