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1 Problem Formulation

1.1 Introduction

The problem formulation section identifies the problem posed to Team Suoicortalaepxcitsiligartilacrepus. A simplified problem and solution may be found in Figure 1.1.1.1. Problem Formulation deals only with the problem, while later sections will deal with the solution.

1.1.1 Background Information

In Phase 1 of the design process the team Suoicortalaepxcitsiligartilacrepus formulated a simplified objective statement as well as a black box diagram. A simplified description of the design process is shown in Figure 1.1.1.1 , illustrating the effect this project will have on the Zane Middle School.

Figure 1.1.1.1:Black Box model showing a simplified outlook of the procedure used to complete the project.

1.2 Objective

The goal of this project is to create an outdoor classroom learning environment for junior high school students.

2 Problem Analysis and Literature Review

2.1 Problem Analysis

The problem analysis identifies criteria established by the client while simultaneously addressing the constraints of the individual criterion. The problem analysis includes specifications, criteria, constraints, usage, and production volume.

2.1.1 Specifications

Specifications for the outdoor classroom identify dimensions and quantities necessary to construct various elements of the project. The seats must support over 250 pounds. The classroom space may not impede on emergency vehicle access to the campus. Materials used must be durable, capable of withstanding stresses placed on them through transport, use, and weather. The classroom must not negatively impact maintenance workers' ability to maintain the school grounds. Components of the classroom must be easily stored if made portable. Seats and writing surfaces must be graffiti resistant. Lastly, the classroom must adhere to ADA standards.

2.1.2 Considerations

Design considerations include the following:

- Students gaining roof access with the assistance of seating.
- Americans with Disabilities Act (ADA) compliance.
- Transportation stresses placed on materials.
- Humboldt weather conditions.

2.1.3 Criteria

The project criteria outlines qualities which the classroom must possess as directed by the client. Table 2.1.1 describes the various criterion established by the client, with each criterion's constraint in the middle column, and its importance in the rightmost column titled "Weight".

Table 2.1.1: Criteria developed with the client identifying key dimensions that influence to project's design (left), their respective constraints (middle), and how heavily they are weighted in comparison to one another (right).

Criteria	Constraints	Weight
Safety	Must not present a cutting or splintering hazard, and resist tipping.	10
Utility	Must function as effectively as an indoor classroom.	9
Cost	Project must be cost less than $450.00	9
Durability	Must have a useful design life of at least five years.	8
Portability	Components must be movable by at least one adult.	7
Plasticity	Must be usable regardless of subject being taught.	7
Storability	Must easily fit into available storage space in staff lounge area.	6
Aesthetics	Must abide by Zane Middle School color scheme of red and yellow or follow STEAM theme.	5
Comfort	Must be easy to sit in for at least 1 hour	3

2.1.4 Usage

Students and teachers will utilize the outdoor classroom for an alternative lecture, and education space at Zane Middle School. The classroom is built to accommodate various subjects and support teacher's different teaching styles and classroom preferences. The classroom may be used for single class periods or for a whole school day with expected usage at approximately seventy-five times per year.

2.1.5 Production Volume

There will be only one outdoor classroom built on the Zane Middle School Campus. The production volume more directly corresponds to the number of seats and writing surfaces to be built. Seating and writing surfaces must be capable of accommodating thirty-three students as well as spares in the event of component failure.

2.2 Literature Review

2.2.1 Examples of Outdoor Classrooms

Outdoor classrooms are areas where lecturing or general learning can take place without the confinement of walls and ceilings. In an outdoor classroom student is able to experience nature while learning (schooloutdoorlearning.com).

There are many examples of outdoor classrooms, from the national parks service, to various schools and colleges. Outdoor classrooms are an extremely popular teaching method, and are used all over the world. The design and arrangement of outdoor classrooms have many subsets and combinations. To better understand and reconcile the plethora of designs, it is necessary to view previously constructed examples currently in use.

2.2.1.1 National Parks and campgrounds

Amphitheaters used by the national parks are very rustic and simple in design, usually featuring a semicircular seating arrangement made of permanent benches that are raised in a series. Smaller, simpler setups used at campgrounds can be made up of simple rows of benches or logs, arranged to face a single speaker (nps.gov).

Figure 2.2.1.1: A typical National Parks amphitheater (nps.gov)

Figure 2.2.1.2: An outdoor classroom at Castolon Cottonwood Campground (SkiAnything.com)

2.2.1.2 School Examples

Some schools build individual seats with simple wooden desks for a design that is much closer to an indoor classroom. Both the desks and chairs are movable for easy arrangement (schooloutdoorlearning.com).

Figure 2.2.1.3: A simple outdoor desk and chair (schooloutdoorlearning.com)

In keeping with the idea of mobile outdoor classrooms with individual seating and desks, students at Philadelphia University designed these mobile stools that also have an adjustable writing surface (philau.edu).

Figure 2.2.1.4: A student demonstrates the outdoor classroom desk designed by Philadelphia university students (philau.edu)

Other schools use more unique methods for student seating. At the Lied Lodge in Iowa, students can relax on a spider-web shaped hammock. This seating arrangement does not focus on any central speaking point or lecturer (wholechildaction.com).

Figure 2.2.1.5: An unorthodox rope and netting web for student seating (wholechildaction.com)

While more labor intensive and much more expensive, concrete seating can be used to create custom seating areas that are decorative, and may be used to complement landscaping. These projects are usually permanent, and cannot be moved or modified easily.

Figure 2.2.1.6: An example of a permanent concrete seating arrangement around a single point (tes.com).

One of the simplest form of outdoor classroom can simply be a single set of benches arranged around a speaker. This setup used for schools is a cheap and mobile option that can be easily moved or transported.

Figure 2.2.1.7: A completely moveable classroom, with simple movable benches around a mobile picnic table (Ozark Upper Elementary School).

