Design Project: Hydroponics for Dorms

GE 1502: Cornerstone of Engineering II

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Ciana Cunningham, Lauren Dunne, Justin Ho, Evan Hostetler, Grace Jansen

Cover Letter

Dorm Hydroponics seeks to address the fact that college students, including those on traditional meal plans, lack reliable access to fresh produce. Simultaneously, some students report experiencing food insecurity, or would appreciate additional clarity regarding the sourcing of produce used in campus dining halls. Enabling students to cultivate their own vegetables and herbs on a small scale may assist in alleviating their nutritional concerns, allowing them to grow more connected to the origins of their food, and cut down on greenhouse gas emissions associated with the global transportation of produce. Project functions, designs, and constraints were established with the target audience in mind. The system was required to remain affordable, simple to operate, and small in size, while simultaneously providing meaningful metrics to the user to monitor the status of their plants.

Numerous avenues for a potential hydroponics system were considered, both horizontally and vertically-oriented. Preliminary designs included a vast array of features, including LED grow lights, rotational aspects, aeration pumps, LCD display screens, and sensors measuring UV index and total dissolved solids. After weighing the relative merits, costs, and feasibility of each of these initial design paths, a vertical hydroponics system constructed from 3” PVC piping was selected. The final proof of concept included two sensors, a display, and a website framework. If further development of Dorm Hydroponics occurred, the website would be updated with real-time sensor data and augmented with supplemental tutorials and resources. The prototype functions by pumping water to the uppermost layer of the system, before gradually flowing back down to the reservoir. The pumping mechanism ensures that the nutrient solution is distributed homogeneously throughout the system. The sensor and display subsystem of the design is controlled by a coded Arduino Uno and powered by battery packs. A wooden frame supports all aspects of the design, while concealing the electronic components, enhancing the aesthetic appeal of the final product.

Throughout the process, the design team learned the importance of following the design process procedure in the proper order. More time should have been allocated to designing the housing and positioning of the electronic system before the onset of the build. Additionally, we were reminded that a design may take multiple iterations and go through numerous stages as more information is gathered. For instance, an ethical concern was raised when it was recognized that PVC may cause chemical leaching into water. By the conclusion of the project, the group had a firmer understanding of how to make design decisions based on the needs set forth in a problem statement.

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Definitions

Duncker Diagram - A Duncker Diagram is a problem-definition technique which explores two major avenues to achieve a desired state. One pathway focuses on designing a solution to reach the desired state, and the other pathway centers around generating ideas which would make it acceptable not to reach the desired state.

Grow Lights - Lights engineered to act as a substitute for natural sunlight, often taking the form of LEDs

Hydroponics - A farming technique utilizing circulating water & a nutrient solution instead of soil; allows for the precise control of plant growth under space constraints.

Kepner-Tregoe Decision Matrix - The Kepner-Tregoe Decision Matrix forces engineers to break components of the desired state into “needs” and “wants.” A design is deemed a “GO” if it fulfills all of the “needs” and otherwise discarded. Ideas which advance past this preliminary check are compared based on their ability to fulfill the design “wants.” The “wants” may be assigned various weights to indicate their relative importance.

PPM - Parts per million; unit used for measurements of very low concentrations of substance in a solution

TDS - Total dissolved solids; a measurement of suspended compounds (organic and inorganic) in a fluid

UV - Stands for the UV index, which measures the presence of ultraviolet light on a 1-11 scale

Executive Summary

Many college students struggle with the harsh adjustment to diets without fresh veggies. Even with large-scale healthy eating and fresh food initiatives, it still remains tough for many to access garden fresh veggies. Many attempts have been made to aid students in the acquisition of fresh produce, however, no solution has stuck around. One of the first challenges that applies to college students is the lack of financial freedom to invest in an expensive solution to their food needs. As hydroponics grows to become an increasingly popular means of farming food, it is apparent that there are no solutions that fit a college student's needs and lifestyle that are small enough to fit in college dorms, cheap enough for a college student's budget, and simple enough for someone without experience to use.

The process of solving this issue required many different steps and involved many iterations of the whole cycle and individual steps. Many companies and individuals have developed similar solutions to adjacent problems; however, a design unique to the previously defined issue was necessary and so far nonexistent. One of the first steps of developing a solution to the problem was brainstorming new and unique possible solutions. Different brainstorming methods were used including the C-Sketch method to generate different solutions for the problem. To move the solution along, individual solutions had to be selected to implement in the development of a prototype. To decide, several different decision-making aids were utilized including: a Kepner-Tregoe Decision Matrix, Rank Order Charts, and Pros and Cons Tables. These comparisons helped finalize an initial design idea to be used for prototyping.

Implementing this design in an initial prototype proved to be the most time consuming portion of the engineering design process. The first major task of this portion was acquiring all necessary materials to begin constructing and fabricating the prototype. This consisted of modeling pieces with Computer Aided Design software and using machinery to make alterations to materials including PVC piping. Throughout this stage, frequent alterations were necessary as certain ideas did not work or new ideas were generated. During this step, the design process became very cyclical and consisted of constant design changes. Many individual components were tested along the way, and the team took advantage of engineering practices including "proof of concept" to illustrate how individual components of the design will function in the final design.

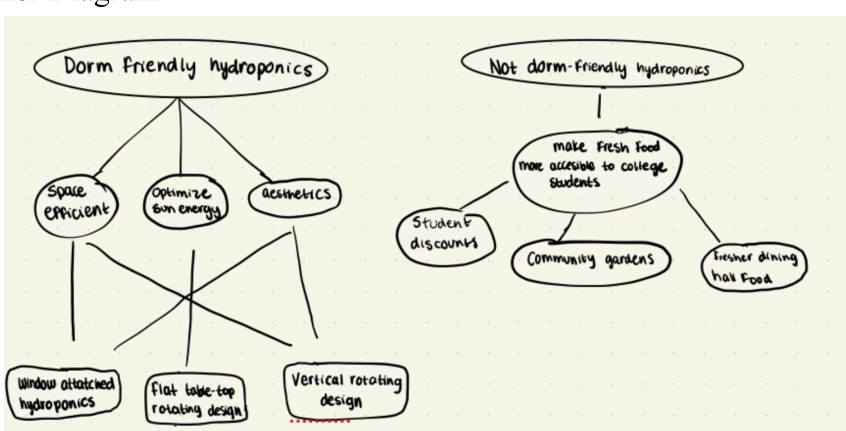
At this point, a final design was manageable, as the engineering process had been applied to each individual need and requirement illustrated in the problem statement. The team worked to compile all elements of the prototype into a single design. Upon completing this final design, it was necessary to test the design according to the pre-defined success criteria, and discuss whether certain changes might be necessary or not. In this reflection, it was found that the design satisfied all goals and constraints of the problem and served as a solution to the identified issue.

Section 1: Problem & Definition

College students reliant on dining hall meals lack consistent access to fresh produce. There is little consistency in dining hall offerings, especially for students with dietary restrictions, allergies, or those following a vegetarian diet. Moreover, some students lack access to the halls entirely. "According to No Hungry Huskies. . . 25% [of students report] facing food insecurity," in part due to the rising cost of Northeastern University's meal plans (Plynton). Additionally, no transparency is offered regarding the sourcing of ingredients. With sustainability standing as one of today's key focus areas, progressively more students are cognizant of the environmental impacts of the food they eat and the social impacts of its production. In fact, "Studies estimate that… fresh produce travels over 1,500 miles, before being consumed" (Hill). Enabling students to cultivate their own food within the limited spaces they are allocated could alleviate some of their nutritional concerns; however, it will simultaneously allow them to take one step towards a more sustainable lifestyle.

To address the aforementioned issues, a student-centric, dorm-friendly hydroponics system was proposed. In order to determine whether this solution was worth pursuing, a Duncker Diagram (Figure 1) was created to weigh different pathways from the present state to the desired state: granting students access to fresh produce. To nullify the need for a dorm-friendly hydroponics system, an alternative solution, such as student grocery discounts, free community garden plots, or improvements to student dining options, would have to be implemented. Since campaigning for widespread policy change takes vast amounts of time and resources, engineering a hydroponics system was deemed appropriate. With an affordable product, students can take independent action to fulfill their needs.

