Wheelable Greenhouse

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Designed For:
Zane Middle School

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2.1 Introduction to the Problem Analysis

The Problem Analysis expresses an initial analysis of the Wheelable Greenhouse for Zane Middle School; discussing the specifications, considerations, criteria with constraints, usage, and production volume for the greenhouse.

2.1.1 Specifications and Considerations

The specifications and considerations are meant to give base for the structure of the project. In this subsection, the dimensions and other considerations will be discussed.
The main Specifications and Considerations will be:

- Has to be mobile
- Considerations include having no more than a width of 32” inches in order to fit through a classroom door. Height must not exceed 6’ and length should be no longer than 6’.
- The greenhouse must be watertight and should be clean due to being stored and shown inside classrooms.

2.1.2 Criteria and Constraints

The criteria and Constraints give insight into what is most important to the project. A list is made including the Weights of the Criteria and the Constraints that describe them.

Table 2.1- Criteria and Constraints

Criteria		Constraints
Safety	10	Greenhouse will be used by middle school children and therefore cannot have sharp edges or easily breakable materials.
Aesthetics	9	Looks professional and appealing toward middle school children.
Sustainability	5	Building with recycled and up-cycled materials.
Portability	10	Must be easily moveable across a rough flat surface by middle school aged children.
Durability	7	Glazing material must last 1 year.
Educational	8	Greenhouse must showcase the advantages of using a greenhouse in the local climate.
Cost	5	$400 ($75 from each team member and $100 from Zane Middle School)
Cleanliness	10	Must not leak water or dirt.

2.1.3 Usage

The Mobile Greenhouse will be used as a learning tool for teaching children about the benefits of using a greenhouse. The greenhouse will also serve as a tool for the use of the garden located on campus. Utilizing the properties of the greenhouse will allow the students that are a part of the edible garden project to start growing vegetables from the beginning. The greenhouse will be stored inside a classroom at night time, and kept outside during the day to take advantage of the solar radiation available. The structure should be used for a minimum of 1 year.

2.1.4 Production Volume
A single mobile greenhouse will be produced for use at Zane Middle School.

2.2 Introduction to the Literature Review
The literature review contains background research pertaining to the development of knowledge to help fuel a wide range of ideas to build a Wheelable Greenhouse using the client's criteria, structural types, materials and, features specific for a middle school in Eureka, California.

2.3 Client Criteria
The most pertinent criteria of the client is that the Wheelable greenhouse is mess free by containing all water and soil in the greenhouse and to be safety for middle school students to use.

2.4 Soils
The most ideal garden soil would be one rich in organic matter. Organic matter serves two important roles. It acts as an absorbent to soak up plant nutrient solutions such as nitrogen, phosphorus and potash. It also provides a home for billions of different microorganisms that are needed to break down organic substances into simpler forms for the plants to convert to energy. You can obtain organic matter by using different techniques. One of the best techniques is composting. Some materials used for composting include fallen leaves, peat moss, and animal manure. The nutrients in your soil or fertilizer are also very important. (Dietz, 1974)

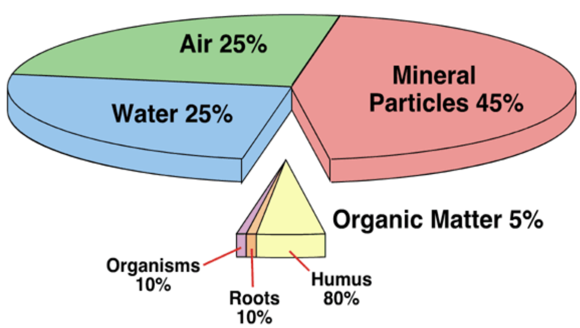


Figure 2-1 Soil Composition (Pidwirny, 2006)

2.5 Nutrient Elements
The three most important nutrient elements to take into consideration are nitrogen, phosphorous, and potassium hydroxide or "potash". These elements are not available to plants until organisms have broken them down. These organisms are dormant at temperatures below 60°F and active at higher temperatures up to 90°F, which means that organic fertilizers are not as effective in the early spring. (Dietz, 1974)

2.6 Water Capacity

The water capacity of various soils is very crucial during times of drought. Large amounts of organic matter in the soil will help increase the water holding capacity so that plants can survive dry times. Watering plants is essential for keeping soil moist. If soil is not moist water will pull out from the roots of plants causing them to dry out. On the contrary, if you over water your plants, it does not allow oxygen to be created in the plant, leaving the plant unable to soak up the water from the roots. (Dietz, 1974)

2.7 Soil Types

Plants with fine roots are best planted in coarse open soil, while coarse-rooted plants are better off in dense soils made up of fine particles. There are numerous types of soils, which include both sandy and clay-like. If either of these types of soils are in bad condition, most of the time you can fix the problem by just adding organic matter. Good flowers to grow in sandy soil are California poppies, annual phlox, calliopsis, morning glories, baby's breath, and yucca. On the other hand, most types of flowers are best planted in clay-like soils. (Dietz, 1974)
It is very unlikely for soils to be useful straight from fields. Most field soils need organic matter or aggregate added to them before they will be able to drain freely in greenhouse conditions. Field soils also usually lack phosphorous and calcium so these need to be added to fertilizer to be used in the soil. (Nelson 1978)

2.8 Insects/Pests

Common pests of greenhouses include insects, mites, slugs, and rodents. If not properly taken care of, they will multiply and lead to the death and destruction of your plants. (Jozwik, 1984) Mites and certain insects tend to be very small, so it is hard to prevent the introduction of them into your greenhouse. Ventilating fans are one way of keeping them out but they aren't the best. Instead, screens should be installed on all entries of greenhouse to keep the larger pests out. You should carefully inspect the plants being put into your greenhouse for pests because they are most likely introduced by being carried in. (Jozwik, 1984)

2.9 Taking Care of Pest Outbreaks

Preventive treatment with sprays will keep major outbreaks from happening. Be sure to check every two weeks for signs of infestation and you may begin to notice that certain plants and growth stages are more susceptible to outbreaks so you should pay more attention to them. It is not recommended to use chemical sprays or aerosols due to the cost and health issues. (Jozwik, 1984)

2.9.1 Biological Control

Biological Control for greenhouses is a great alternative to pesticide use because it is more environmentally and cost friendly. It is especially important considering the pressure from the public to cut out chemical pesticides. Predators and parasitoids are put into greenhouses to naturally get rid of pests. For example, the first organisms used for biological control in China were *Trichogramma spp.* and *Rodolia Cardinalis* which helped to control *Ostrinia furnacalis, Helicoverpa armigera,* and *Cerya purchasi.* Since these organisms proved to be a success, this system was implemented in other agricultural ecosystems. A few organisms that would be good to put into greenhouses include various types of predatory mites, predatory ladybirds, predatory stink bugs, lacewings, and parasitoids. Although biological control seems to be the best way to treat your plants of pests, it tends to take more time to become effective. (Yang et al, 2014)

2.10 Most Common Pests and Pest Management

The most common greenhouse pests include aphids, whiteflies, spider mites, and thrips. The most useful predator for these pests is the multicolored Asian ladybird. *E. Formosa* is the most common type of whitefly used to control pests and is available in the USA as well.
(Yang et al, 2014)

2.11 Plants

In different areas, certain plants thrive more easily than in others. This section will describe plant conditions and types of plants that would most easily survive in Humboldt counties climate.

2.11.1 Plant Structure

For most flower crops, it is almost impossible to find or provide good outdoor conditions because temperature is not consistent enough year-round. Flowers need good sunlight, uniform temperature, moderate aeration, and decent amounts of moisture. Not only is it a risk for flower growth during dry periods, but also it is very hard to control over watering during downpours. The greenhouse structure is the best structure for plants because it is much easier to control the specific conditions that they need. (Nelson, 1978)
Greenhouses protect crops against harmful environmental conditions, which mean that crops can be produced year round with greater quality and yields than in an open field.
(Yang et al, 2014)

2.11.2 Cut Flower Crops

It is very important that a good soil mix is used for cut flowers because it is usually used for many years. A coarse soil is recommended because it drains readily and will ensure good air supply. You should also add organic matter from time to time. Enough water must be supplied so that water is able to drain through the bottom. Also make sure to spray the water over instead of applying it directly from the hose so it doesn't compact the soil. Cut flower crops also need a constant supply of fertilizer. It is very critical to add fertilizer regularly in the first month of growth. Nitrogen and phosphorus are essential for a good fertilizer. Daffodils, irises, and carnations are fairly easy to maintain in a greenhouse. (Nelson, 1978)

2.11.3 Pot Plant Crops

Standard greenhouse flowerpots are usually 6" tall and 6" wide. Potted plants require space between each other to grow to maximum potential. Potted plants may not be suitable for smaller greenhouse environments. (Nelson, 1978)

2.11.4 Succulents

Xerophytes, commonly known as succulents, can be found in arid habitats and display characteristics such as thick cuticles, small stature, thickened outer cell walls, and sclerotic cells and fibers. Succulents are more likely found in humid and arid habitats. A succulent is a plant possessing succulent tissue, which is a living tissue that serves temporary storage of utilizable water, which can make the plant temporarily independent from outside water sources. This special ability enables succulents to live in habitats that endure periodic droughts. Although succulents can survive dry habitats, they are not adapted to aridity but only to periodic drought cycles. The most basic feature of succulents is its ability to store water, which makes it easy to care for. (Willert et al, 1992)

2.11.5 Easy to Manage Succulent Plants

Sempervivum tectorum and Echeveria elegens are both great types of succulent plants with a flower like look to them. Jade plants have thick stems and thick, glossy green leaves. Panda plants have thick green leaves covered in small silver hairs and lined with rusty colored hairs. Pincushion cacti are small cacti with pink flowers. Snake plants have long leaves with a striped pattern. This particular plant is known to be able to come back to life when you water them. To care for these plants, allow soil to dry completely before watering and fertilize three times each summer with a balanced 10-10-10 fertilizer. (Hanscom and Ting, 1977)

2.12 Materials

Greenhouses require a variety of materials when determining the overall design of a greenhouse. There are a variety of variables to consider such as what type of materials the structure is made from, the shape of the greenhouse, the glazing of the walls, and any ventilation being considered.