The simplest design can use cross sections of trees for heavy, but movable, seating.

Figure 2.2.1.8: Rainbow Community School's simple setup; tree cross sections for seating, and a bed of chipped wood makes up the floor (rainbowcommunityschool.org).

2.2.2 Pedagogy

Pedagogy deals with the study and methodology of teaching. Learning environment, grade level, teacher practices, and gender all affect a student's capacity to learn (Hayes 2000). California has some of the most diverse classroom environments in the nation. Concurrently, Zane Middle School has wide sweeping demographics both in terms of economic standing, as well as ethnicity (Trevor 2018).

Teachers continue to strive to teach material in new ways to develop new perspectives and education. A 2004 study found American teachers try to formulate more creative and intuitive approaches to mathematical teaching as opposed to peers from other nations (An 2004). This innovation drives the need for new teaching aids and venues. Furthermore, classrooms and educators face a heightened need to address the increasing variety of learning styles including visual, auditory, conceptual, and kinesthetic learners.

2.2.2.1 Learning Habits of Middle School Students

Middle school poses as a particularly difficult transition period for students in the entry level grade. As children enter middle school they become responsible for their own study habits (deBetancourt 1999). As grade-level material becomes more complex it becomes more important for teachers to instruct students on study-skills and learning-strategies to apply in times of critical thinking. Study-skills deal with students having a plan to approach a situation, such as note taking, whereas learning-strategies involve processes where students perform critical thinking and self-reflection about the progress they make, such as test-taking strategies (deBetancourt 1999).

In 2002 the Dunn and Dunn learning style model was evaluated based on children's standardized test scores. At every grade level, Kindergarten-12, students with exposure to the Dunn and Dunn model outperformed their peers who did not. (Dunn, 2002). The Dunn and Dunn learning style provides a more unique multi-sensory approach to learning. The Dunn and Dunn model incorporates environmental, emotional, sociological, physiological, and psychological factors into its design. Students have preferences that enhance their learning capacity, and the Dunn and Dunn model aims to identify these, and make the student more aware of what may help them to learn.

2.2.3 California Learning Standards for Middle School Children

California standards for grade school children vary dependent on learning outcome goals. Moving from elementary school through middle school students transition from arithmetic to algebra. With adjustments in curriculum, California math classes are beginning to focus increasingly on "real world" applications of math strengthening the need for more applied examples (California Department of Education 2013).

In 2013 the California Department of Education (CDE) adopted the Next Generation Science Standards (NGSS) as a means of improving upon the California's grade-school scientific education (CDE, 2013). The NGS possesses three dimensions for ensuring both retention of information and mastery of course content. The first two are Scientific and Engineering Practices (SEP's) and Cross-Cutting Concepts (CCC's) which both deal with the content taught and integrating them with other material presented in the courses (CDE, 2013). The other dimension of the NGSS system is Disciplinary Core Ideas (DCI's) which are grade dependent courses and topics such as an instructor teaching a life sciences class about cells (CDE 2013). The NGSS are stringent enough to allow for learning outcome goals, but offer enough autonomy for local schools to further structure and develop curriculum.

2.2.4 California Classroom Standards

California classrooms are required to comply with Title 5 Code of Regulations, Division 1, Chapter 13, Subchapter 1, Article 4, § 14030. In this section standards are outlined for classrooms. Particularly important in this section is spacing and capacity. Classrooms are typically required to be a minimum of nine-hundred and sixty square feet, and capacity is expected to meet or exceed the expected number of students to occupy the space (CCR 5, § 14030). It is also important to consider physical location of classrooms as they relate to each other as students are expected to make it from one class to another on time. Lastly classrooms should easily accommodate activities for which they are to be used.

2.2.5 Seating Setup

Seating set-up is an intrinsic manner of structuring a classroom for both learning and activities. Seating even has effects on the way students perceive each other. Students sitting nearer to the center of the classroom are perceived as more popular, while students collocated get along better with one another (Van der Berg, 2014). The teaching style of the instructor may also influence the seating structure of the classroom (Shalaway 1998).

2.2.5.1 Circle or U-Shaped

Provides an upfront experience for the student, where every student is in the front of the class. This can allow the instructor to make specific eye contact with each student easily. This arrangement facilitates frequent whole-group discussions (Shalaway 1998). Circle or U-shaped seating also generates more questions asked from the students (Wannarka 2008).

2.2.5.2 Rows

Students exhibit significantly greater study behavior when seated in rows practicing independent work. Rows makes interacting with peers inconvenient and apparent to teachers (Wannarka 2008).

2.2.5.3 Group

This style off seating involves arranging students in multi-person pods typically ranging from two to six individuals. Group seating is useful for helping students to collaborate in small groups (Shalaway

1998). This form of seating allowed students to be most engaged in brainstorming activities that required peer interaction (Wannarka 2008).

2.2.6 Nature Deficit Disorder

Nature Deficit Disorder is described as the gap between nature and children. The amount of time children spend outdoors has steadily decreased and the exposure of our kids to nature is imperative to their physical and emotional health. Student behavior may change positively as they are exposed to more outdoor experiences. Studies suggest that sufferers of Attention Deficit Hyperactivity Disorder (ADHD) may benefit from exposure to nature (Louv 2006).

2.2.7 Climate in Humboldt County

The climate of the Humboldt County Region and the city of Eureka is considered Mediterranean, and has minimal temperature fluctuations. The area is prone to high humidity and fog year-round. (Puffer 1998). The average annual high and low temperatures of Eureka are 59.6 °F and 46.2 °F, respectively (U.S. Climate Data 2018). Average annual rainfall is 39.45in. The highest and lowest average annual rainfall are 67.21 inches and a low of 21.71 inches, respectively, as shown by the map in Figure 2.2.7.1. Summer and Winter precipitation averages are 1.15 inches and 19.07 inches, respectively. (Western Regional Climate Center 2012).