Figure 1. Duncker Diagram



As it stands today, students do not have the requisite knowledge, funding, or space to produce their own hydroponically-grown vegetables. After all, "As of the first quarter of 2023, student loan debt in the U.S. [stood] at a total of over $1.77 trillion" (Safier). It is abundantly clear that the typical student cannot afford existing hydroponics systems, especially with the average hydroponics system costing between $300 and $1,000 in the United States. Even technologically-minimal systems range in price from approximately $50 to $200 (Ogletree & Dudley). Therefore, any design generated to address this issue must remain inexpensive, small in stature, and easily operated by the average university student. The design should output useful metrics to an integrated display to inform the user whether their plants are receiving adequate sunlight and nutrients. Ideally, the sensor data will also sync to a website so students can check on their garden via their mobile device or laptop. Along with sensor data, a website should feature tutorials and troubleshooting guides to provide a pleasant and straightforward user experience. Finally, aesthetics must be considered in order to appeal to the target demographic. These functions, objectives, and constraints for a successful design were organized into a chart in Table 1.

Table 1. Design Functions, Objectives, & Constraints

Functions	**Objectives**	**Constraints**
- Enable the growth of plants in the confined space of a dorm room while maintaining ease of use	- Output sensor data to a display screen, allowing the user to monitor plant growth conditions - Produce a website which displays sensor data & provides tutorials - Produce an aesthetically-pleasing product that appeals to students	- Obey Northeastern University's Housing & Residential Life policies - Budget of $100

Afterwards, the comparative weights of design goals were determined using a Rank Order Chart, included as Table 2. Based on the chart outcomes, it is most critical that the hydroponics design remains economical. To meet this objective, the final product must not exceed our budget of $100, which is a reasonable upper-limit for a functional product marketed towards college students. Producing a small system was also deemed integral to the success of our dorm hydroponics. A design fulfilling this criteria must take up more vertical space than horizontal space, be comfortably carried by one individual, and be no more than approximately two feet in length. Finally, at least two useful metrics must be exhibited to the user, such as the level of UV light, the water level in the system, the pH of the water, or the total dissolved content of the water. The latter two metrics assist in tracking the presence of nutrient solution in the circulating water.

Table 2. Rank Order Chart

Objectives	Low Cost	Small Size	Aesthetically Pleasing	Provides Sensor Data	Syncs with Website	**Sum of Rows**
Low Cost	--	1	1	1	1	4
Small Size	0	--	1	0.5	1	2.5
Aesthetically Pleasing	0	0	--	0	0	0
Provides Sensor Data	0	0.5	1	--	1	2.5
Syncs with Website	0	0	1	0	--	1

Although the design team had a cursory understanding of hydroponics, further research was conducted on the subject. Special attention was directed to any technical aspects essential to the development of a successful hydroponics system.

In brief, hydroponics is a farming technique which relies on the circulation of water through a network of pipes. In lieu of soil, plants are grown in an alternative medium, such as coconut husks, perlite, rockwool, gravel, pumice, or clay pellets. These mediums assist in the stabilization of the plant, giving the roots a surface to cling to (Boylan). Regardless of the media selected, it should be sterilized via steam or chemical methods before use to avoid a buildup of pathogenic microorganisms in the system (Kratsch). Typically, the plants and their media are placed in net pots, which are simply pots with slits in the sides which allow water to pass through readily. Net pots of various dimensions can be purchased online, 3D printed, or otherwise fabricated from readily-available materials.

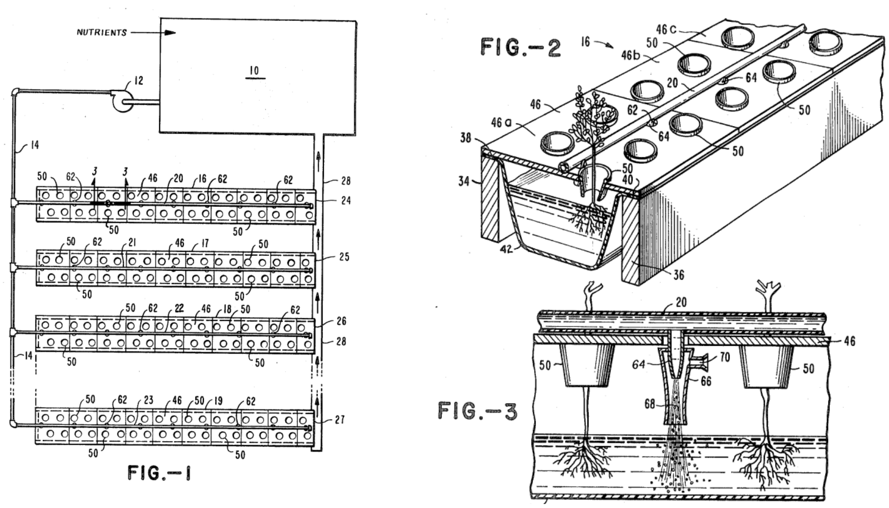
A nutrient solution containing compounds crucial for plant growth must be added to the circulating water. It is possible to purchase fertilizing solutions specific to a given crop type to maximize growth; however, all nutrient solution formulas contain “nitrogen, phosphorus, and potassium. . . calcium, magnesium, sulfur, manganese, iron, molybdenum, copper, zinc, boron, chlorine and nickel” in various concentrations (Hoidal). It is important to note the composition of a nutrient solution before adding it to a hydroponic system, as ammonium or nitrate-based fertilizers may alter the pH of the water. Plants tend to thrive between pH 5.4 and 7; therefore, it may become necessary to monitor and manipulate the pH of circulating water to ensure that it remains within this critical range (Hoidal).

One of the key benefits of hydroponics is that it can be used year round indoors regardless of climate-related factors such as the availability of sunlight, temperature, and adverse weather events. Moreover, it eliminates the need for weeding and the use of pesticides.

According to Columbia University's Mailman School of Public Health, pesticides such as the widely-used DDT have been linked to breast cancer in humans. Thus, health-conscious individuals or proponents of organic foods may prefer hydroponically-grown produce. Additionally, hydroponic plant growth tends to be more rapid than plant growth observed using conventional growing methods. Aerating the circulating water increases the amount of oxygen that can be accessed by the plant, leading to an increase in photosynthetic activity. Finally, hydroponics reduces overall waste by recycling the water and nutrients within the system (Shrestha & Dunn). Despite these positive aspects of hydroponics, there are some notable negatives associated with the growing method. Start-up costs for hydroponics farms tend to be significantly greater than conventional farms due to the need for pumps, tanks, and controls alongside accessory items such as LED grow lights. Furthermore, hydroponics systems require a consistent input of electricity in order to run. Finally, a certain level of expertise is required in order to operate most hydroponics farms (Bartok).

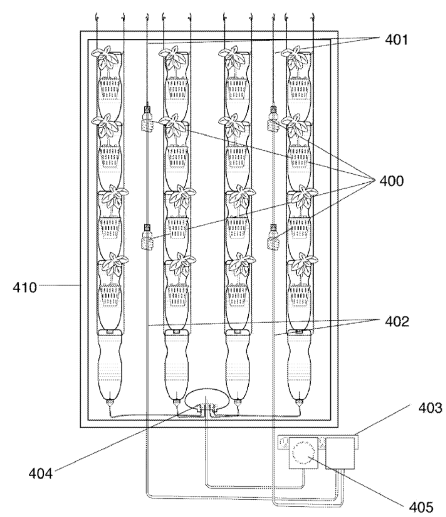
Numerous patents exist for hydroponics systems, each operating at different scales and including different sets of features. Figure 2 depicts a patented design for full-scale crop production in a larger farming venture. This design is notable due to its plurality of nutrient solution dispenser outlets. Moreover, "Each outlet has an associated aspirator…[which provides] uniform aeration of the nutrient solution" (Wong). Due to the comparatively small magnitude of our design, a single inlet for nutrient solution will likely suffice. However, reviewing this design highlighted the importance of maintaining a uniform concentration of nutrients and promoting water aeration in all regions of the system. Thus, our design will be examined to identify any regions of water stagnation. Moreover, Wong's patent is significant for its horizontal layout, which seems to be suboptimal. Despite the existence of patented horizontal hydroponics designs, "The vertical integration of plants allows for farmers to optimize the total space usage of their growth area, making it possible for farmers to reduce their land use by up to 90-99% while also increasing productivity" (Boylan).