2.12.1 Steel

Steel is used in building of all structures and has benefits when using it in greenhouses. Steel has a high tensile strength and can support the loads associated with greenhouse design. Downsides of using steel are it can be difficult and therefore expensive to form the shapes required for most types of glazing. Steel also needs to be treated against corrosion. Due to the general higher than average humidity observed inside greenhouses, cheap forms of anti-corrosion processes are often found to be inadequate. (Walls, 1973)

2.12.2 Aluminum

Alloys, most commonly Aluminum is used extensively due to the multiple benefits and small number of downsides. Aluminum is lightweight and thusly keeps the total weight of the structure to a minimum. It is also easily formed and can easily be used for specific purposes like connecting sheets of glazing. Alloys are generally not as strong as other metal substances like steel, but they are generally much less prone to corrosion. One downside to using aluminum is its high thermal conductivity. This can lead to rapid changes in temperature which can lead to the exterior temperatures having a greater impact on the interior temperatures of the greenhouse. (Walls, 1973)

2.12.3 Wood

Wood is one of the most common types of materials used in the building of greenhouses. Wood is considered to be a good material for greenhouses due to its low thermal conductivity. There are generally four types of timber used, they are: redwood, pine, cedar, and spruce. (Walls, 1973)

2.12.3.1 Redwood

Redwood is easy to work with in that it is usually devoid of knots and cuts fairly easily despite its high strength. It also naturally preserves well and it can also easily be treated to help preserve the wood. (Walls, 1973)

2.12.3.2 Pine

Pine is very similar to redwood in strength. It is prone to splitting when nailed and not as easily treated for preservation. (Walls, 1973)

2.12.3.3 Cedar

Cedar has poor strength characteristics compared to other types of woods used. It should mainly be used for smaller projects that do not have large weight requirements. Cedar is naturally resistant to decay and thusly does not need as much preserving treatment as other types of wood. (Walls, 1973)

2.12.3.4 Spruce

Spruce has similar strength to redwood and pine. It has a lower cost than all other types of wood but does not last as long and therefore needs to be treated for preservation. Spruce is resistant to splitting which makes it easy to work with. (Walls, 1973)

2.13 Shape

There are three general greenhouse shapes to be considered. They are the gable, Quonset, and gothic shapes. These shapes are chosen to analyze because they are three of the more common shapes found in commercial greenhouses. The heating requirements of each of the three are: 8.15 MJ/m^2 for the gothic arch, 8.37 MJ/m^2 for the gable, and 8.51 MJ/m^2 for the Quonset shape. The gothic arch thusly has the largest thermal efficiency requiring 2.6% less energy than the gable shape, and 4.2% less energy than the Quonset shape. (Mathala, 2002)

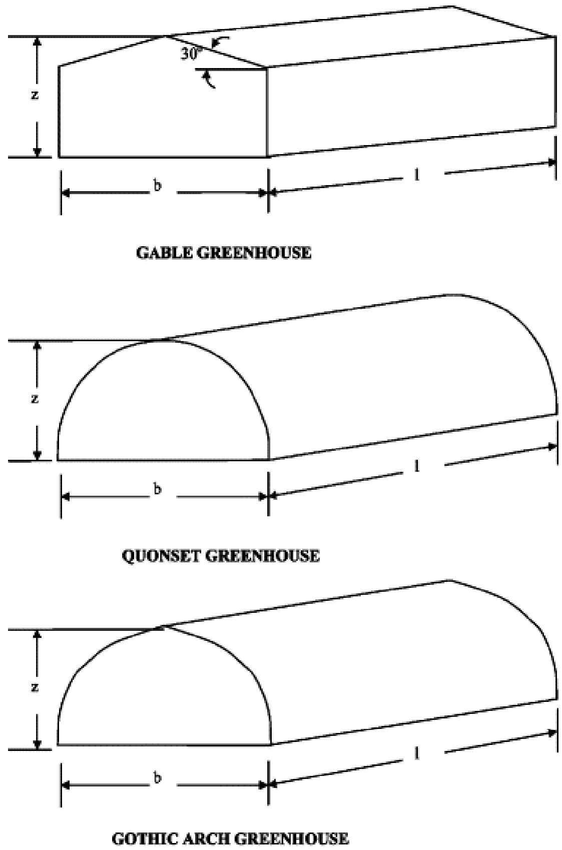


Figure 2-2 Common commercial greenhouse shapes (Mathala, 2002)

2.14 Glazing

There are three general materials used for use in the exterior walls also known as glazing. These three different types are listed as glass, rigid plastics, and plastic films.

2.14.1 Glass

Glass is advantageous to use because of the three types listed above, it has the highest transmittance of light, and it will last around 30 years of use. The downsides of glass are it is more expensive to use than the other options and if broken can be dangerous. Glass can also be extremely difficult to install on curved shapes. (Both, 2006)

2.14.2 Rigid plastics

Plastics such as acrylic and polycarbonate are generally lighter and less prone to breakage than their glass counterpart. Although they do have a high transmittance of light, it is not as high as glass, and can reduce with time due to yellowing of the plastic. They have good insulation properties due to the fact that normally they are double walled with a layer of air in between to help insulate. They generally last anywhere from 7 to 20 years and can be difficult to install on curved shapes due to their rigid nature. (Both, 2008)

2.14.3 Plastic Films

Plastic films, most notably polyethylene, are the cheapest form of glazing to use. When using a double walled construction they have a significant advantage in insulation and heating requirements, when compared to rigid plastics (Cemek, 2006). They are very easy to use on all shapes of greenhouse but they are prone to ripping easily. Plastic films also have the shortest lifespan, lasting around 3-4 years. (Both, 2008)

2.15 Ventilation

Ventilation is an important design factor when building greenhouses. Varying species of plants have different humidity requirements and stagnant air can spread disease. In order to obtain proper ventilation in a greenhouse there needs to be a vent towards the bottom of the structure and a vent at the top of the structure as well. Since hot air rises, the purpose of the top vent is to let out hot air in order to keep a habitable temperature within the greenhouse. The vents located toward the bottom of the greenhouse serve to bring in cold air and to keep a steady airflow going throughout the greenhouse. The pressure differential from hot air leaving the structure causes a small vacuum effect within the greenhouse which brings in the colder air closer to the ground. (Preston, 1951)

2.16 Mobility

One of the most essential parts of a mobile greenhouse is of course the mobility. All aspects must work together to allow performance of the machine to balance with effectiveness of the design.

2.16.1 Handles

The requirement of the structure to be mobile facilitates the use of a handle for ease of movement. Handles are made from a variety of materials and have many different shapes. Handles for the greenhouse should be sturdy and at a proper height for people of all ages to move the greenhouse.

2.16.1.1 Wooden, Metal, or Plastic

There are three ideal types of handle materials, Wood, Metal, and Plastic. The wood handles could cause some problems from the in climate weather in Humboldt County. The wood would have to be coated in a material like a waterproof paint or sealant. It would also need to be maintained in order to keep the aesthetics of the design pleasing to the audience. Metal also can deteriorate due to in climate weather causing rust to form on the material, leading to decay. This would also need to be replaced/ maintained but would last much longer. Plastic is a material that would break easily or become dirty/ damaged if not taken care of. The plastic would need to be strong enough to push a heavy cart without breakage just as the other materials would.

2.16.2 Volume

Intending to move the greenhouse in and out of the doors of the school classrooms, the size of the greenhouse should correspond with the appropriate size of the doors of the facility. The "Average" American classroom door is: 36" x 80", the smallest standard size doors are 30" x 80". (Wikipedia, 2014.) The average height of a middle school child being around 52" tall of 4'4," will be accounted for. (EHow, 2014).

2.16.3 Wheels

From a range of options considering wheels, Casters are "an undriven, single, double, or compound wheel that is designed to be mounted to the bottom of a larger object so as to enable that object to be easily moved." (Wikipedia, 2014.) They swivel on an access creating a more balanced range of motion. Usually performed in combination a platform mounted upon a base as shown in figure 2-3, where 4 joints at each corner are connected to form an evenly dispersed support system. (Vassar, 1981) The caster wheels provide "Exceptional ease of use and quietness in the swivel operation." (Caster Industries, 2014)

Figure 2-3 Phenolic Medium Duty Swivel, Caster (The Caster Guys, 2014)

2.17 Climate

Greenhouses are useful in areas where the climate is not advantageous to growing particular crops at different times of the year. The amount of sunshine, precipitation and average temperature all greatly affect what can be grown in a particular area.