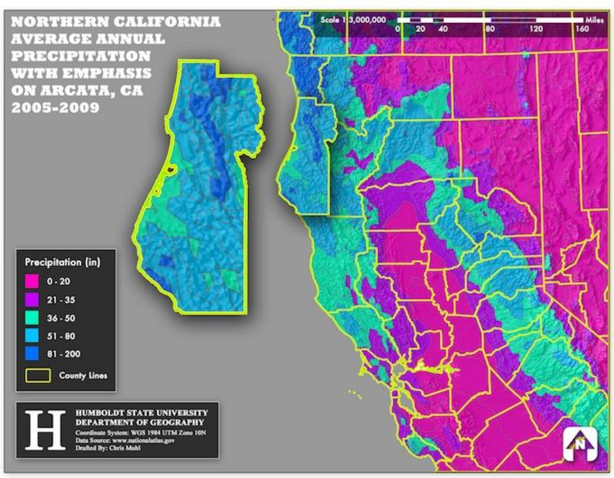

Figure 2.2.7.1: Average rainfall of Northern California with Humboldt County prominent (HSU Geospatial Club 2014).

2.2.8 Materials

Materials chosen for a design affect an overall project's perception, utility, and durability in a multitude of ways. Using cheap or water-soluble paints will yield a dilapidated and run-down aesthetic in a short amount of time. Metals that are not structurally sound to bear weight may be used for seating, and show a rapid decline in structural integrity. Wood not sealed or treated to prevent water absorption may rot in a matter of years. For these reasons it is important that a thorough analysis of potential materials is completed with a focus on durability.

2.2.8.1 Chalkboard

Modern chalkboards are typically made of varying thicknesses of steel and porcelain enamel, which is a tough and durable material. Silica is a primary component along with other inorganic compounds, opacifiers, and oxides. The finished products can have many accessories and must adhere to a gloss standard (MadeHow 2018). Traditional porcelain chalkboards are typically non-porous, while blackboard paint creates a porous surface. The former should be resistant to water seepage into the surface, while the latter is not (Versachalk 2017).

2.2.8.2 Dry Erase Boards

Dry Erase boards, also known as “whiteboards,” are more convenient to erase than a chalkboard. Some classes of whiteboards have materials that are cheaper than the enamel-steel components in chalkboards. Other whiteboards can be made with porcelain and steel and are non-porous to prevent any staining, which lower quality boards are prone to. The whiteboard has proliferated and almost entirely replaced chalkboards at educational institutions (Workplace Depot 2014).

2.2.8.3 Seats

Seats in a class affect student performance in several different dimensions. See section 2.2.5 on seating setup. As an integral part of the classroom design, it is important that students have a positive perception of the seats they will use in the classroom. Concurrently, it is also important that the seats are designed to last as they will be placed outside where weather conditions, humidity, and temperature vary.

2.2.8.4 Rubber Tire

Rubber tires are highly durable compounds capable of withstanding thousands of miles of travel under the weight of vehicles. When tires no longer serve their purpose for transport they are easily recycled in many ways such as being shredded and incorporated into various concrete elements. Tires are composed of sixty-two percent rubber matrix compounds, either natural or synthetic, and thirty-one percent carbon black as a reinforcing agent. The remaining seven percent are various compounds used to reduce internal friction, and increase tensile strength (Amari 1999).

Ground rubber’s resilience to impact and longevity make them excellent uses in many civil engineering applications. Crumb rubber is often used in playground, and athletic track surfaces (Takeshi, 1999). Tires may even be shredded and used as a ground cover to improve drainage in play areas (Amari 1999).

2.2.8.5 Plastics

Plastics are an inescapable resource in modern life. Consequently, there exists an abundance of plastic waste. Two of the most common plastic polymers existing in the world currently are polypropylene, and polyethylene. Plastics lend themselves well to various upcycling as these plastics frequently exist as containers which are easily filled, and they relative ease of compressibility.

Polyethylene (PE) pictured in Figure 2.2.8.1, comes in two forms: low density (LDPE) and high density (HDPE). The difference in the two arises from the length of polymer chains, with HDPE having uniform long chains and LDPE having short chains (British Plastics Federation 2018). Many grocery bags, chemical containers, and waterproof plastic sheets are often composed of primarily HDPE. In addition to being weatherproof, PE’s high impact strength and flexibility make it a useful and versatile material (British Plastics Federation 2018). The major weakness of PE is its susceptibility to weakening by ultraviolet light (UV). Prolonged exposure to UV light may cause PE to become brittle losing the qualities that make it a desirable building material (British Plastic Federation 2018). This inconvenience is often handle by coating the PE surface with carbon black.

Figure 2.2.8.1: Containers are often composed of HDPE or PP due to their impermeability and resistance to corrosive chemicals. (Medfor.co.uk)

Polypropylene (PP) possesses many of the same properties as PE, but is of a lower density, is more rigid, and maintains its structure at higher temperatures than PE (British Plastics Federation 2018). Likewise, PP also has low UV resistance. The increased rigidity of PP makes offers a wide array of applications from blow-molding to automobile plastics, as well as food containers.

For upcycling applications see Plastics in section 2.2.11.2.

2.2.8.6 Steel

Steel lends itself as a robust building material. Capable of withstanding extreme temperatures and having a great durability, it is a reliable building material. Steel does not succumb to insect attacks or mold, unlike wood, which has less resistance to these and other factors. (Durability of Steel, 2017). However, when evaluating steel as a component the issues that arise are as follows:

- Steel is inherently costly in comparison to wood and other alternatives.
- Steel also corrodes, and rusts easily, especially in coastal environments.
- The ease of workability with steel is much less than that of wood.

The corrosivity of steel may be mitigated by powder coating which acts as a barrier sealing the steel from water (Durability of Steel, 2017). Workability steel is inherently costly as the equipment needed is seldom found in the everyday tool box. Concurrently, the cost of steel makes this resource difficult to obtain.