Figure 2. Patented Large-Scale Hydroponic System (Wong)



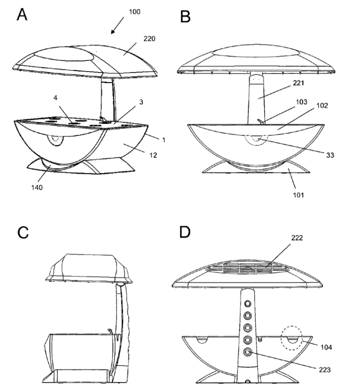
Britta and Ulrich hold a patent for an in-home vertical hydroponics system, depicted in Figure 3, which assumes a “vertical column grid orientation that optimizes use of available sunlight coming through a window.” Plastic bottles are utilized as suspended plant containers. A pumping mechanism positioned below the primary assembly transports water to the top of each vertical chain of plants, where it then drips downwards. The designers claim that, due to the spacing between plant columns, the hydroponics system does not markedly reduce the amount of light allowed to enter a room. On the other hand, the exposed wiring and piping poses an aesthetic concern. In addition, the drip-down mechanism and minimalistic pot suspension system lead to concerns about leakage and the tipping of plants. That is not to say that this design is without merits: it may be worth considering a window-mounted design or the use of recycled materials in a student-centric hydroponics system.

Figure 3. Patented Window-Mounted Hydroponics System (Britta & Ulrich)



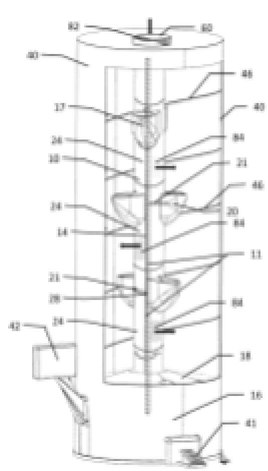
Next, a modestly-sized countertop hydroponics system (Figure 4) was evaluated. The holders of the patent integrated a display panel featuring the time elapsed, notifications when the water or nutrient solution levels drop, and settings for the lighting cycle which can be arranged to emulate a typical day-night cadence. They recognize that “A challenge in consumer level hydroponics is incorporating a reliable method for reminding the user to regularly care for the growing plants” (Bissonnette et al). However, their overhead grow lights (referred to as the “photoradiation hood”) generated sufficient excess heat that a set of vents were deemed necessary. Consequently, if grow lights were incorporated in the dorm-room hydroponics design, this heat buildup must be considered. Finally, while this design negates the need for a pump, it lacks a clear method for water aeration which may have a detrimental impact on overall plant growth.

Figure 4. Patented In-Home Hydroponics System (Bissonnette et al)



Upon breaking into the middling price range for ready-for-use hydroponics systems, vertical column designs represent a dominant force on the market. The patented design depicted in Figure 5 represents one such column design, which also includes a rotating aspect. This design utilizes a novel approach for water aeration, employing a “fan mounted in a roof panel to supply ambient air to the hollow interior of the planting column” (Sperry). Additionally, “an optional modular greenhouse enclosure can be used for plant protection and climate control” (Sperry). This introduces a variable not yet considered in the scope of this report: ambient humidity. On the other hand, considerations for humidity and other environmental concerns likely exceed the capacities of a small, affordable hydroponics system. There are relatively simplistic methods to add humidity to a garden if a particular plant requires it, such as misting with a spray bottle. These procedures could be detailed within a user guide or on a website. While this particular design includes LED grow lights, negating any UV loss due to the greenhouse enclosure, a similar housing may not be appropriate for a design lacking artificial sunlight. Similarly, a rotating design would not be advantageous if it inhibits some plants from accessing sunlight for long durations of time.

Figure 5. Patented Vertical Rotating Hydroponics System (Sperry et al)



Section 2: Generate & Decide

The brainstorming process for this project was time consuming with several designs being considered until the final design was settled on. One method used to help generate ideas was the C-Sketch method where each member of the group drew an idea. Circular bases, rectangular bases, and upright structures were drawn, but the upright design where the water flowed back and forth was our favorite, and a modified version of it is what was eventually built. Figures 6, 7, and 8 were alternative designs, but Figure 9 is the first draft of the actual design.

Figure 6. Rectangle Base Design

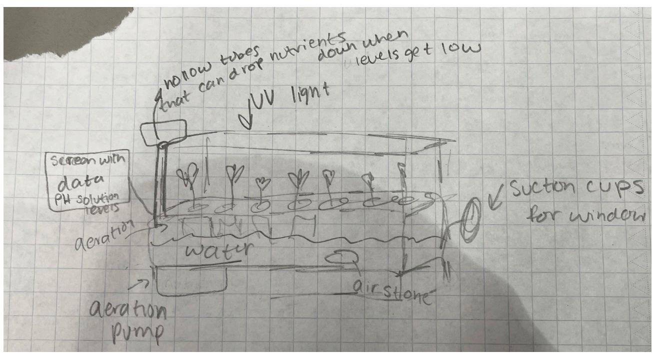


Figure 7. Circular Upright Design

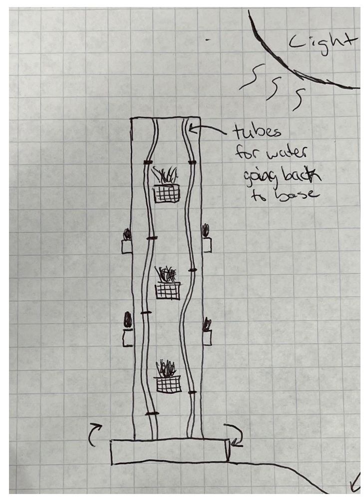


Figure 8. Circular Base Design

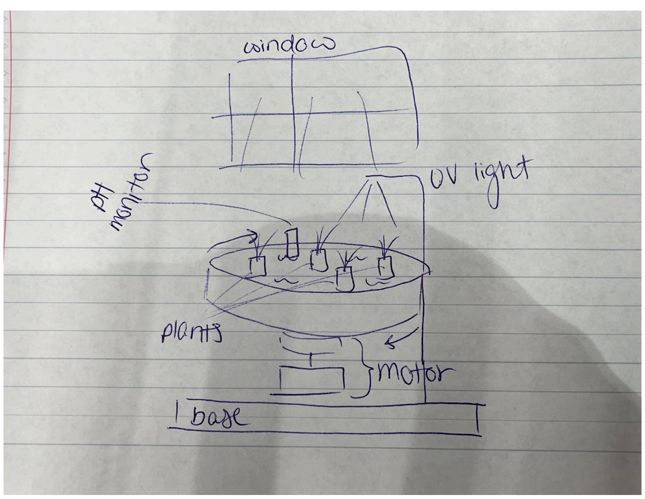
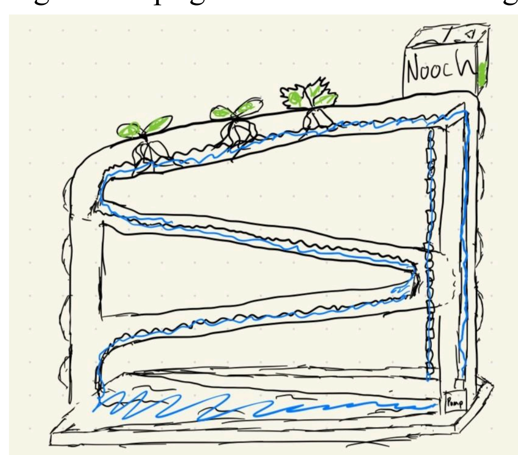


Figure 9. Upright Back and Forth Design



Once this was decided upon, one discussion that was had during the planning phase involved the usage of PVC pipes versus plastic bins. Figure 10 shows the PVC being used, and Figure 11 demonstrates the plastic bins. To come up with a solution, a Kepner-Tregoe Decision Matrix was utilized to weigh both options. The PVC and bins would have both technically worked, since they each met the objectives that needed to be considered. The PVC ultimately won by a small margin, which is why we ended up going with that design. The PVC was able to be sourced from a relative, and it is also easier to work with, and those were weighed the highest out of the six objectives. The table can be seen in Table 3. The final design was already evolving by this time with both designs looking a lot more similar to the proof of concept that was eventually built.