2.17.1 Eureka, California's Weather

Eureka, California is found on the northern coast of California and subject to climate conditions associated with the pacific northwest of the United States.

2.17.1.1 Temperature

As seen in the graph on the next page, the temperature in Eureka, California stays constant throughout the year with an average high ranging from 64.3˚F – 55.8˚F and an average low ranging from 52.8˚F – 40.6˚F.

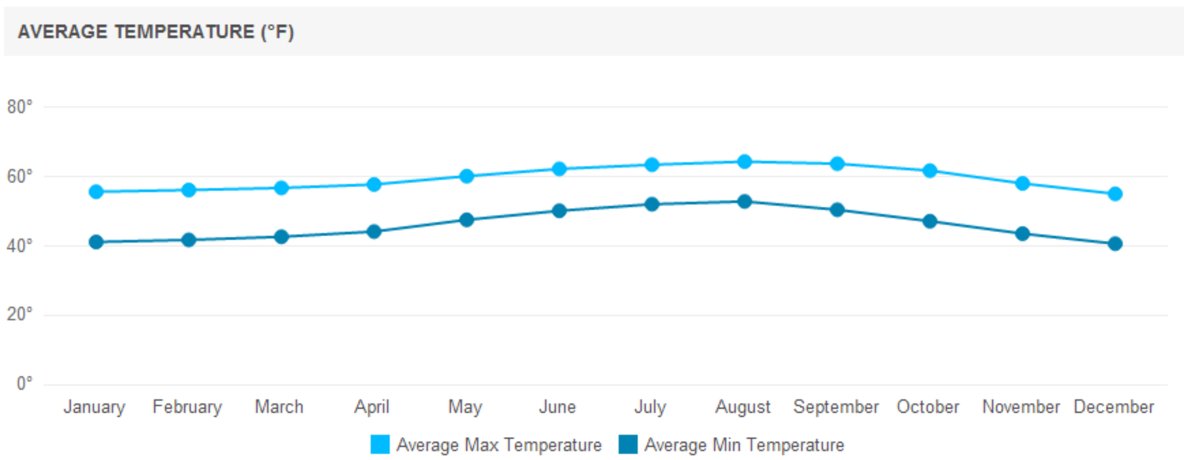


Figure 2-4 Graph of average temperature in degrees Fahrenheit

2.17.1.2 Precipitation

In Eureka, California the average total precipitation is 49.15 inches; with the highest amount of rain in December counting in at an average of 8.12 inches and the lowest average amount of rain fall of 0.18 inches in the month of July.

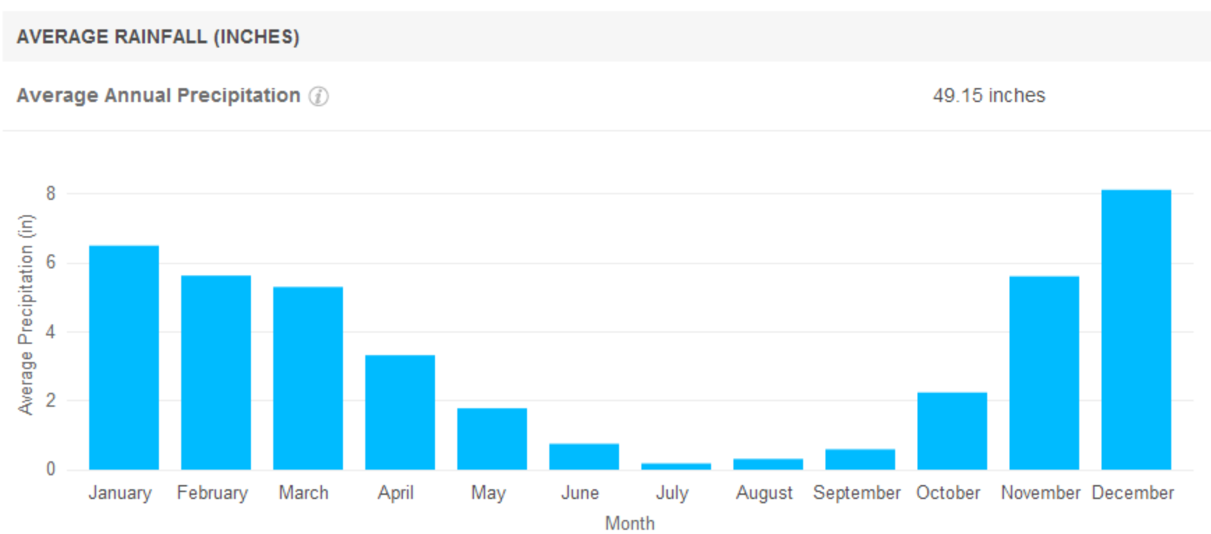


Figure 2-5 Average Precipitation of Eureka, CA over the course of a year

2.17.1.3 Cloud Coverage

The Eureka sky is mostly covered by clouds and overcast. According to the *Median Cloud Cover* graph from WeatherSpark Beta, around the mid-month of May is the beginning of the clear part of the year. The cloudier part of the year begins around mid-November.

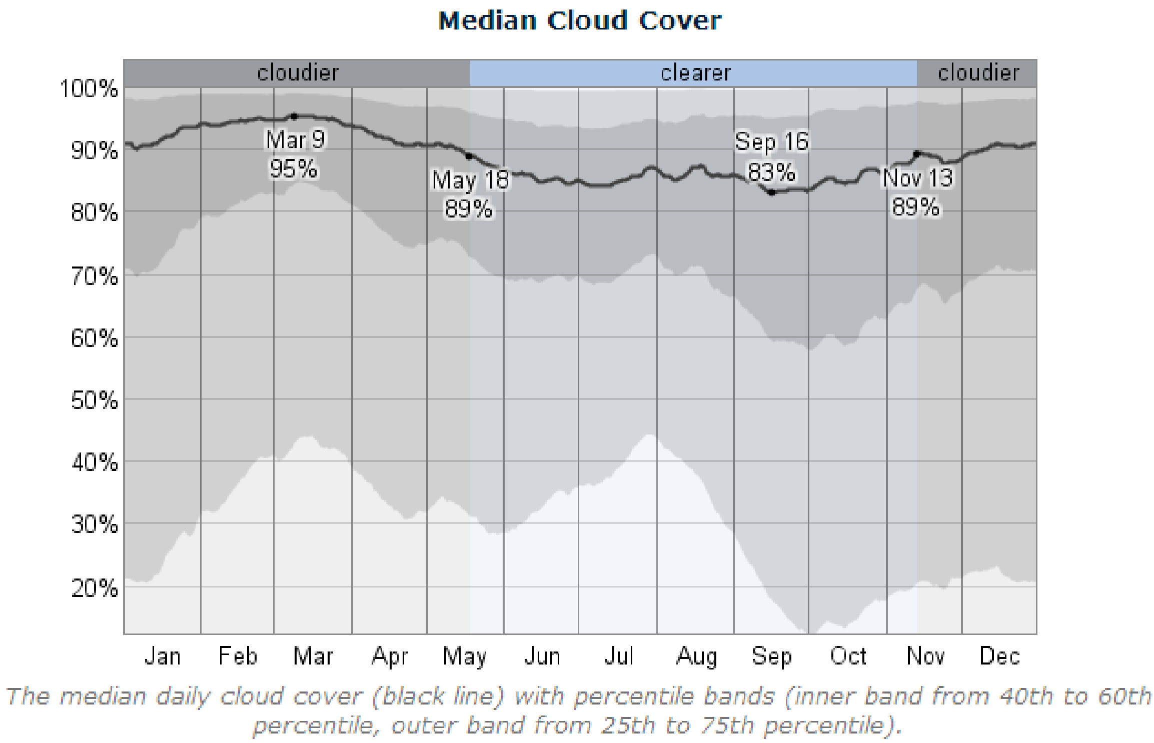


Figure 2-6 Graph of Annual Cloud Cover for Eureka, CA showing clarity of clouds

2.17.1.4 Humidity

Throughout the year the humidity levels vary from mildly humid at 60% humidity to very humid at 90% humidity.

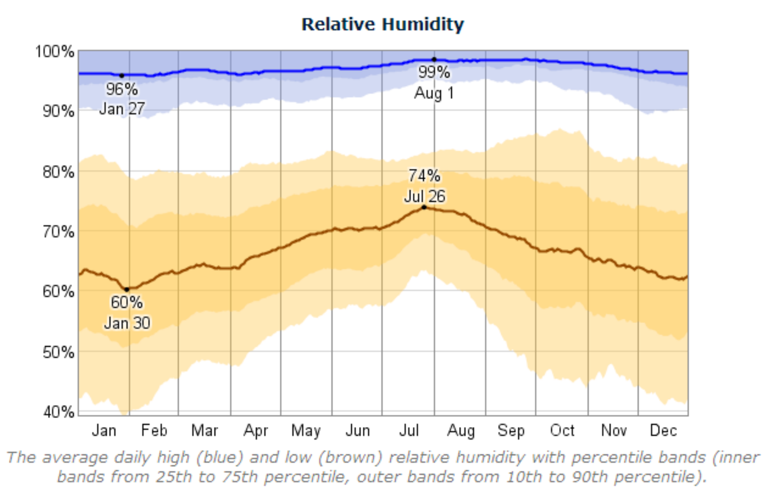


Figure 2-7 Graph of the Average Humidity in Eureka, CA over the course of a year

3 Alternative Solutions

3.1 Introduction

A couple brainstorming sessions took place to develop alternative solution designs for the Wheelable greenhouse. Eight designs were created for alternative solutions. Each alternative solution achieves the objective statement from Section 1, and the design criteria from Section 2.