2.2.8.7 Wood

Wood is one of the most common building materials in residential building applications. It is both globally available and comes in a variety of styles from plywood, to 2x4. Wood has high strength to weight ratios, and when compared to metals, is very easily workable, and finally has excellent heat retention (de Belie 1999). While wood is both a useful and easy medium to work with its durability faces degradation by both biological and weathering means. Wood's weakness to biological attack is affected predominantly by fungal decay, and insects (de Belie 1999). In Humboldt County, the primary concern with biological degradation relates to the relatively high humidity causing wood to absorb excess water and fuel fungal decay like that of Figure 2.2.8.2.

Figure 2.2.8.2: An example of dry rot in wood caused by fungal decay (Archinect.com).

Weathering is the second factor greatly affecting wood's durability and longevity. Wood exposed to recurrent wetting, and drying will experience warping affecting fastening locations, durability, and structural integrity (de Belie 1999). Wood may also change in color as it decays in outdoor or other unfavorable conditions losing aesthetic appeal.

Wood durability may be improved through proper weather-proofing, maintenance, and selection of naturally durable woods. Weather-proofing typically involves using chemicals to reduce permeability of the wood, as well as making the wood impenetrable or toxic to insects. Unfortunately, many treatments are potentially carcinogenic, mutagenic, toxic, or some combination of the three (De Belie 1999). Other weather-proofing may be done with polyurethane finishes, or plastic based stains and lacquers.

2.2.8.8 Cob

Cob refers to an ancient earthen building technique which combines clay soil, sand, straw, and water together. The product is strong, dense, and tensile gaining much of its structural integrity from the matrix of interwoven straw (Smith 2000). Cob lends itself effectively to coastal climates as it resists degradation in high humidity, however the material is susceptible to damage by rain necessitating proper coverage, and drainage (Smith 2000). Creating the slurry necessary to make cob is very labor intensive as the mixture is very dense. Concurrently, due to the need for previous layers of the cob to be mostly dry before the next is applied limits the amount of cob height laid in a day to approximately one foot (Smith 2000). Finally, when compared with other earthen materials cob has a lower density and lower compressive strength, but can still easily support a person's weight (Micolli 2014).

2.2.8.9 Concrete

Concrete is one of the most widely used building materials in the entire world, lending itself well to a plethora of different applications, and being exceedingly easy to utilize. Concrete's properties may be very different depending on the type of aggregate used, amount of water added, and even the type of cement. Modern concrete engineering has begun to recycle old concrete as a means of reducing the overall environmental impact of the concrete industry (Filaj 2016). Concrete durability is a complex interplay between composition and environment. Where a mixture poured and set in one environment may last a century, when poured in a different environment it may not last ten years (Transportation Review Board 2013). The primary agreed upon mitigation of the problems associated with concrete durability is ensuring the use of high quality concrete (concrete with a higher amounts of cement), as well as proper curing (Transportation Review Board 2013).

2.2.9 Weather Protection

Humboldt county is known for its precipitation, amongst other things. In the seasonal months the driest areas of the county can accumulate more than 40 inches of rain, while the wettest areas can get over 100 inches (Humboldt County 2018). In addition to large amounts of rain, the proximity to the coast causes a high relative humidity year-round. Exposed materials will most likely benefit from some form of weather-proofing.

2.2.9.1 Paints and Stains

Paints and stains come in a variety of colors and serve to prevent moisture entry. They are relatively easy to apply but must be maintained. Stains are more breathable and effective at managing temperature changes, while paint provides a better moisture barrier to UV and moisture. Semi-transparent stains will highlight the wood more than traditional stains, and require less preparation (Agwilliamspainting 2012)

2.2.9.1.1 Acrylic or Latex

Acrylic or Latex paint is a water-based paint that is durable and flexible for conditions that include the expansion and contraction of a material when temperatures change. It is available in flat to high gloss, has excellent adhesion, and will dry very rapidly on hot days (Paint Types 2018). This type of paint can be used on all exterior surfaces; however, some metals may be better suited for an oil-based paint (Paint Types 2018).

2.2.9.1.2 Oil Enamel

Oil Enamel paint is an oil-based paint that will be available in a slight sheen up to a full oil gloss, it is more washable than water-based paints if it gets dirty (Paint Types 2018). However, oil enamel does not flex like water-based paints, so it may not be as durable on surfaces that expand and contract as the temperature changes (Paint Types 2018). It is sometimes slow to dry and should only be applied when surfaces are very dry (Paint Types 2018). This type of paint can be used on all exterior surfaces, especially durable for metals, may not be as durable as acrylics when applied to wood or vinyl surfaces (Paint Types 2018).

2.2.9.2 Protecting Concrete

Different concrete surfaces have different exposure classes. An exposure class is assigned to different concretes based on corrosion resistance. There are class types for different varieties of corrosion as well as different intensities within the classes. The class of concrete used will determine what other measures need to be taken to protect the concrete from the environment (Peck 2006).

Concrete surfaces need to be protected from moisture. Water from the air may infiltrate the surface layers and cause corrosion, or in low temperatures, flaking. There are a wide range of treatments including paint, silicone, plastic, and linseed oil. They work by penetrating or coating the surface to create a barrier to ward of moisture (Staff 1966).

2.2.9.3 Commercial Silicone

Environmental concerns have led to the development of wood coatings that are of low toxicity to the environment and mammals. The coating creates a hydrophobic effect in the treated surface, preventing excess moisture build-up and protecting against fungal decay. Newly created silicone emulsions have also been proven to provide resistance to stain fungi (Ghosh 2009).