Figure 10. PVC Design

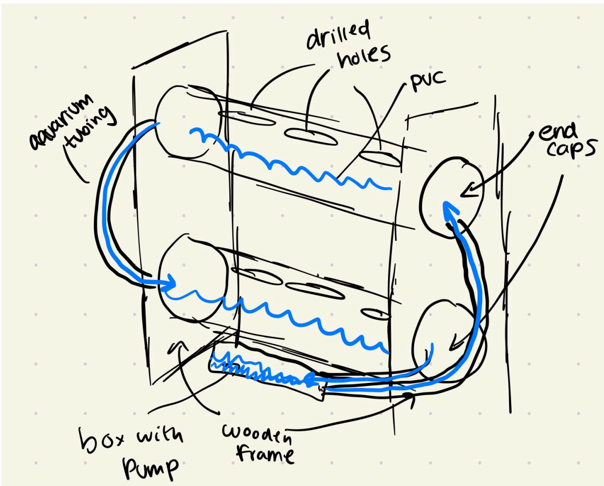


Figure 11. Plastic Bin Design

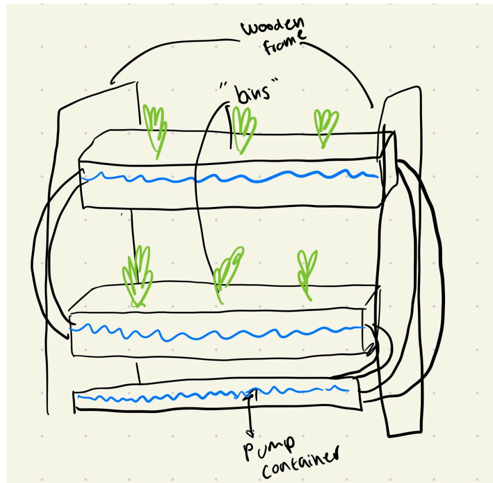


Table 3. Kepner-Tregoe Decision Matrix

Must Objectives	Can be water tight & can hold plants	Uses off the shelf parts
Alternative Designs	GO or NO GO	
Design 1: PVC	GO	GO
Design 2: Bins	GO	GO

Kepner-Tregoe Decision Matrix for PVC v. Bins

Wants Objectives	Low Cost	Small Size	Aesthetically Pleasing	Provides Sensor Data	Syncs with Website	Ease/Feasibility of Construction	
Weights	7	5	4	5	4	7	
Alternative Designs							**Totals**
Design 1: PVC	**7 / 49**	**6 / 30**	**7 / 24**	**8 / 40**	**8 / 32**	**9 / 63**	**238**
Design 2: Bins	6 / 42	6 / 30	8 / 32	8 / 40	8 / 32	7 / 49	225

The coding portion of the project involved the sensors, which was a fairly simple task. The code for the UV index and total dissolved solids (TDS) sensors is included in Appendix XX. From the beginning, it was established that it was something we wanted to include because it was a technical component that could add an interesting element to the overall design, and it would also aid users in the growing process. If the round base design was used, making the base spin to ensure even sunlight among the plants was considered, but that design was dismissed. Pursuing a rotating component would have further complicated the design and reduced the UV light received by the plants overall..

Another idea that was eventually scrapped was the addition of grow lights. Ultimately, it was decided that they would cost too much, as well as too complicated due to the design that was chosen. With the round or rectangular base, the grow lights would just have to cover the one layer; however, the multiple layers made it so that more lights would have to be bought to make sure every layer grew evenly. The number of layers that were going to be constructed was up for debate during this time, and with no set conclusion yet, it was just another reason to scrap that aspect.

The final prototype ended up consisting of only two layers of three inch PVC pipes. Because the final design only had to be a proof of concept, it was decided it was not worth spending the extra money on more layers, when two can clearly show what the final model would look like. More PVC, tubing, and wood would all add expenses to our already diminishing budget. If this was an actual product on the market, more layers might be an option available, but for the purpose of the assignment, it was not a necessary addition. Because of the upright design, a water pump was necessary. This component was easy to work with and set up, making it something that was not disputed throughout the building process.

Feedback during the presentations was a way to come to certain conclusions, as well. For example, an oversight in the building process was where the electrical components were going to go on the build. It was not until this problem was brought up during one of the update presentations that it was realized that it was a problem that needed to be addressed. Professor Whalen mentioned building a box on the side to cover the components, and that is exactly what was built.

Section 3: Implement & Iterate

According to the lecture slides, a prototype is the first embodiment of our design tested in the actual operating environment, or as close to it as possible. The first embodiment of our design largely ended up becoming the final product that was presented at the EXPO. The important large pieces and cuts all worked out largely according to plan. That is: the PVC pipes, PVC end caps, the aquarium tubing, sealant, wooden legs, and electronic (arduino) components.

There were only five minor adjustments that were made due to failing components. The first was that the wooden boards on their own were unstable, so a wooden rectangular base was glued on to keep the legs from wobbling (Figure 12).

Figure 12. Wooden Base

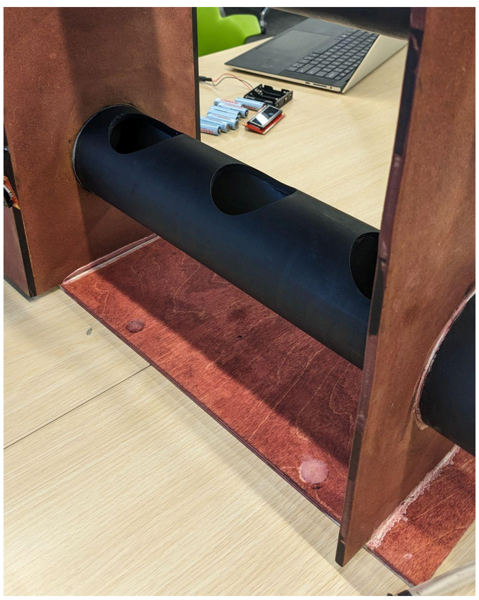


Figure 13. End Cap and Tubing

Second, when a small amount of water was added to the system, the tubing at the end of the PVC started leaking water (Figure 13). Additional sealant was added to each part of the connecting end-cap tubing to be sure the system was water tight at the joints. There was plenty of sealant to spare, so there was not an issue when it came to cost.

Figure 14. Reservoir Bin

Figure 15. Top Edge of Sliding Door

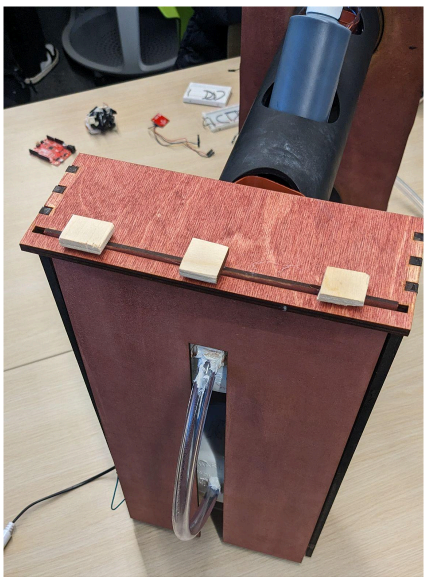


Figure 16. Side of Sliding Door

Next, when the full capacity of water was added to the system, the reservoir bin started to leak. This was due to holes on the sides of the box where the clamps are to keep the top in place (Figure 14). We came up with a few solution ideas, but ultimately decided on simply not filling the reservoir up anywhere near the level where the holes are. After testing with water, we added the electronic pieces. This involved hot-gluing a popsicle stick onto the top edge of the sliding door piece (allowed access to electronic components) in order to prevent it from dropping straight through (Figure 15). This popsicle stick popped off, but once assessing what EXP had to offer, we figured that three wooden squares cut from a thicker sheet of spare wood would have sufficient strength. The final component we prototyped were two popsicle sticks hot-glued onto either side of the bottom of the box encasing the electronic components. These sticks were in place to prevent the sliding door from swinging out at the bottom, keeping it flush against the project (Figure 16). Unfortunately, these popsicle sticks popped off easily as well. We tried wood glue which also failed, and ultimately gave up on this sub-necessary component. It was too close to EXPO day and not very important.