3.2 Brainstorming

Team Jurassic Greenhouse conducted two separate brainstorming sessions in order to generate alternative solutions for the project. One unstructured session took place providing an array of undeveloped ideas and overly creative ways to match the criteria. The second brainstorming session was structured, and helped to discard the more irrational solutions. This helped to determine the 8 best solutions in which to pursue. Team Jurassic Greenhouse utilized sketch paper to draw the ideas while the brainstorming session took place. See Appendix A for the brainstorming documentation.

3.3 Alternative Solutions

Eight alternative solutions are listed below which were developed during brainstorm sessions. Each solution has a detailed description as well as a hand drawn diagram to help give an idea of what the solution will look like. In the next section, each alternative solution will be weighed against each other to help form a final solution.

- **The Hobo**

The Hobo is a greenhouse inside of a shopping cart. The inside of the shopping cart is lined with Plexiglas to ensure that no soil or water can escape to ensure cleanliness. Small holes may be drilled under the shopping cart to allow water to run through, but some type of catchment for the water will be installed so you can reuse the water. On top of the shopping cart is a removable gable shaped piece of Plexiglas to provide a "roof". Under the shopping cart is a storage unit for various gardening tools and a watering can. The baby pull out seat on the shopping cart can hold smaller potted plants such as herbs. The shopping cart is an ideal greenhouse structure because it is easily replicable, can fit through a door, and has sturdy wheels that can go through doors.

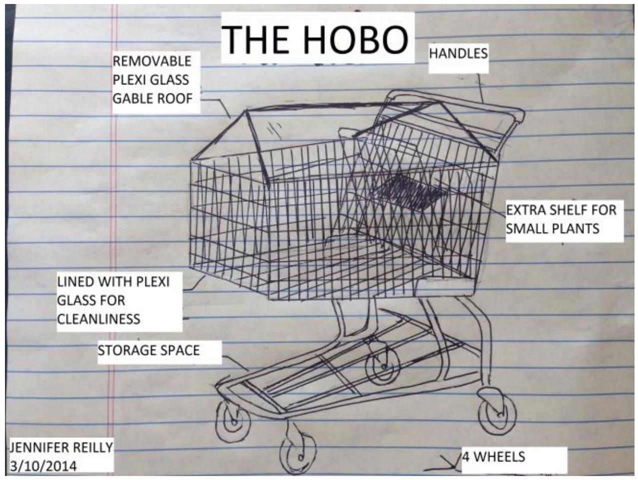


Figure 3-1 The Hobo drawn by Jennifer Reilly

- **The Plantquarium**

The Plantquarium is a fish tank attached to a cart. The fish tank would be about 5 ft. long and the width would be less than 30". The fish tank would rest on top of a two-tiered cart so that the bottom tier could be used as a shelving unit to store gardening tools and water supply. The cart has wheels on it to make it easily portable and looks much like the carts used to carry projectors in schools. The Plantquarium will fit through doors, be clean, and clear through the side walls so that you can look at the sides of the plants growing through the soil.

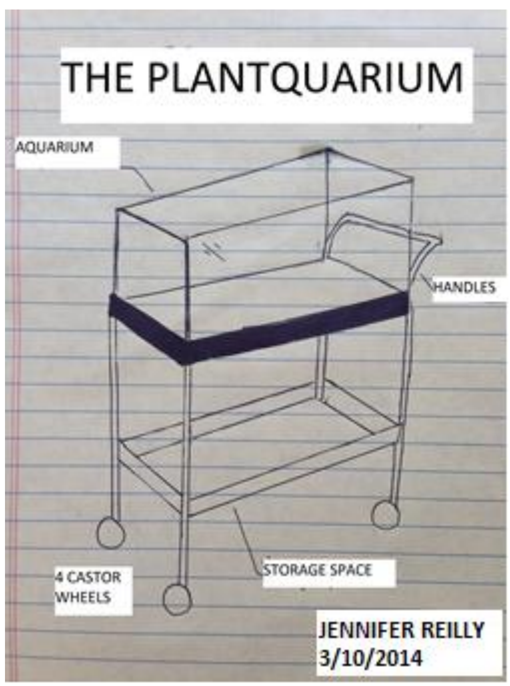


Figure 3-2 The Plantquarium drawn by Jennifer Reilly

- **Wagon Design**

The Wagon design was inspired by the team brainstorming session. The design was primarily based upon a red wagon and has many of the same features as the common red wagons. This low to the ground design has 4 caster wheels mounted to the bottom of the wooden frame. This allows for easy swivel and good maneuvering. The wooden frame is simply to support the use of the Plexiglas on 3 sides. The fourth side, the side away from the handle is left empty to allow a tray with multiple seed starting pots to slide easily into the center of the frame. This allows for very easy access to the seeds and gives the children a way to watch easily as the seeds grow over time. This design would be around 5’ is length, 2’-8” is width and 3’ in height making it the optimal size for adolescent teenagers. This clean design will make it easy to maintain and could be easily replicated as shown in Figure 3-3.

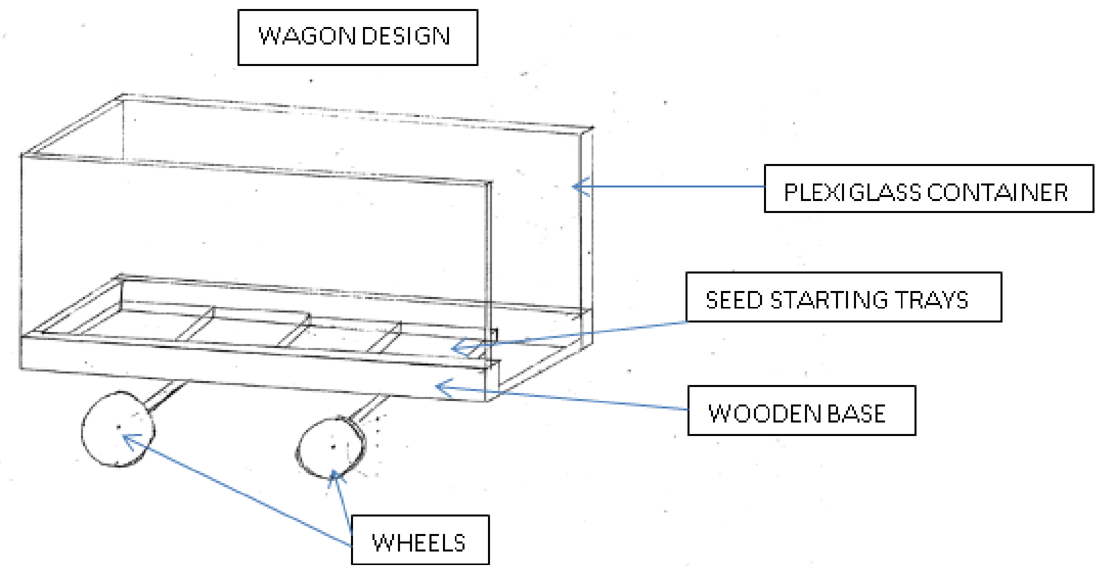


Figure 3-3 Wagon Design by Braden Nichols

- ## Wheelbarrow Structure

The design of the wheel consists of two front wheels and 2 posts on the rear side of the design. The front wheels are supported by an axel and the axel is mounted onto the bottom of the structure across two 2x4s. The 2x4s are rounded at the edges to create a balance that if pushed completely forward will not create dents in the ground. The top of the design is comprised of Plexiglas and is shaped like a rectangle with length 5' and width 2'-5". The back of the structure has a handle that allows for easy maneuver of the greenhouse and the handle is also mounted to the back 2 pegs that rest on the ground to keep the greenhouse at a 90 degree angle whenever immobile. This design is clean sturdy and easy to use with a short height making it perfect for children under the height of 5 feet to easy reach all necessary sides.