2.2.9.4 U.V. Cured Coatings

UV-cured coatings have been used on wood before to a low degree of effectiveness. This was due to low adhesion rates between the wood and the coating. New formulations have been produced to increase adhesion. This coating's advantages are: low energy requirements, fast drying, selective application area, and no use of volatile organic carbon (VOC) solvents. This coating can be cured by exposing the liquid to UV light until it sets and is found to have an improved resistance to scratches and chemicals (Bongiovanni 2002).

2.2.10 Shade

The need for shelters and shade structures protect people from the sun, they can help to reduce the risk of skin cancer, heat stroke and dehydration as well as simple discomfort (Klingensmith 2018). Sunscreen, as an alternative to shade, may offer little protection if it is not reapplied during the day and will offer no protection if it is forgotten.

2.2.10.1 Canopies

Canopies incorporate a freestanding, rigid frame covered with fabric as a means of shading occupants. However, they have no easy way to let the sun into the space below without removing a section of fabric. They are generally bought as a kit and bolted to the ground (Snyder 2011). Figure 2.2.10.1 displays a basic canopy implementation.

Figure 2.2.10.1: Canopy over a playground at the Miami Children's Museum

2.2.10.2 Pergolas

A pergola is a structure, such as an arbor, with a roof of trelliswork along the top that provides partial shade as shown in Figure 2.2.10.2 (Snyder 2011). To increase the amount of shading provided vines can be planted alongside the structure to create a living structure or operable shades can be installed below the trellis to fully shade the area. Pergolas can be massive structures requiring permits and concrete piers to anchor the base securely in place (Snyder 2011). Pergolas are usually made of primarily cedar or redwood, but some manufacturers utilize synthetic material that is dimensionally stable and maintenance free. (Snyder 2011).

Figure 2.2.10.2: Renovated Pergola at Kiest Park in Dallas, Texas

2.2.10.3 Sun or Shade Sails

Sun/Shade Sails, like the one in Figure 2.2.10.3, offer an inexpensive option for shading small areas. They can be set up in minutes and taken down and stored at the end of the season (Snyder 2011). They can be elevated using up little space but their lightweight construction makes them susceptible to wind damage (Snyder 2011).

Figure 2.2.10.3: Multi Sails Structure over playground in Phoenix, Arizona

2.2.11 Upcycling

The reuse of materials that have little to no value to construct new useful items is a preferred alternative to recycling, as it does not use the energy and additional materials that reprocessing can use (Oyenuga 2017). Over the last few decades Upcycling has been growing in popularity as a cheap, effective way of creating useful products while also reducing waste and preventing damage to the environment (Zimring 2016).

2.2.11.1 Aluminum:

Aluminum upcycling uses the valuable metal from cans, sheeting, and other waste as a durable, cheap waterproof building material. This material can be used for a diverse range of purposes, from construction and insulation to decoration as seen in Figure 2.2.11.1.

Figure 2.2.11.1: Eve Earthship house construction, made from aluminum cans and adobe.

In addition to simply being used for structural components of buildings, cans and other aluminum waste can be used for decorative applications, demonstrated by Figure 2.2.11.2.

Figure 2.2.11.2: Aluminum materials used to decorate a wall (NY times).

Not only may aluminum be used as a construction material and decoration, raw aluminum sheeting from signs can be reused for a plethora of designs where large costly aluminum sheeting would normally be used. These purposes may include roofing and furniture like that shown in Figure 2.2.11.3.

Figure 2.2.11.3: Aluminum street signs used to create new furniture (photo curtesy of Boris Bally)

2.2.11.2 Plastic:

Upcycling of plastic waste into building materials is one of the most environmentally friendly construction methods. While plastic is recyclable, it requires entire reprocessing of the material, which makes it one of the most inefficient materials to recycle. Plastics are lightweight, rigid, and semi-weatherproof, allowing it to be used in many forms of upcycling. Through clever cutting or interlinking, many kinds of products may be created like those seen in Figure 2.2.11.4 and Figure 2.2.11.5. It is also possible to use plastic products, pieces, and fibers to increase the strength of concrete through integration into cement (Siddique 2008).

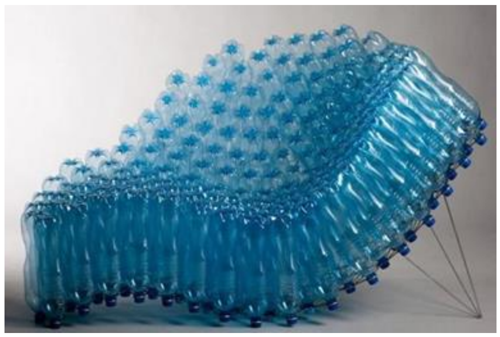

Figure 2.2.11.4: A chair created through assembly of water bottles (lushome.com).

Figure 2.2.11.5: A privacy wall made from interlinking bottoms of plastic bottles (lushome.com).

3 Search for Alternative Solutions

3.1 Introduction

Providing and addressing alternative solutions helps to elucidate the practicality of various designs and their shortcomings as well. The goal of searching for alternative solutions is to find the best possible solution to the problem at hand, constructing an outdoor classroom. Through a series of brainstorming sessions and various meetings, we found many different designs, and a plethora of different specifications and possibilities for each. The result of these sessions may be found in Section 3.3.

3.2 Brainstorming

Two brainstorming sessions were used. The first of these took place in a classroom, where we utilized a whiteboard to have an unstructured brainstorming session on various elements of our project, as well as criteria, materials, and feasibility. After this we started a structured brainstorming session where we thought of designs and concepts that met our criteria. These brainstorming sessions may be referenced in our appendix.

The next day we met at a local diner and discussed our designs and continued our structured brainstorming session from the evening before.

3.3 Alternative Solutions

Below are a series of eight alternative solutions that were the products of both our structured and unstructured brainstorming sessions. Each of these designs were conceptually conceived, developed in a group setting, then rendered into a sketch and summarized individually. Over time, these designs will be compared to each other, and then either eliminated, accepted, or merged with other solutions into one that will be used as our final design. Refer to Table 4.3.1 for how the various alternative designs below rank in respect to Criteria in Table 2.1.1.