According to the lecture slides, a model represents a component or process and is tested in a controlled environment. Mathematical computer models are also used to test how a design may function. A concept we modeled on Solidworks were 3-D printed plant pots. This concept was tossed because we realized that we could simply reuse plastic water bottles that would otherwise get recycled. This idea required less time (printing) and worked towards our sustainability and affordability project goals.

Most of what drove the decision to make versus buy came down to if it could be made out of wood. 3-D printed parts were largely a no-go because they are not watertight, and watertight sealant for 3-D printed parts was too expensive. So we looked into the next cheapest material other than free 3-D printed plastic. The piping, sensors, tubing, and the reservoir bin could not be made of wood because they either touched water and/or were too complex to be made of it. The wooden legs, base piece, and protective box for the electronic components were the only things we found that could be made of the cheap or spare wood we sourced.

Table 4. Cost of Materials

Material	**Cost**
PVC pipe	Crowd Sourced
Sensors	$11.99
Pump	$9.99
End Caps	$34.65
Tubing	$2.95
Sealant	$8.30
Reservoir Bin	$7.50
Wood	$2.50
Paint	$3.16
Stain	Crowd sourced
Total	$77.88

Section 4: Evaluate - Final Design

Upon completing the final prototype, it became necessary to evaluate the success of the design relative to the predetermined goals. As mentioned in the earlier sections, there were many goals that the solution must address, including that the final design, “must remain inexpensive, small in stature, and easily operated by the average university student”, as well as, “output useful metrics to an integrated display to inform the user whether their plants are receiving adequate sunlight and nutrients”. While it was believed that the design accomplished all these goals, it was necessary to test all of these qualities individually to prove that they work as intended. First and foremost, it was necessary to prove that the design could function as a hydroponics system. To prove this, several individual tests were carried out. The first step of this process sought to prove the quality of the design’s water retention. To operate as a successful hydroponics system, the design must not leak water from the pipes or tubing. To test this, the team filled the system with water and allowed the water to stand for 30 minutes. The test was deemed successful when the system did not show any signs of leakage after standing for the given 30 minute time frame. While this showed a partial success of the system, it was not enough to fully prove that the hydroponic system functioned as the water must circulate on its own. Therefore, a similar procedure was carried out as previously explained with the only change being that the pump was turned on to allow the water to be pumped from the base to the top. This test was also purely observational and proved successful as the system consistently moved water from the bottom container to the top pipe and then down through the system. These two successes allowed the team to determine that this design was a functioning hydroponic system.

Despite the success, more work needed to be done to prove that the problem the team faced was actually solved. Seeing as other hydroponic systems are currently on the market, it was necessary to test that each constraint and objective was met as outlined in Section 1. Starting with the most important objective (as defined by Table 2: Rank Order Chart), low cost, the team compiled the total cost of the design and compared it to the given limit of $100. The total cost of this design was found to be $77.88, using under 80% of the given budget. Using this, the project was deemed “low cost” and considered a success. One of the next most important objectives was the size of the system as outlined in previous sections. The final design remained less than a 1 by 2 by 3 cubic foot rectangle which is considered a success for this design. The final objective to test before considering the final design a success was that the system provided sensor data. To test the functionality of the total dissolved solids sensor, the sensor was tested in three different solutions: air, water, salt and peppered water. As shown in Figure 17, the TDS sensor displayed different readings for each of the solutions. The readings were as expected, the air with no dissolved solids, water with very limited dissolved solids, and the salt and pepper solution with the greatest portion of dissolved solids.

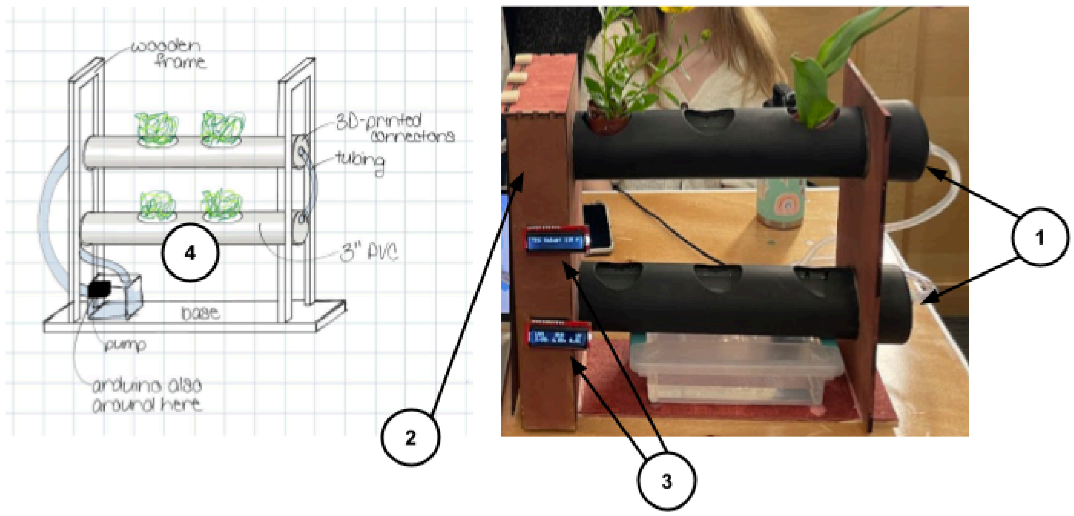
Figure 17. TDS Value - Air, Water, Salt & Pepper Solution

TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm
TDS Value:0ppm	TDS Value:98ppm	TDS Value:1175ppm

Based upon these findings, each of the objectives that were defined as important had been met and were enough to consider the final design a success.

The evaluation of the project was not done at this point, as the only part of the evaluation process is not just checking for one success. This analysis allowed the team to realize that the final design remained almost unchanged to the drawing of the final prototype, with just a few alterations made. The changes in the design can be summarized as four changes (labeled in Figure 18 following). The first major change (labeled ‘1’) is the switch from 3D printed end caps to industry standard PVC end caps. This change was made as it would make the sealing process significantly simpler than 3D printing the pieces. 3D printed parts are not 100% solid which would mean that extra steps would need to be taken to seal the parts. The switch to PVC end caps meant that this extra step was no longer needed and was a solution that has been proven to work in industry. This switch did prove to be easier and worked as expected in the design; however, it proved to be more expensive than expected. The total cost for all four end caps totaled to just under $35, nearly half of the total cost of the entire design. Reflecting again on the initial objectives (low cost specifically), it would be easier to achieve the most important goal by opting for the 3D printed end caps as they could have been included at no cost. Despite this, the PVC end caps were sufficient in producing a working design. The second change, ‘2’, was the addition of a wooden box on the left portion of the frame to house the electronic components. This change occurred because the previous designs failed to recognize the need for such a compartment to protect the electronics. Adding this was a significant addition as without it, water would have direct access to the electronic components which would cause the sensors to malfunction. As such, this addition has a direct correlation to the success of the sensor objective. Change ‘3’ is the location of the sensors. The final design has the LCD displays mounted on the left portion of the frame. The initial design had all of the electronic components located at the base of the design. This switch was made to allow for easier readings for future users. The final switch , ‘4’, is the number of plants per row. This increase is purely to maximize the efficiency of the system. The addition of one extra hole per row meant that two additional plants could be grown at a time without compromising the growth of any other plants.