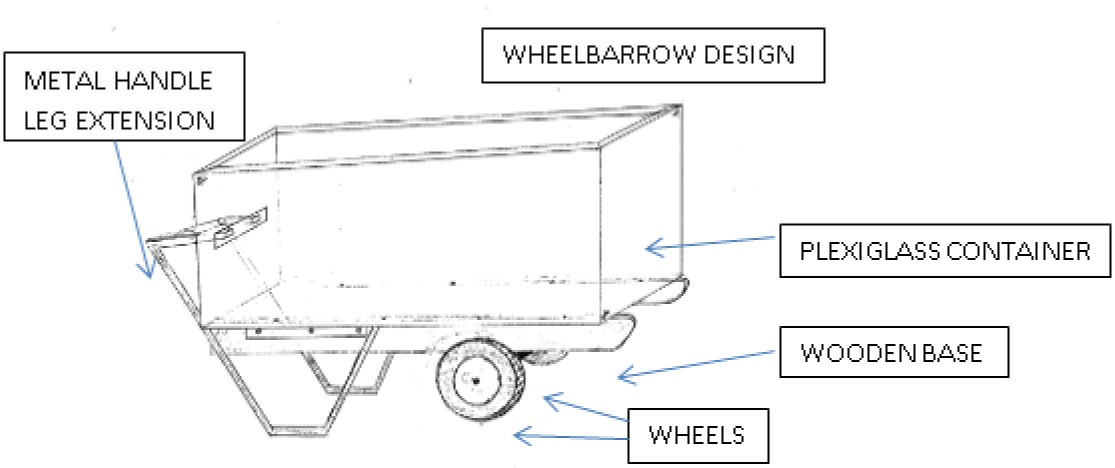


Figure 3-4 Wheelbarrow Structure drawn by Braden Nichols

- ## Standard Greenhouse

The Standard Greenhouse as shown by the figure is a basic shape of a rectangle with the top being made of a triangle as shown by Figure 3-5. The structure of the greenhouse is made out of redwood timber. Redwood is naturally resistant to decay and it is very strong which makes it ideal for use in the greenhouse. The exterior of the structure is to be covered in twin walled polycarbonate plastic. The plastic will let in adequate light and help to retain heat well. The polycarbonate plastic is also very durable which is advantageous as the greenhouse is being used at a middle school. On the top of the greenhouse will be two windows that will act as ventilation and can be propped open as needed. On the exterior of the greenhouse there is mounted handle that will help for pushing or pulling when moving the greenhouse. On one side of the greenhouse will be a door that opens outward that will allow access to the interior of the greenhouse.

On the interior of the greenhouse will be two sets of shelves, one set per side of the greenhouse. These shelves will support trays that can slide on which will house the plants being grown inside the greenhouse. The floor of the greenhouse will be made of corrugated wood, which will allow water and debris from the plants to pass though. Under the floor is a trough which channels all water to a spigot so that the entire greenhouse will be sealed as to not leak and water or dirt. The spigot may then be opened when the greenhouse is outside as to let out excess water that can then be reused to water the plants.

On the bottom of the greenhouse will be a set of caster wheels and a set of bike wheels. The caster wheels will be mounted directly to the bottom of the greenhouse and will allow the greenhouse to pivot. The bike wheels are attached to one another by an axle, and that axle is attached to the bottom of the greenhouse.

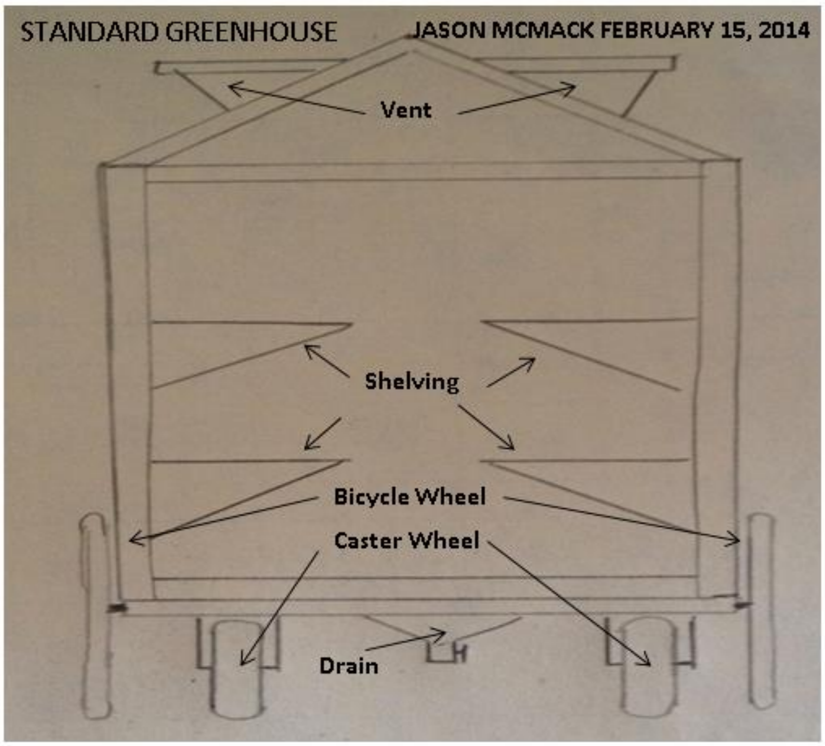


Figure 3-5 Standard Greenhouse drawn by Jason McMack

- ### Shelving Special Greenhouse

The Shelving Special Greenhouse as shown in figure 3-6 is primarily made out of metal shelving provided by Zane Middle School. The shelving is constructed with four metal pillars connected by four metal shelves at varying heights. The top of the greenhouse will be constructed by three pieces of PVC piping. The PVC piping is attached to the frame of the greenhouse at the four corners of the greenhouse. This framing will provide a base to cover the greenhouse in a double layered polyethylene film. This film is very pliable and therefore can be wrapped around the entire shape of the greenhouse. The film is not as durable as hard plastics or glass, but it is very easy to work with and cheap, therefore it can be replaced every year or two with low costs. The film will be glued down on the frame at key points in order to create a seal around the greenhouse, providing a relatively enclosed environment.

The shelving of the greenhouse will be mounted to a base constructed of wood that will house a water catchment system. This system will catch all water that drips down from the plants above and channel water to a spigot that can be opened to drain out water when appropriate. The base will also be the point where the casters attach. One set of casters will pivot thus providing steering for the greenhouse, and another will be fixed providing stability for the structure.

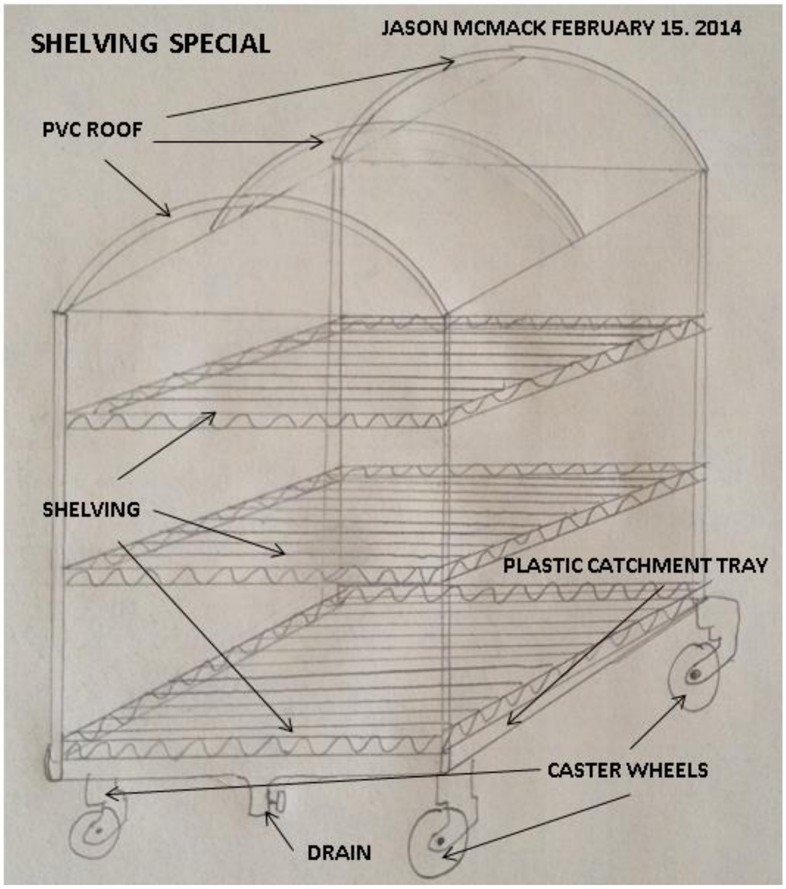


Figure 3-6 Shelving Special drawn by Jason McMack

- **Accordion Cart**

The Accordion Cart is rectangle shape cart with two rear wheels that are larger than the two twistable wheels in the front for easy movement in change of direction. As seen in Figure 3-7, the base of the cart is open on all four sides and has a base and is boarder to use as storage for supplies. The roof of the cart is framed in an arch form that is made out of foldable plastic. That allows the roof to be pushed backed in order for the students to view the plants without moving the plants out of the cart. There is a bar on both sides of the length of the cart on the top that gives the roof a skeleton to help keep its form which does not fold back with the plastic roof, but detaches from the carts. The handle is rectangle shape bar with one long side bar absent to attach the two widths to the cart.

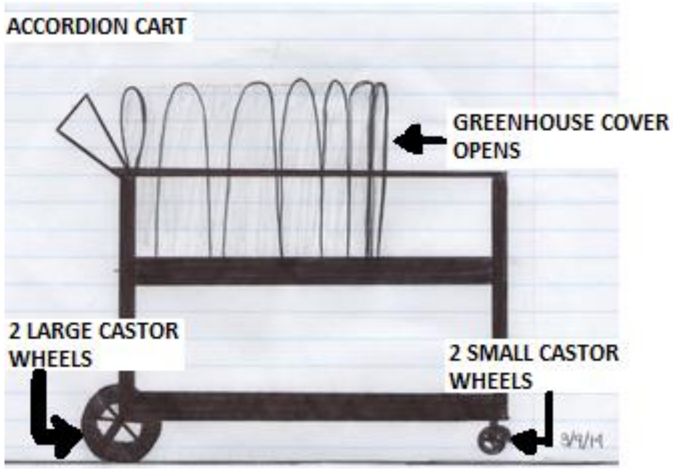


Figure 3-7 Accordion Cart by Toni Castillo

- **Plant Grower Stroller**

The Plant Grower Stroller has two levels. As seen in figure 3-8 you can see the bottom layer has a base and borders for storage space. The upper layer is the carrier for the plants. This layer has a base and border, with slots along the border to place and hold the Plexiglas up right and in place of the rectangular shape of the stroller. On top is a dome like plastic cover that is made of two arches that opens in the middle to allow the students to view the plants. The dome is center in the middle of the length of the top layer and there is a spot were all the ends of the two arches meet to make the dome allowing them to pivot open. The two layers of storage and plant carrier are connected together by two bars that have a scissor like connection allowing the top layer to change heights for easy viewing of the plants. There are also handles as seen in strollers. These handles are connected to the base of the top layer.