3.3.1 The Lego Block Solution

The Lego Block Solution, drawn in Figure 3.3.1.1Figure 3.3.1.1 incorporates a progressive and more modern approach than conventional construction materials and techniques. The components of the seats are made of 3D-printed inter-locking pieces of hard plastic, see Figure 3.3.1.1. The components are comprised of 6”x6”x6” cubes. Cubes are designed to be universal with three 2”x2”x2” extrusions and three 2”x2”x2 intrusions, refer to Figure 3.3.1.1Figure 3.3.1.1. An epoxy plastic binding glue reinforces the interlocking locations to resist internal forces placed upon the structure from student use. The bench dimensions are1-½’x2’x6’ , with the expectation of fitting three students per bench. Corner cubes have rounded edges to reduce cutting hazards. Concurrently, extrusions will not be printed on the surface blocks that are exposed. Benches are anchored to the ground with a 4” concrete foundation. The classroom will be arranged in two rows, a front with five benches, and a rear row with six. The benches’ hard plastic composition makes it durable to Humboldt weather patterns and graffiti, and its permanent structure design relinquishes the need for the design to be easily portable, or storable. The classroom arrangement is simple to approach and be used for all teaching styles. The design meets aesthetic criteria by introducing students to an area of emerging technology that can produce viable building materials. However, 3-D printing blocks is very costly, and based on the quantity needed to construct the eleven benches, poses a significant difficulty.

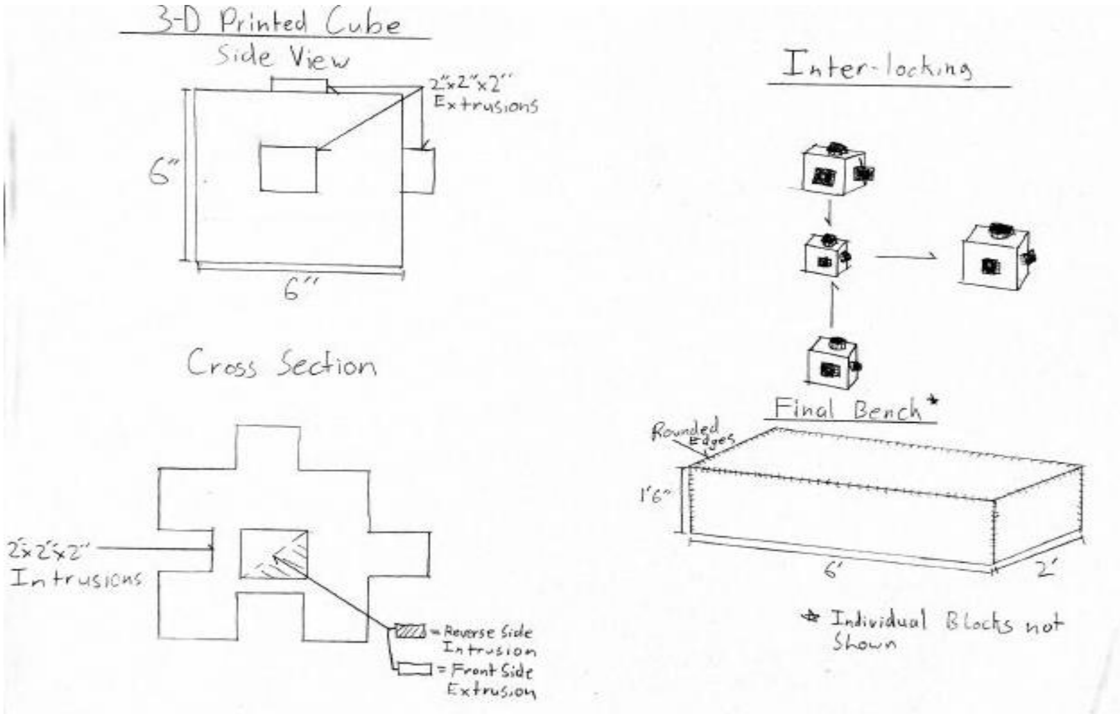

Figure 3.3.1.1: An illustration displaying various attributes and dimensions of “The Lego Block Solution” (Richard Cupp).

3.3.2 The Tire Solution

The Tire Solution, sketched in Figure 3.3.2.1Figure 3.3.2.1, is a semi-permanent structure solution to the outdoor classroom. Recycled tires make up the bench posts, while bench tops are plastic wood. Tires are approximately half-buried and anchored in the ground by with a 6” concrete foundation. The rest of the tire is buried with the original soil. As the tires are donated, not all are the same size or brand. The size difference problem is mitigated by setting a uniform height requirement of 18”. Tires are placed at 6’ intervals while the bench tops are 6’ long and may accommodate three students. Figure 3.3.2.1Figure 3.3.2.1 shows the bench tops have 2” dowels placed on either end that slide into slots drilled into the tops of tires to secure them the tires. This insertable feature allows for easy removal, and mitigates that damage caused by graffiti. There are eleven benches in total capable of accommodating the maximum class size at Zane Middle School. The benches are numbered according Figure 3.3.2.1Figure 3.3.2.1.

As stated above, The Tire Solution is a semi-permanent, semi-portable solution. The design increases durability by reducing stresses placed on transporting materials to only the benchtops as well as using highly durable tires as bases. Safety is obtained by removing benchtops to decrease the likelihood of students climbing or breaking benchtops without staff supervision. Cost of The Tire Solution is markedly low by using reclaimed tires as the bases the largest expense becomes the benchtops. Utility is readily achieved through the simplicity of the design, and plasticity is only limited by the arrangement of the tires. Aesthetics are achieved by providing the bench tops to the school art department to paint various designs that relate to school curriculum, and sealing them with a polyurethane coat when finished. The Tire Solution meets comfort criteria by ensuring the benches are not too high or low to the ground.