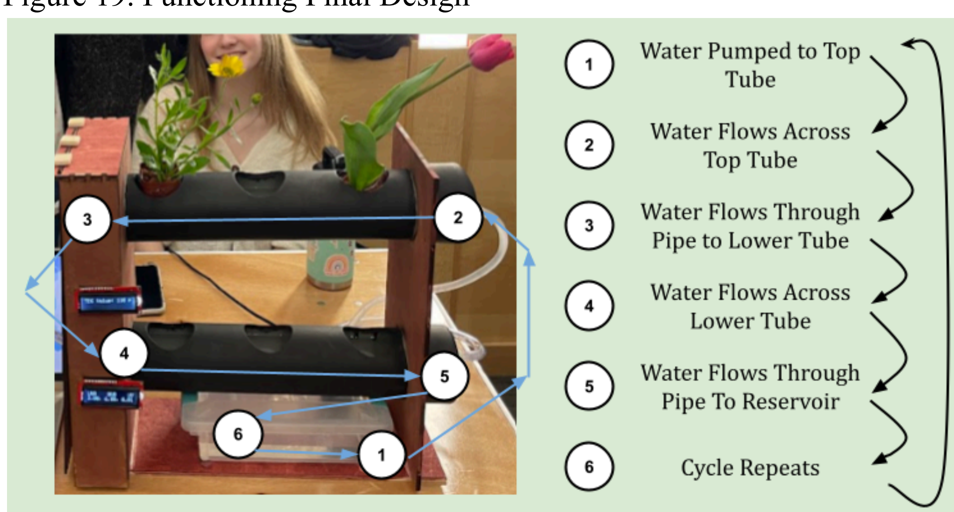
Figure 18. Prototype Drawing vs Final Design



These adjustments were all very important to the overall success of the project and allowed for all design criteria and objectives to be met.

Based upon these tests and this reflection, the team was able to determine that the design met expectations. The final design functioned as expected and accomplished what it set out to do. During different iterations of the process, there were concerns that the design might not function as desired because the system would not remain water-tight. This was a major flaw that was resolved in the final design which allowed the design to achieve all of the goals that were set initially and all goals set or modified throughout the engineering process. The most influential iteration of the design, which allowed the design to work, was changing the sealing of the pipes and the endcaps. This step allowed the system to go from not functioning at any level to immediately functioning as expected. In summary, many iterations led to a fully functioning design demonstrated below in Figure 19.

Figure 19. Functioning Final Design



Section 5: Reflection

Main ethical considerations in this project were surrounding the environmental impacts and the health impacts of our design. This was especially apparent in how we sourced our materials. We aimed to crowd source as many materials as possible and use scrap materials available to us, not only to reduce costs, but to decrease our environmental footprint. The PVC was crowd sourced from a family member who had leftover PVC from an old project that would otherwise not have a purpose. The majority of wood used for the frame of our project was crowd sourced from people with leftover wood from another Cornerstone class, and the cruft shelf. We had to buy one piece of wood and PVC end caps, which had environmental implications; however, we are proud that a large portion of our project materials were made from scrap materials.

The largest ethical qualm we experienced while choosing our materials was in our debate between using plastic planter bins or PVC pipes to pump water through and house the plants. PVC posed a possible health concern, as certain types of PVC pipe are known to leach potentially harmful chemicals into water. Our KTDA chart aided the team in deciding the best course of action. Our decision ultimately led us to go with a successful design that didn't produce issues while in construction, which was the PVC. The main reason PVC was chosen for our design was because it was a material made for the purpose of holding water, so it was more reliable. Additionally, we knew we could crowd source the material. According to USA Today, "people who live near facilities involved in the production of vinyl chloride face those risks and more. These communities, he said, are disproportionately low-income and minority." The distribution of the downsides of production are not ethical, as they affect low income and minority groups disproportionately. Therefore, there are ethical issues with the production of PVC pipe. As a group, it felt okay to use, as we were using scrap pieces and saving them from going to waste rather than buying new.

An article from USA Today quotes a former regional EPA administrator, Judith Enck: "When people say that plastic is cheap, they are dead wrong," Enck said at a virtual news conference Tuesday. "The price is paid widely and for decades through health care costs and tax dollars." link This is a utilitarian way to think about the situation, as it looks at overall cost associated with using potentially harmful plastics. While we had concerns about PVC leaching, it was decided that as our project was just a proof of concept, and it wouldn't be putting anybody at risk to use PVC pipe.

This project helped us as a team understand effective and ineffective ways to use the engineering design process. Something our team was successful at was deciding course of action, implementation, and testing. One thing we learned is that we could have done more repetition through the engineering design process to improve our design, specifically in the piping design.

Our implementation of our design was methodical and done in clear steps. Each work session we declared our goal for the session. In our first session, the PVC pipe was cut to size and wood pieces were sourced. Next session, holes were drilled into the PVC pipe. After that, holes were drilled in the endcaps and the frame pieces were laser cut. In our fourth session, the pieces were glued together and the pipes and tubing were sealed. In the final session, the seals were tested and a solution for mounting the electronic components was developed and implemented the day after.

The testing of the seals was crucial to the success of our project as we did it before mounting our electrical components. Water leaking on our electrical components would have been detrimental to our project, so testing was something we really emphasized. After testing the watertightness of our seals, more silicone sealant was applied on the outside of the tubing and PVC end cap joints to really ensure everything was sealed properly. While everything was initially properly sealed, due to the accidental twisting on the outflow tube, the seal was compromised and needed to be resealed. This is an instance where we could have better utilized the engineering design process to improve our design. Had we left time to test this tubing design and reiterate through the design process, we would have switched to a design that was more reliable and less likely to move such as using an end cap with a threaded nipple and using rigid piping that would not accidentally twist. An important aspect of our design was making it dorm friendly, so iterating through the design process again would have allowed us to make a more transport-friendly design which is crucial to being dorm friendly.

Another improvement we could have made in our process was figuring out where the electronic components would be stored. We didn’t outline exactly how we planned to mount the electronic components, as well as the displays. This could have happened in our deciding course of action phase. In the end, it worked out and we figured out how to mount the pieces; however, the process would have gone smoother had we outlined how it would work sooner.

Overall, the engineering design process guided the development of our hydroponic system and helped us make the best prototype we could with the given time constraints. If we did this project again, we would try to use rigid tubing in our design. As for the engineering design process, we would create a more concrete plan prior to construction and leave enough time to test a wider variety of solutions.

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Appendix

Appendix A: Sensor Code

TDS Sensor Code

```
//Grace Jansen
//I found this code online, edited it to suit our needs, and added some
comments to clarify what it's doing.
// Original source code:
https://wiki.keyestudio.com/KS0429_keyestudio_TDS_Meter_V1.0#Test_Code
// Project details:
https://RandomNerdTutorials.com/arduino-tds-water-quality-sensor/

#define TdsSensorPin A0
#define VREF 5.0              // Analog reference voltage (Volt) of the ADC
#define SCOUNT  30            // Number of sample points to take the median of
in the median filtering algorithm

#include <LiquidCrystal.h>          //the liquid crystal library contains
commands for printing to the display

LiquidCrystal lcd(13, 12, 11, 10, 9, 8);   // tell the RedBoard what pins are
connected to the display

int analogBuffer[SCOUNT];     // Store the analog value in the array
int analogBufferTemp[SCOUNT];
int analogBufferIndex = 0;
int copyIndex = 0;

float averageVoltage = 0;
float tdsValue = 0;

// Temperature influences the readings, so there is an algorithm that
compensates for fluctuations in temperature
float temperature = 25;      //In degrees Celsius

// Median filtering algorithm
// As far as I understand, this provides a more stable measurement by taking
the median of multiple readings.
int getMedianNum(int bArray[], int iFilterLen){
  int bTab[iFilterLen];
  for (byte i = 0; i<iFilterLen; i++)
  bTab[i] = bArray[i];
  int i, j, bTemp;
  for (j = 0; j < iFilterLen - 1; j++) {
    for (i = 0; i < iFilterLen - j - 1; i++) {
```

```
      if (bTab[i] > bTab[i + 1]) {
        bTemp = bTab[i];
        bTab[i] = bTab[i + 1];
        bTab[i + 1] = bTemp;
      }
    }
  }
  if ((iFilterLen & 1) > 0){
    bTemp = bTab[(iFilterLen - 1) / 2];
  }
  else {
    bTemp = (bTab[iFilterLen / 2] + bTab[iFilterLen / 2 - 1]) / 2;
  }
  return bTemp;
}

void setup(){
  Serial.begin(9600);     //Initialize the serial monitor at a baud rate of
115200
  pinMode(TdsSensorPin,INPUT);     //Set the TDS sensor pin as an input
}

void loop(){
  static unsigned long analogSampleTimepoint = millis();
  if(millis()-analogSampleTimepoint > 40U){     // Get new TDS readings every
40 milliseconds
    analogSampleTimepoint = millis();
    analogBuffer[analogBufferIndex] = analogRead(TdsSensorPin);    // Store the
readings in the buffer
    analogBufferIndex++;
    if(analogBufferIndex == SCOUNT){
      analogBufferIndex = 0;
    }
  }

  static unsigned long printTimepoint = millis();
  //Every 800 milliseconds, run everything in the buffer through the median
filtering algorithm created earlier
  if(millis()-printTimepoint > 800U){
    printTimepoint = millis();
    for(copyIndex=0; copyIndex<SCOUNT; copyIndex++){
      analogBufferTemp[copyIndex] = analogBuffer[copyIndex];

      // Use median filtering algorithm, then convert to a voltage value
      averageVoltage = getMedianNum(analogBufferTemp,SCOUNT) * (float)VREF /
1024.0;

      // Temperature compensation formula: fFinalResult(25^C) =
fFinalResult(current)/(1.0+0.02*(fTP-25.0));
```

```
      float compensationCoefficient = 1.0+0.02*(temperature-25.0);
      // Temperature compensation
      float compensationVoltage=averageVoltage/compensationCoefficient;

      // Convert voltage value to TDS value

tdsValue=(133.42*compensationVoltage*compensationVoltage*compensationVoltage -
255.86*compensationVoltage*compensationVoltage +
857.39*compensationVoltage)*0.5;

      // Print results
      Serial.print("TDS Value:");
      Serial.print(tdsValue,0);
      Serial.println("ppm");

      lcd.setCursor(0, 0);
      lcd.print("TDS Value: ");
      lcd.print(tdsValue,0);
      lcd.print(" ppm");

    }
  }
}
```