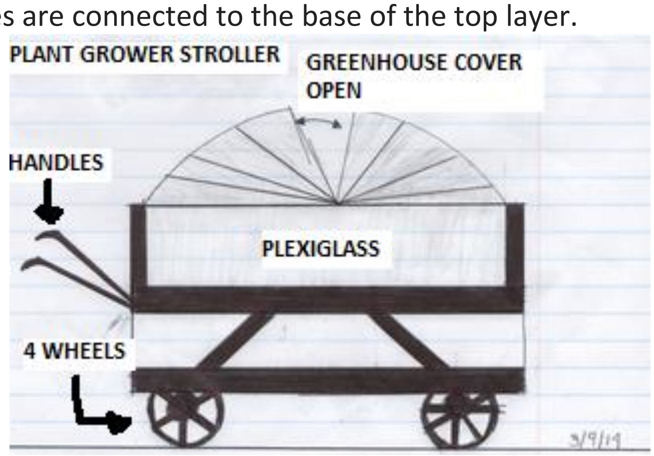


Figure 3-7 Plant Grower Stroller by Toni Castillo

4 Decision Making Process

4.1 Introduction

The design process is explained in Section 4. This section will go over the alternative solutions from the previous section and one of these solutions will be selected using the Delphi Matrix. The Delphi Matrix is a graph that helps find a solution based on the criteria from Section 2. The best fitting solution will have the highest number in the end accounting for Criteria weight. This section will also go over and explain the criteria and the reasoning behind why the decision made was made.

4.2 Criteria

The explanations of each criterion are listed below. The importance of each one of these criteria is used to help find the best fitting solution.

Safety- The finished product must contain no glass or anything easily breakable. Also, it must have no sharp objects that can put any of the students in harm. Everything must be secure so no objects will fall off while the greenhouse is in motion.

Aesthetics- Looks properly built and is eye catching; should look appealing to students from 6^{th} to 8^{th} grade as well as faculty members of the school. Also should be easy to duplicate.

Sustainability- Should be as eco-friendly as possible with the use of as many up-cycled materials that will work well and look nice.

Portability- Must be able to roll over grass, hard gravel, and doorways without disturbing anything in the greenhouse.

Durability- Must be able to withstand outside weather and must be able to be transported without anything falling/breaking.

Educational- The inside of the greenhouse must be able to be viewed by multiple people and will serve as a lesson on plant growth and care.

Cost- Must not go over the budget described in Section 2.

Cleanliness- Must retain all water and soil inside the greenhouse. Leaking of any of these substances is unacceptable. All plants should be securely placed so they won't fall around inside as well.

4.3 Solutions

The alternative solution were recorded and diagrammed in Section 3. Here is a list of the names of all the solutions that were discussed upon:

- The Green Wagon
- The Wheelbarrow
- The Hobo
- Plantquarium
- Standard Greenhouse
- Shelving Special Greenhouse
- Accordion Cart
- Plant Grower Stroller

4.4 Decision Process

The decision process was largely based upon the results of our Delphi Matrix shown in table 4.4.1. After the matrix was created, our group discussed the results and made an educated decision for the project. To begin the Delphi Matrix, the group chose an appropriate weight for each of the criteria. Each group member had a say in whether or not a criterion should receive a high weight completely based upon personal opinion and a final weight was found through team correspondence. A list of the criteria weights is shown in table 4.4.

The next step was for each alternative solution to be graded on a scale from 1-50 and agreed upon with a team consensus based upon how well the solution reached the individual criterion's standards. A low score would be awarded to the solution if it did not fulfill the criterion's standards to the full amount. A high score (50 being high) would be awarded if the solution fully met the standards of the criterion and how well they did meet them. These results were acquired through much deliberation and persuasion in our group meeting.

The third step was to take all the agreed upon solution scores (on a scale from 1-50) and multiply that score by the individual criterion's weight to get a total score for that criteria for every solution. After the matrix was completed using this method, the highest scoring solutions would be discussed and an overall decision for the Design Project would be made for our project.

Table 4.4- Criteria and Constraints

Criteria	
List	Weight
Safety	10
Aesthetics	9
Sustainability	5
Portability	10
Durability	7
Educational	8
Cost	5
Cleanliness	10

The Delphi Matrix is designed to help the decision process. The matrix calculates the criteria weights and how well each alternative solution meets the constraints.

Table 4.4.1 The Delphi Matrix

Criteria		Solutions							
List	Weight	The Hobo	Plantquarium	Wheelbarrow	Wagon	Standard Greenhouse	Shelving Greenhouse	Accordion Cart	Plant Stroller
Safety	10	40 / 400	35 / 350	40 / 400	35 / 350	35 / 350	30 / 300	40 / 400	35 / 350
Aesthetics	9	35 / 315	40 / 360	35 / 315	40 / 360	45 / 405	30 / 270	35 / 350	45 / 405
Sustainability	5	45 / 225	30 / 150	35 / 175	35 / 175	30 / 150	35 / 175	35 / 175	30 / 150
Portability	10	40 / 400	35 / 350	35 / 350	45 / 450	40 / 400	30 / 300	40 / 400	40 / 400
Durability	7	45 / 315	35 / 245	45 / 315	40 / 280	45 / 315	30 / 210	35 / 245	40 / 280
Educational	8	40 / 320	40 / 320	30 / 240	40 / 320	45 / 360	35 / 280	45 / 360	40 / 320
Cost	5	45 / 225	30 / 150	30 / 150	40 / 200	20 / 160	35 / 175	35 / 175	20 / 100
Cleanliness	10	40 / 400	35 / 350	40 / 400	35 / 350	45 / 450	30 / 300	45 / 450	40 / 400
	Total	2600	2275	2345	2485	2590	2010	2555	2405

4.5 *Final Decision*

The Delphi Matrix method concluded that The Hobo design best suited our criteria for a Wheelable greenhouse. After careful consideration of the options, however; a decision was made to not use the Hobo design. For many reasons, a new design was chosen. The new design being a hybrid of the Standard Greenhouse and the shelving greenhouse would have shelves like a cart but a greenhouse structure mounted to the top of it.

5 Design Specification

5.1 Introduction

The purpose of section 5 is to explain the final solution that was decided based on the list of solutions from section 4. This section contains figures showing the final project as well as a detailed explanation of the solution. This section also contains explanation of the costs involved and the amount of time dedicated to the project as well as time requirements and costs associated with maintenance of the project.

5.2 Solution Description

The Mobile Greenhouse is a small greenhouse that is mobile so that it can be brought into classrooms for demonstration for students as shown in Figure 5-1. The greenhouse itself can be described as containing two main components. There is main structure where the plants are stored and grown, and the base on which the main structure is attached.

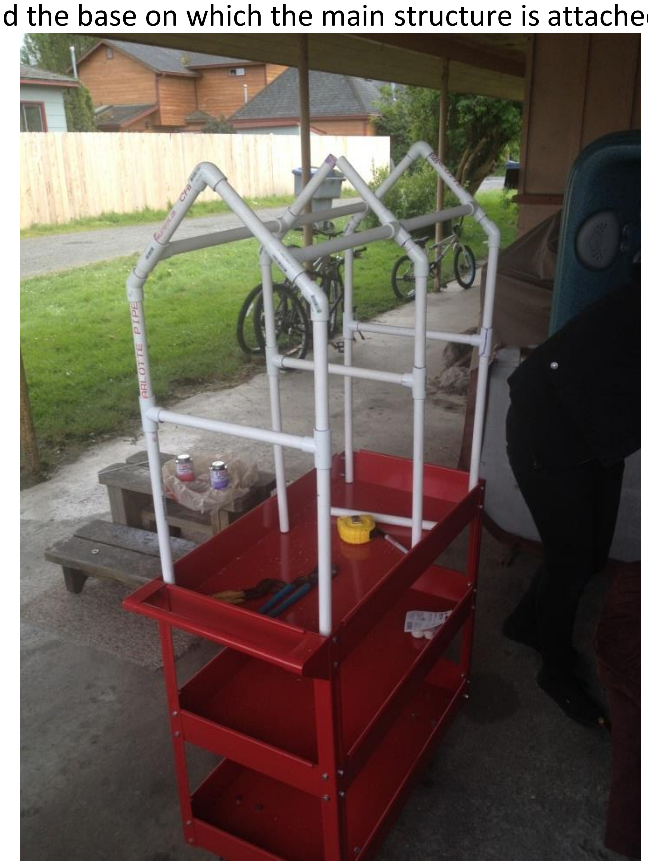


Figure 5-1 Overview of the Greenhouse

The top structure where the plants are stored is made from PVC pipe and shown in Figure 5-2. Sections of ½" PVC pipe are connected to one another using PVC junctions. The sections of PVC are secured by use of PVC cement to make a solid structure. There are two levels of shelves to maximize the amount of plants that can be grown. A shelf is located in the middle of the top structure. This shelf is made from cross member sections of PVC piping. A clear piece of rectangular Plexiglas with dimensions of 30"x18" is laid on the cross members to make the shelf. The top structure in Figure 5-3 is covered with a polyethylene film which allows for maximum amount of light transmittance. The cover is made from 4 separate pieces which are secured together by using an iron to melt together the seams. The film is secured to the greenhouse by use of plastic clips which connects to the PVC pipe that is a part of the top structure. At the base of the greenhouse there are recycled bricks that line the bottom of the pan to help increase the thermal mass inside of the greenhouse. Adding dense materials such as brick allow for more absorption of heat by the entire system within the greenhouse. Figure 5-4 shows a 1/2" diameter hole that has been drilled that allows for drainage of excess water. A ½' brass fitting is mounted to the hole by use of silicone sealant and then a tube is connected to the fitting. This tube runs down the height of the base of the greenhouse into a container which allows for the collection of water to be recycled.