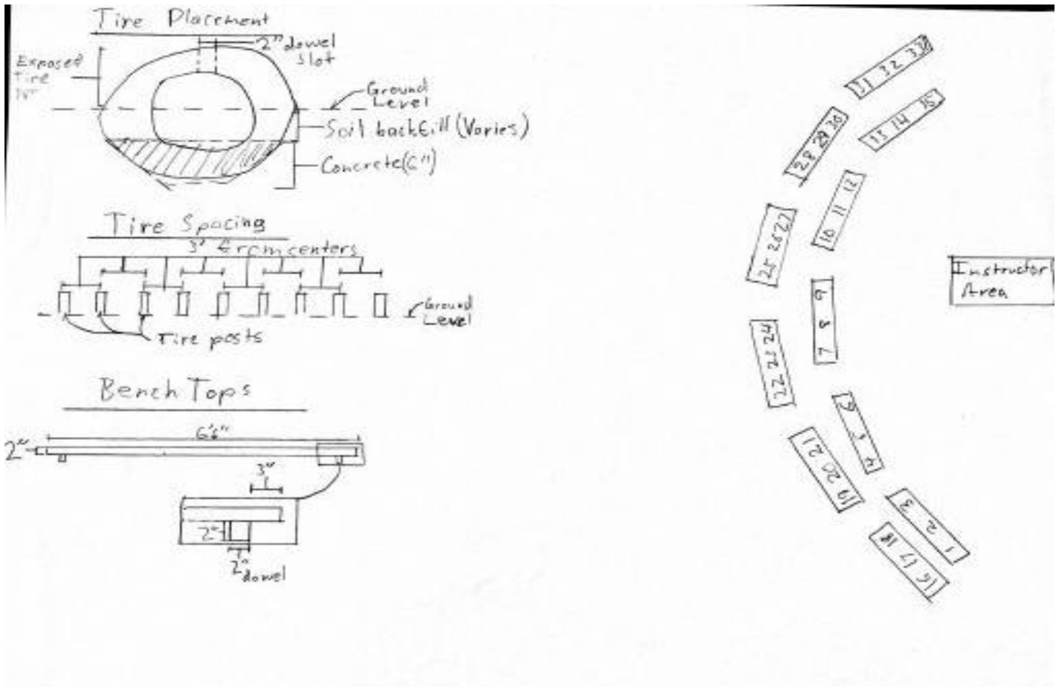

Figure 3.3.2.1: Drawing that reflect the various dimensions and application of "The Tire Solution" (Richard Cupp).

The classroom also has accessory features including individual portable writing surfaces, and a cart to carry the bench tops. Figure 3.3.2.2Figure 3.3.2.2 displays the accessories and their dimensions. Individual writing surfaces are reclaimed white boards numbered on the side not used for writing, so they may be easily assigned to students.

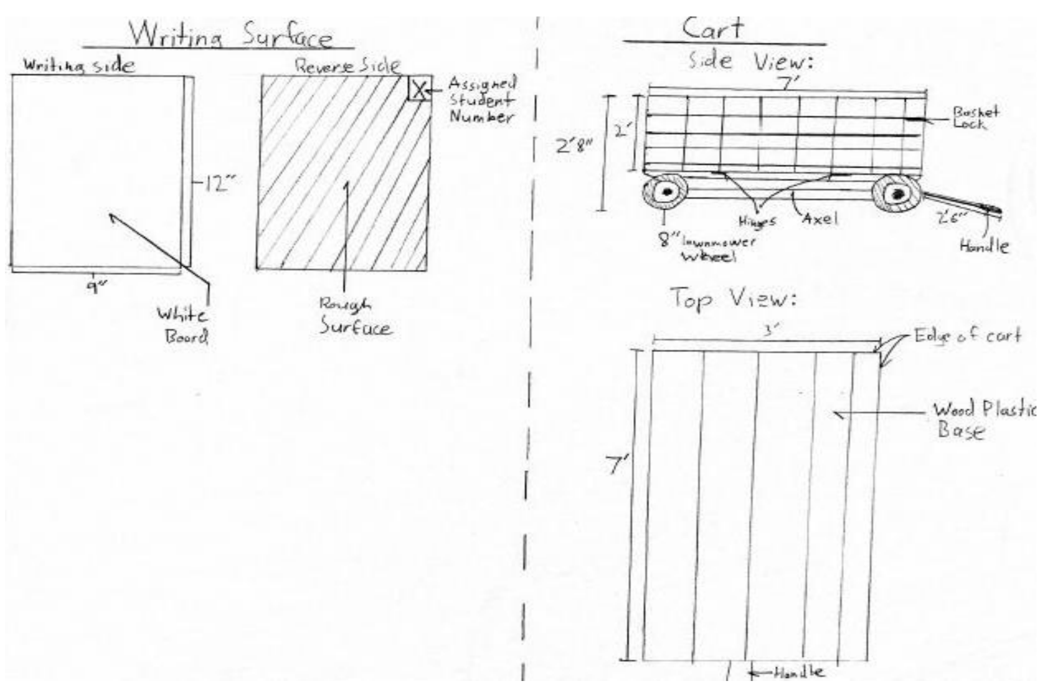

Figure 3.3.2.2: Accessory items to accompany the bench components (Richard Cupp).

3.3.3 The Roll-Out Tire Seating Solution

The Roll-Out Tire Seating Solution, drawn in Figure 3.3.3.1Figure 3.3.3.1, is a portable solution for seating in the outdoor classroom. Each individual seat is composed of one used tire laid flat on its side. A plywood, circle the same diameter as the tire is cut out and adhered to both sides of the tire to allow support for students sitting on the tire and to prevent bugs, trash or water from accumulating in the tire. Cushion and fabric are stapled to one plywood side before adhering to the tire to further improve comfort. Tires are rolled out to the designated outdoor classroom by each student, one per tire seat, and may be placed in a variety of setups suitable for the teacher. Due to having a flat side, weight is distributed across the tire preventing the seat from sinking into potentially unstable soil. Tires are assigned to each student via a numbering system painted on the rolling side or underside of the tire.