UV Sensor Code

```
/*
  Grace Jansen
  I found this code online, edited it to suit our needs, and added comments.
  Make sure to include the SparkFun VEML6075 library.
  Follow this link: http://librarymanager/All#SparkFun_VEML6075

  Source Code:
https://learn.sparkfun.com/tutorials/qwiic-uv-sensor-veml6075-hookup-guide?_ga=
2.225147794.983975460.1710884857-1189975397.1710277124#example-code
  Using the VEML6075 -- UVA, UVB, and UV Index monitoring
  By: Jim Lindblom, SparkFun Electronics
  Date: May 23, 2018
  License: This code is public domain
*/

#include <SparkFun_VEML6075_Arduino_Library.h>

VEML6075 uv; // Create a VEML6075 object

#include <LiquidCrystal.h>          //the liquid crystal library contains
commands for printing to the display

LiquidCrystal lcd(13, 12, 11, 10, 9, 8);   // tell the RedBoard what pins are
connected to the display

void setup()
{
  Serial.begin(9600);

  Wire.begin();

  lcd.begin(16, 2);                   //tell the lcd library that we are using a
display that is 16 characters wide and 2 characters high
  lcd.clear();                        //clear the display

  // The VEML6075's begin function can take no parameters
  // It will return true on success or false on failure to communicate
  if (uv.begin() == false)
  {
    Serial.println("Unable to communicate with VEML6075.");
    while (1)
      ;
  }
  Serial.println("UVA, UVB, UV Index");
```

```
  lcd.setCursor(0, 0);              //set the cursor to the 0,0 position (top
left corner)
  lcd.print("UVA    UVB    UV ");
}

void loop()
{
  // Use the uva, uvb, and index functions to read calibrated UVA and UVB
values and a
  // Calculated UV index value between 0-11.
  Serial.println(String(uv.uva()) + ", " + String(uv.uvb()) + ", " +
String(uv.index()));
  lcd.setCursor(0, 1);              //set the cursor to the 0,0 position (top
left corner)
  lcd.print(String(uv.uva()) + ", " + String(uv.uvb()) + ", " +
String(uv.index()));
  delay(250);     // Sensor readings will stream every 250 milliseconds (can be
changed here)
}
```

Appendix B: Website Code

App.tsx File Code

```
import './App.css'
import React from "react";

function App() {

  return (
    <>

      <head id='root'>
        <meta http-equiv="X-UA-Compatible" content="IE=edge"></meta>
        <meta name="viewport" content="width=device-width, initial-scale=1.0"></meta>
        <title>Dorm Hydroponics</title>
      </head>

      <body id='root'>
        <div id='home'>
          <div className='nav-bar'>
            <nav>
            <a href="#home"><img src="public/Images/DH Logo.png" className="logo"></img></a>
                  <ul id="topmenu">
                    <li><a href="#dorm-hydro">DormHydroponics</a></li>
                    <li><a href="#our-team">Our Team</a></li>
                    <li><a href="#about">About Our Project</a></li>
                  </ul>
              </nav>
          </div>
          <div className='sensor-tile-container'>
            <div id='tile-one'>
              <h2>TDS Sensor</h2>
              <p>The Total Dissolved Solids is currently reading <span>98</span> parts per million!</p>
              <a
href="http://www.cqrobot.wiki/index.php/TDS_(Total_Dissolved_Solids)_Meter_Sensor_SKU:_CQRSE
NTDS01">Learn more</a>
            </div>
            <div id='tile-two'>
            <h2>My Past Plants</h2>
              <li>Butter Lettuce</li>
              <li>Baby Spinach</li>
              <li>Oregano</li>
```

```
          <p></p>
          <a href="">Learn more</a>
        </div>
        <div id='tile-three'>
        <h2>Ultra Violet Sensor</h2>
          <p>The current Ultra Violet index is a <span>7</span>!  The light level is great for
growing!</p>
          <a href="https://www.britannica.com/science/ultraviolet-radiation">Learn more</a>
        </div>
      </div>
    </div>

    <div id="dorm-hydro">
    <div className="container">
        <h1 className="sub-title">DormHydroponics</h1>
        <div className="work-list">
            <div className="work">
                <img
src="https://oikotimes.com/wp-content/uploads/2021/04/pexels-pragyan-bezbaruah-4199758.jpg"></img
>
                <div className="layer">
                    <h2>How To Use DormHydronics</h2>
                    <h3>Click below for step-by-step instructions on how to set-up and use
DormHydroponics</h3>
                    <a
href="https://docs.google.com/document/d/1LNwu1_gwERtyeM76DTKI_GVxToXTkA4l6jANFTpLx_Y
/edit?usp=sharing">More</a>
                </div>
            </div>
            <div className="work">
                <img
src="https://gardeningheavn.com/wp-content/uploads/2019/05/drip-hydrorganic-1024x684.jpg"></img>
                <div className="layer">
                    <h2>Watch Our Commercial</h2>
                    <h3>Learn more about DormHydroponics and see if we just might be the solution for you!
</h3>
                    <a
href="https://drive.google.com/file/d/1iiXmIhjdBiiB-M6KilDrvpYpUE1DF2QA/view?usp=sharing">Mo
re</a>
                </div>
            </div>
            <div className="work">
```

```
                    <img
src="https://cdn.shopify.com/s/files/1/2723/8896/files/hydroponics_3_mini_1024x1024.jpeg?v=15676138
39"></img>
                    <div className="layer">
                        <h2>FAQ's</h2>
                        <h3>Click to read some Frequently Asked Questions from some of our other users in dorm
like yours</h3>
                        <a
href="https://docs.google.com/document/d/1FnJkzMQzQwHCXGyzM2MxmbAdW3-OvYKQsyIq9W39j
xA/edit?usp=sharing">More</a>
                    </div>
                </div>
            </div>
        </div>
        </div>
      </body>
    </>
  )
}

export default App
```