Figure 5-2 Top Structure of the Mobile Greenhouse

Figure 5-3 Top Structure with the cover attached

Figure 5-4 Drainage system located on the top level of the tool cart

The base on which the greenhouse structure is built is a metal tool cart shown in Figure 5-5. The cart contains three levels. The lower two levels are used for storage of tools as well as a reservoir for excess water being used in the greenhouse. The top level is where the greenhouse structure is attached. The structure is attached to the metal cart by use of 6 round rubber feet shown in Figure 5-6. These stoppers are mounted to the top level of the tool cart through screws and wingnuts. The vertical components of the top structure are then pushed into the rubber stoppers forming a strong seal and prevent the top structure from coming off of the tool cart.

Figure 5-5 Tool Cart used for the base of the Greenhouse

Figure 5-6 Rubber Feet used to mount the top structure to the tool cart

5.3 Cost analysis

This subsection gives an overview of the costs associated with the project. These costs are listed in prices that were spent on the project as well as the time dedicated to the project. The maintenance costs and time requirements are also listed.

5.3.1 Design Costs

The total amount of time spent on the project is shown in Figure 5-7. These costs are broken up into the amount of time spent on each section.

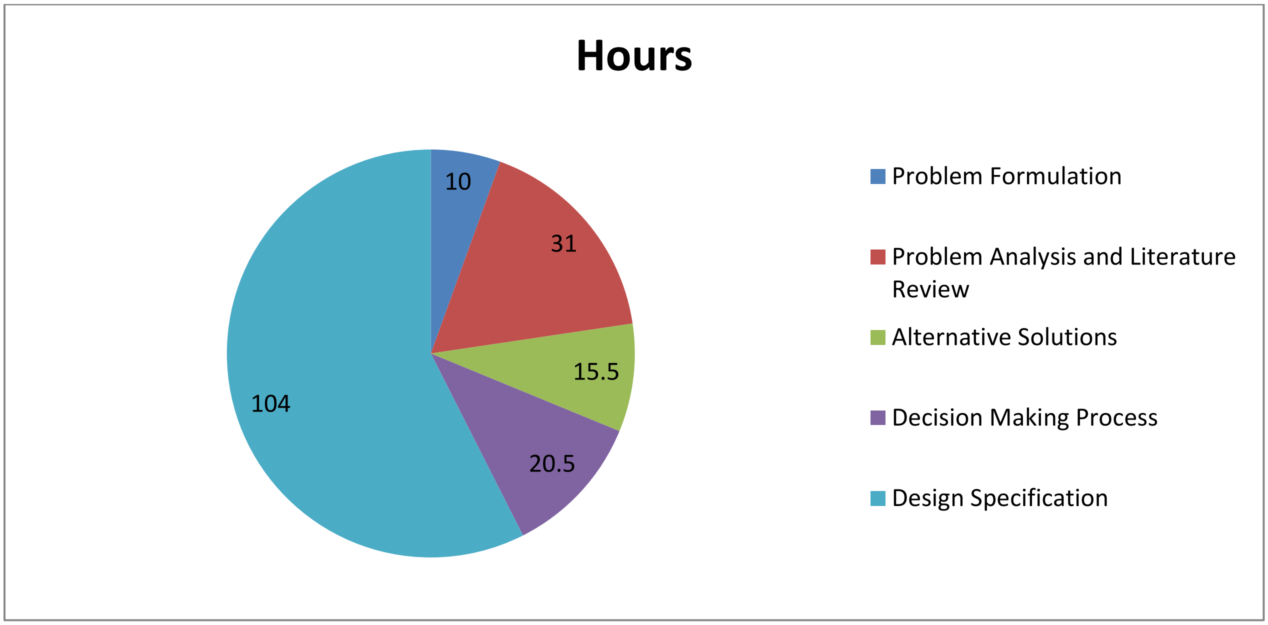


Figure 5-7 Design Hours for the production of the Mobile greenhouse separated into the 5 sections of the project development.

The total implementation cost of the Mobile Greenhouse is shown in Table 5.1. All materials used are listed in the table with each item, cost, and the quantity of each item used.

Table 5.1: Implementation Cost for the recreation of the Mobile Greenhouse.

Item	Quantity	Cost ($)
Service Cart 3-Shelf	1	54.11
Plastic Sheeting	1	11.14
PVC Pipe	6	17.94
PVC Connector	34	22.01
PVC Purple Primer	1	7.59
PVC Cement	1	8.49
Hack Blade 10”	1	2.79
Hack Saw 10”	1	6.99
Rubber Leg Stoppers	2	6.58
Black Spray Paint	1	4.99
Tube of Silicon	1	5.99
Clamp Hoes	1	1.59
Vinyl Tubing	1	2.76
Brass Drain	1	1.79
Hardware	18	2.58
Total		**157.34**

5.3.2 Maintenance Cost

The maintenance of the Mobile Greenhouse is relatively low. The cost and time associated with maintenance is listed in Table 5.2.

Table 5.2: Maintenance Cost for the Mobile Greenhouse in time needed and monetary cost for each item.

Task	Frequency per Year	Price ($)
Glazing	1	2.00
Drain Tube	5	2.76
	Total	4.76

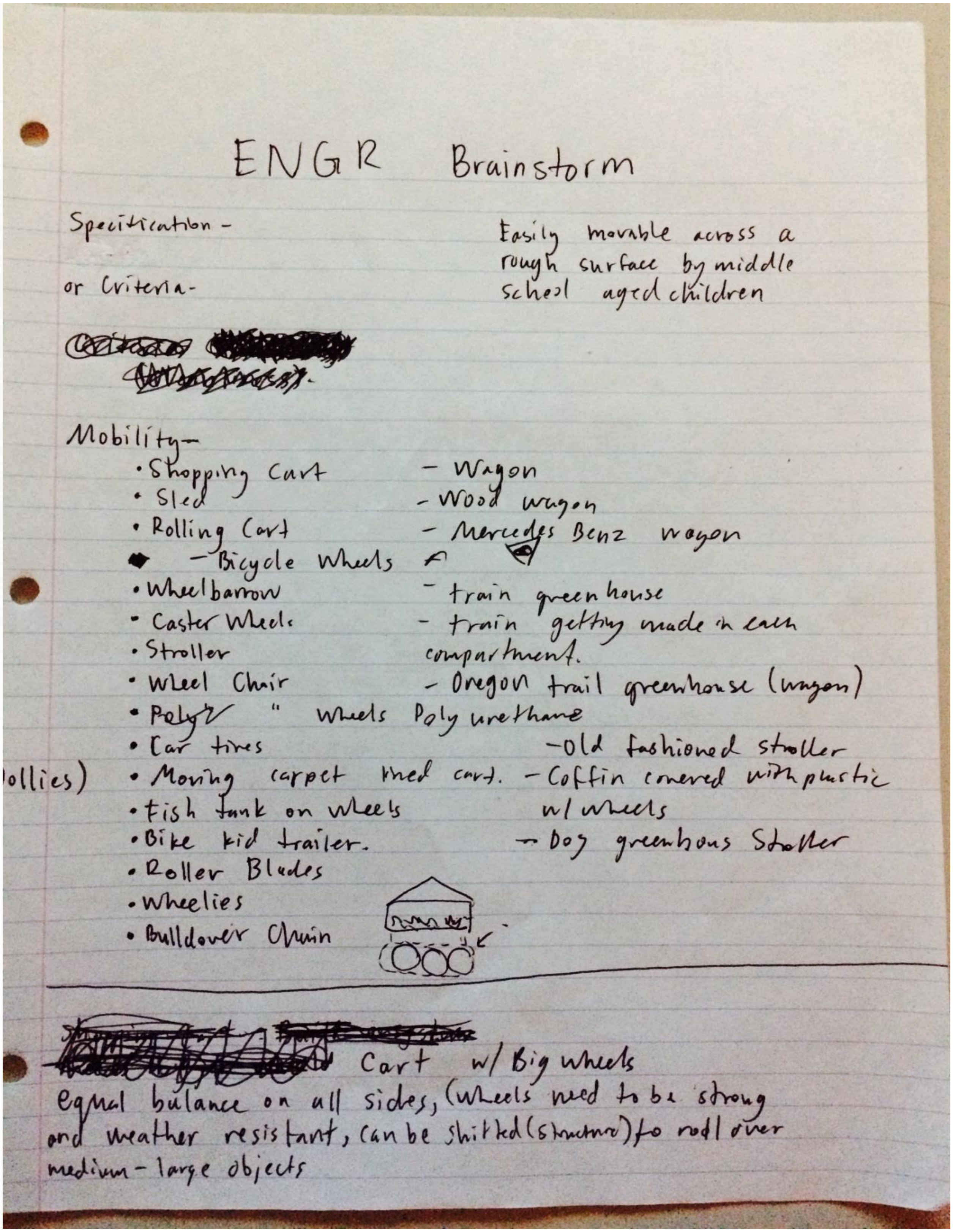
5.4 Implementation Instructions

Instructions for replicating the Mobile Greenhouse can be found online at:
http://appropedia.org/Mobile_Greenhouse_Instructions.

5.5 Results

The Mobile Greenhouse needed to be tested in two ways to evaluate its effectiveness. First the cleanliness of the greenhouse needed to be tested so that no dirt or water leaks out of the greenhouse from the seal around the drain or any of the holes drilled for the rubber mounting feet. The base of the greenhouse was filled with water mimicking the amount of water that would be used in watering plants and all holes and seals were checked for leakage. No leakage was detected at this time. The second test for the greenhouse involved testing the temperature inside greenhouse. A thermometer was inserted in the greenhouse to measure the temperature when it was located outside during the day as well at night when the greenhouse is stored inside. The temperature outside was measured at 68 degrees Fahrenheit during intermittent sunshine and 72 degrees inside the greenhouse. When being stored inside the ambient temperature was 64 degrees outside and 66 degrees inside the greenhouse.

6 Appendix A- Brainstorming



ENGR Brainstorm

Specification - or Criteria-

Easily movable across a rough surface by middle school aged children

Mobility-

- Shopping Cart
- Sled
- Rolling Cart
- – Bicycle Wheels
- Wheelbarrow
- Caster Wheels
- Stroller
- Wheel Chair
- Poly " Wheels Poly urethane
- Car tires
- Moving carpet lined cart.
- Fish tank on wheels
- Bike kid trailer.
- Roller Blades
- Wheelies
- Bulldozer Chain

ollies)

- Wagon
- Wood wagon
- Mercedes Benz wagon
- train greenhouse
- train getting made in each compartment.
- Oregon trail greenhouse (wagon)
- Old fashioned stroller
- Coffin covered with plastic w/ wheels
- Dog greenhouse Stroller

Cart w/ Big wheels

equal balance on all sides, (wheels need to be strong and weather resistant, can be shifted (structure) to roll over medium - large objects

Figure 6-1 Brainstorming Session Part 1

Appendix A- Brainstorming

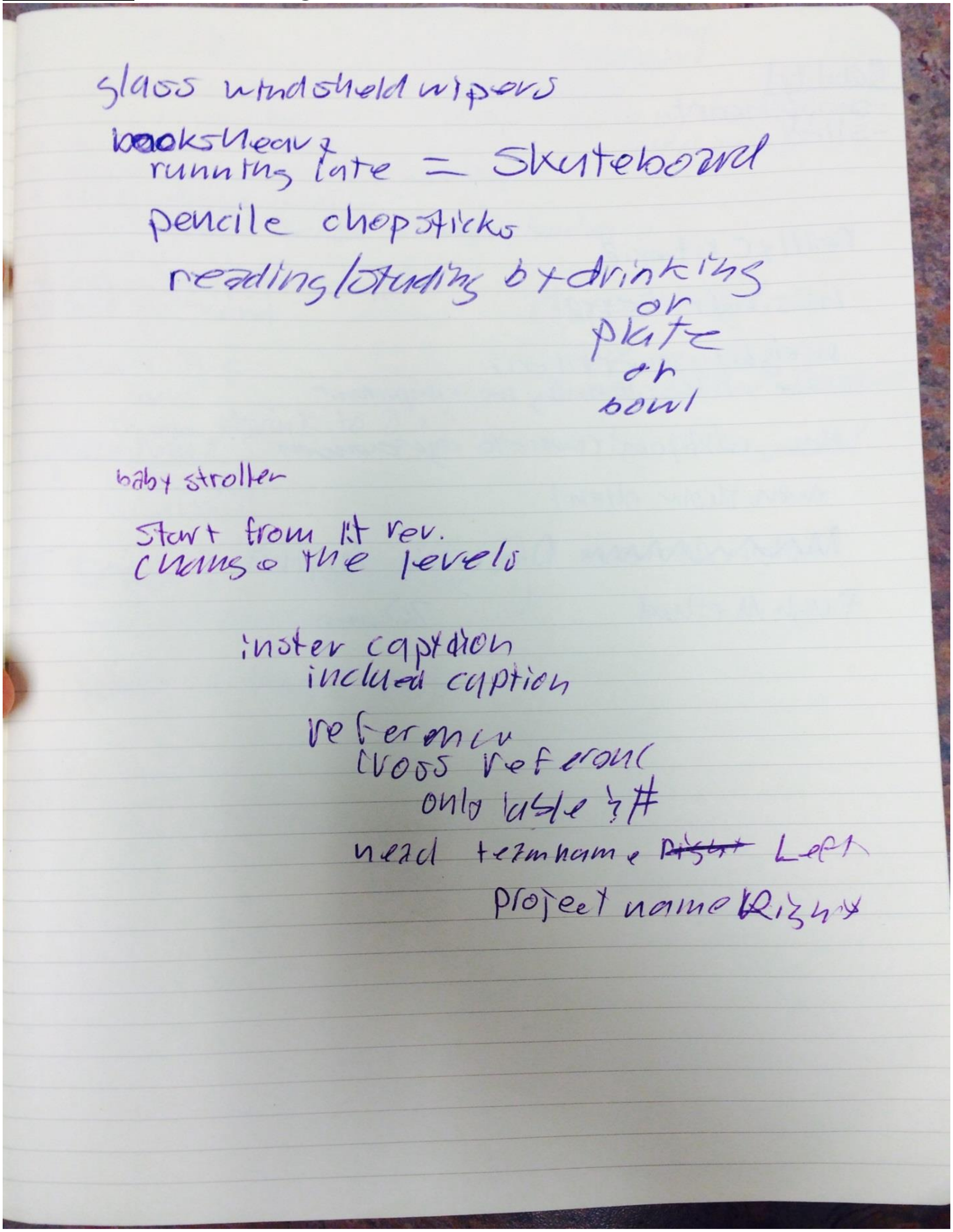


Figure 6-2 Brainstorming Session 1 Part 2

References

Andrea, J. (2014) “Normal Height and Weight for a School-Age Child”. http://www.ehow.com/about_5412669_normal-height-weight-schoolage-child.html (February 25, 2014)

Both, A.J. (2008). “Greenhouse Glazing” http://njveg.rutgers.edu/assets/pdfs/ajb/Glazing.pdf (February 24, 2014)

Caster Industries. “Industrial and Institutional Casters and Wheels”. http://www.casterindustries.com/pdfs/castercatalog.pdf (February 26, 2014)

Cemek, B., Demir, Y., Uzun, S., Ceyhan, V. (2006). “The effects of different greenhouse covering materials on energy requirement, growth yield and of aubergine.” *Energy,* 31(12), 1780-1788

Dietz, M. (1974). *10,000 Garden Questions Answered by 20 Experts,* 3rd Ed., Garden State, New York.

Hanscom Z., Ting, I. (1977). “Responses of Succulents to Plant Water Stress” *Plant Physiology,* <plantphysiol.org> (March 1978).

Jozwik, F. (1984) *Plants for Profit,* 1st Ed., Mills Wyoming.

Nelson, K. (1978) *Flower and Plant Production in the Greenhouse,* 3rd Ed., Danville, Illinois.

Pidwirny, M. (2006). "Introduction to Soils". *Fundamentals of Physical Geography, 2nd Edition*. Date Viewed. http://www.physicalgeography.net/fundamentals/10t.html

Mathala, G. J., Pitam, C. (2002). “Effect of greenhouse design parameters on conservation of energy for greenhouse environmental control.” *Energy,* 27(8), 777-794.

Preston, F. G. (1951). *The Greenhouse*. Ward, Lock & Co., Suffolk, United Kingdom. Chapter 1, p 29-31.

Vassar, H.P. (1981) “Caster Brake and Swivel Lock”. US Patent No. US4248445 A. Rumson, New Jersey.

Walls, I. G. (1973). *The Complete Book of Greenhouse Gardening*. Quadrangle/The New York Times Book Co., New York, New York. Chapter 4, p. 31-48.

Willert, D., Eller, B., Werger, M. (1992). *Life Strategies of Succulents in Deserts,* 1st Ed., Cambridge, Great Britain, 2-24

Wikipedia contributors, "Door," *Wikipedia, The Free Encyclopedia,* http://en.wikipedia.org/w/index.php?title=Door&oldid=597273839 (February 28, 2014).

Yang, N., Zang, L., Wang, S., Guo, J., Xu, H., Wan, F., (2014). “Biological Pest Management by Predators and Parasitoids in the Greenhouse Vegetables in China.” *Biological Control,* <sciencedirect.com/science> (January 2014)