App.css File Code

```
html{

   scroll-behavior: smooth;

}

 body{

   background-color: #000000;
   color: white;
   font-family: 'Bodoni MT', serif;
   align-items: center;
   flex-direction: column;

 }

 #root{

   margin: 0;
   padding: 0;
   font-family: 'Bodoni MT', serif;
   box-sizing: border-box;
   width: 100%;
   height: auto;


 }

#home{

  width: 100%;
   height: 100vh;
   background-image:
url(https://th.bing.com/th/id/R.5f38bd66f8742a2b6fa6887bf9bf8e94?rik=f7P6%2bhg8GcjB8A&riu=http
%3a%2f%2fwww.t5fixtures.com%2fwp-content%2fuploads%2f2016%2f07%2fHydroponics.jpg&ehk=zt
V3v0zN7nBPyHsrVlPlDuONr0hINkeVHzNtN3vwx1M%3d&risl=&pid=ImgRaw&r=0);
   background-size: cover;
   background-position: center;

}

#home .logo{
```

```
  width: 150px;

}

.nav-bar{

   padding: 5px 2%;
   background-color: black;
   opacity: 0.9;

}

nav{

  display: flex;
  align-items: center;
  justify-content: space-between;
  flex-wrap: wrap;

}


nav ul li{

  display: inline-block;
  list-style: none;
  margin: 10px 20px;

}

nav ul li a{

  color: #86CB5C;
  text-decoration: none;
  font-size: 25px;
  font-weight: 600;
  position: relative;

}

 nav ul li a::after{

  content: '';
```

```
  width: 0;
  height: 3px;
  background: #86CB5C;
  position: absolute;
  left: 0;
  bottom: -6px;
  transition: 0.5s;

}

nav ul li a:hover::after{

  width: 100%;

}


#dorm-hydro{

  background-color: black;
  background-size: cover;
  padding: 2%;
  height: 100%;
  color: #86CB5C;
  text-align: center;
  font-weight: 500;

}

.sensor-tile-container{

  display: grid;
  grid-template-columns: repeat(auto-fit, minmax(250px, 1fr));
  grid-gap: 40px;
  margin-top: 7%;
  padding: 30px;

}

.sensor-tile-container div{

  background: #252525;
  opacity: 0.9;
  padding: 40px;
```

```
  font-size: 30px;
  font-weight: 300;
  border-radius: 10px;
  text-align: center;

}

.sensor-tile-container div h2{

  color: #86CB5C;

}

.sensor-tile-container div a{

  color: #86CB5C;

}

.sensor-tile-container div p span{

  color: #86CB5C;
  font-weight: 700;

}


.work-list{
  padding: 2%;
  display: grid;
  grid-template-columns: repeat(auto-fit, minmax(250px, 1fr));
  grid-gap: 5%;
  margin-top: 50px;
}
.work{
  border-radius: 10px;
  position: relative;
  overflow: hidden;
}
.work img{
  width: 100%;
  border-radius: 10px;
  display: block;
  transition: transform 0.5s;
```

```
}
.layer{
  width: 100%;
  height: 100%;
  background: linear-gradient(rgba(0,0,0,0.5), #86CB5C);
  border-radius: 10px;
  position: absolute;
  left: 0;
  bottom: 0;
  overflow: hidden;
  display: flex;
  align-items: center;
  justify-content: center;
  flex-direction: column;
  text-align: center;
  font-size: 14px;
  transition: height 0.5s;
}
.layer h2{
  color: white;
  font-weight: 1000;
  font-size: 200%;
}
.layer h3{
  padding-left: 1%;
  padding-right: 1%;
  color: white;
  font-weight: 600;
  font-size: 20px;
}
.layer a{
  color: white;
  font-weight: 600;
  font-size: 20px;
}
.work:hover img{
  transform: scale(1.1);
}
.work:hover .layer{
  height: 100%;
}
```

Main.tsx File Code

```
import React from 'react'
import ReactDOM from 'react-dom/client'
import App from './App.tsx'
import './index.css'

ReactDOM.createRoot(document.getElementById('root')!).render(
  <React.StrictMode>
    <App />
  </React.StrictMode>,
)
```

Index.css File Code

```css
:root {
  font-family: Inter, system-ui, Avenir, Helvetica, Arial, sans-serif;
  line-height: 1.5;
  font-weight: 400;

  color-scheme: light dark;
  color: rgba(255, 255, 255, 0.87);
  background-color: #242424;

  font-synthesis: none;
  text-rendering: optimizeLegibility;
  -webkit-font-smoothing: antialiased;
  -moz-osx-font-smoothing: grayscale;
}

a {
  font-weight: 500;
  color: #646cff;
  text-decoration: inherit;
}
a:hover {
  color: #535bf2;
}

body {
  margin: 0;
  display: flex;
  place-items: center;
  min-width: 320px;
  min-height: 100vh;
}

h1 {
  font-size: 3.2em;
  line-height: 1.1;
}

button {
  border-radius: 8px;
  border: 1px solid transparent;
  padding: 0.6em 1.2em;
  font-size: 1em;
```

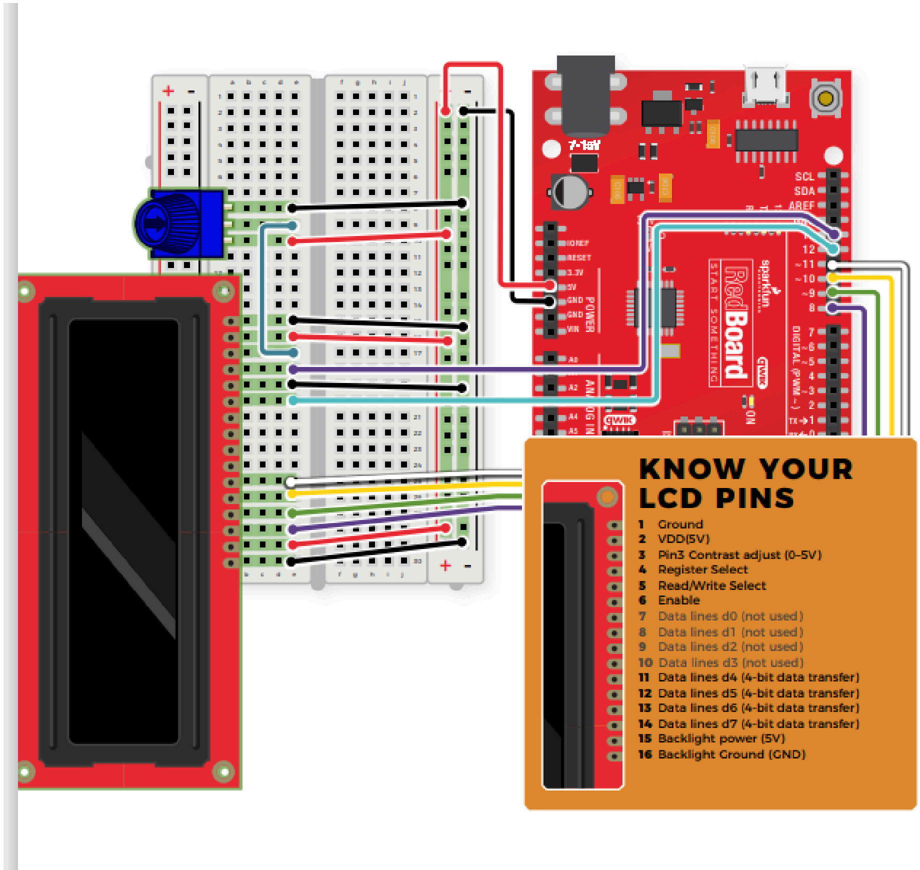
```
  font-weight: 500;
  font-family: inherit;
  background-color: #1a1a1a;
  cursor: pointer;
  transition: border-color 0.25s;
}
button:hover {
  border-color: #646cff;
}
button:focus,
button:focus-visible {
  outline: 4px auto -webkit-focus-ring-color;
}

@media (prefers-color-scheme: light) {
  :root {
    color: #213547;
    background-color: #ffffff;
  }
  a:hover {
    color: #747bff;
  }
  button {
    background-color: #f9f9f9;
  }
}
```

Appendix C: Wiring Guidelines

Make sure baud rate is set to 9600 on Arduino

LCD display & potentiometer wiring as follows (Referenced from the SparkFun guidebook):



UV Sensor:

- Red goes to power (+) on breadboard
- Black goes to ground (-) on breadboard
- Yellow goes to SCL on the Arduino
- Blue goes to SDA on the Arduino

TDS Probe:

- Green goes to A0 on the Arduino
- Red goes to power (+) on the breadboard