The tire design mentioned above is a low cost portable solution due to the material it is made from, a tire. The tire design lowers cost through the use of reclaimed used tires, where most of the cost would derive from plywood and cushion material such as fabric. This design is portable due to being easily moved by rolling on its side like a tire would do. Safety is addressed in this design by being without sharp edges or pinching areas, safety could be questioned by its overall weight which can be mitigated easily by adult supervision. The design can function easily as compared to an indoor classroom by giving each student their own independent seat that can be move into various arrangements as previously mentioned. The design is made from a tire which is a durable material that lasts for years, however, the cushions incorporated into the design to provide a level of comfort can succumb to tearing. The design is heavy and bulky making it difficult to stack on top of one another or store easily in small spaces.

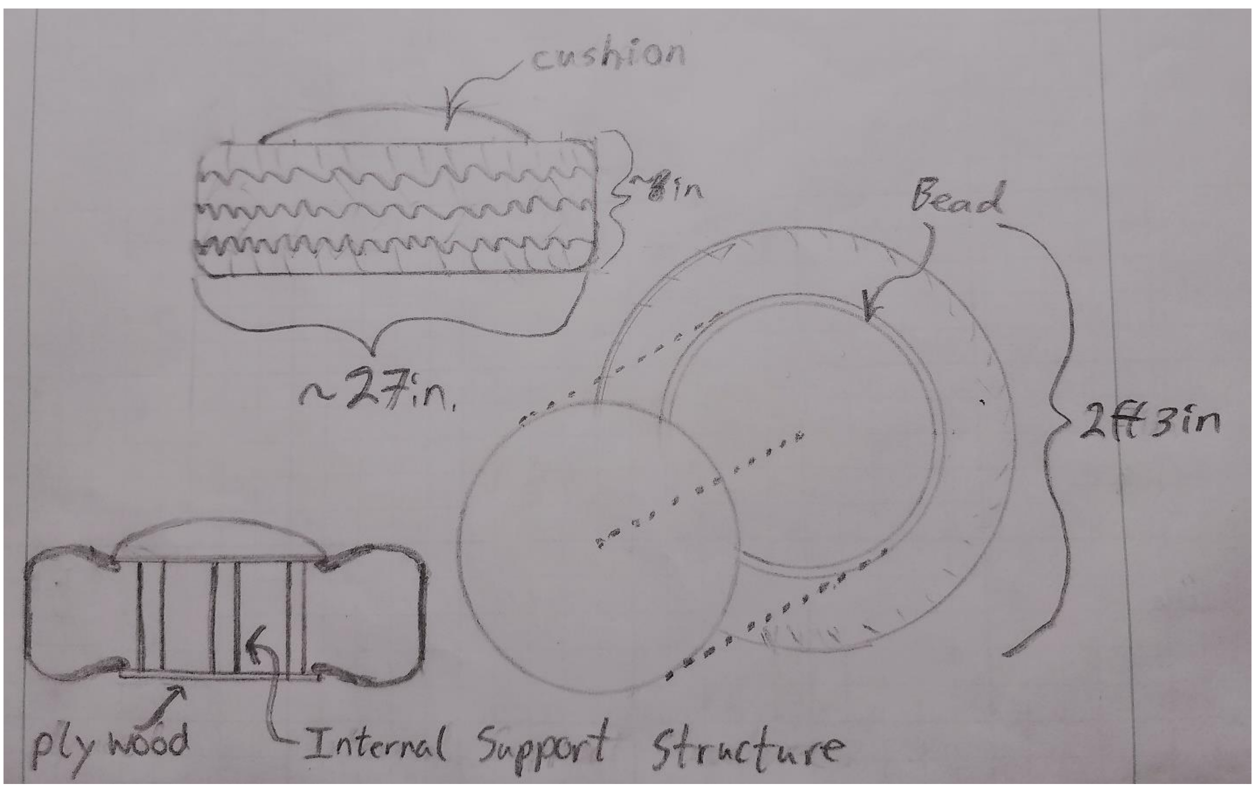

Figure 3.3.3.1: Drawing representing the tire seat concept (Vincent Thomas).

3.3.4 Collapsible Chairs Seating Solution

The collapsible chairs drawn in Figure 3.3.4.1 is a portable solution for seating students or people outside at various locations on campus. Each individual seat is made from one flat piece of 3½ft x 1¼ ft x 1in. plywood cut into a four-piece pattern that allows for the wood to fold out into a chair. The large cut out section serves as the seat, cut from the top center of the plywood in a 1⅛ft x 1¼ft rectangle with a zipper like cut near the center to serve as a joint when folding. The two forked cuts serve as the supporting structure for the seat which interlaces when unfolded providing weight distribution across the ground to prevent sinking into unstable soil. The support structure is cut 1in. from previously mentioned center hinge and run parallel to the hinge a scissor like fashion to provide another hinge. The interlacing cut forms parallel sections of wood 2ft long that hinge every other direction at the center. Wooden dowels are run through the hinges and the center of the interlacing structure to maintain the form of the chair. Cushion and fabric are stapled to the seat section of the chair to provide comfort. Holes are drilled at the top of the chair for hand holds and mounting on an A frame trailer or cart. The design is portable and easy to store folding into one-inch seats of plywood when not in use. The design is cost effective due to being only made of plywood and dowels, but labor intensive based on the high number of intricate cuts that need to be made for it to fold and set up properly. The design is not structurally stable if cuts are not made accurately.

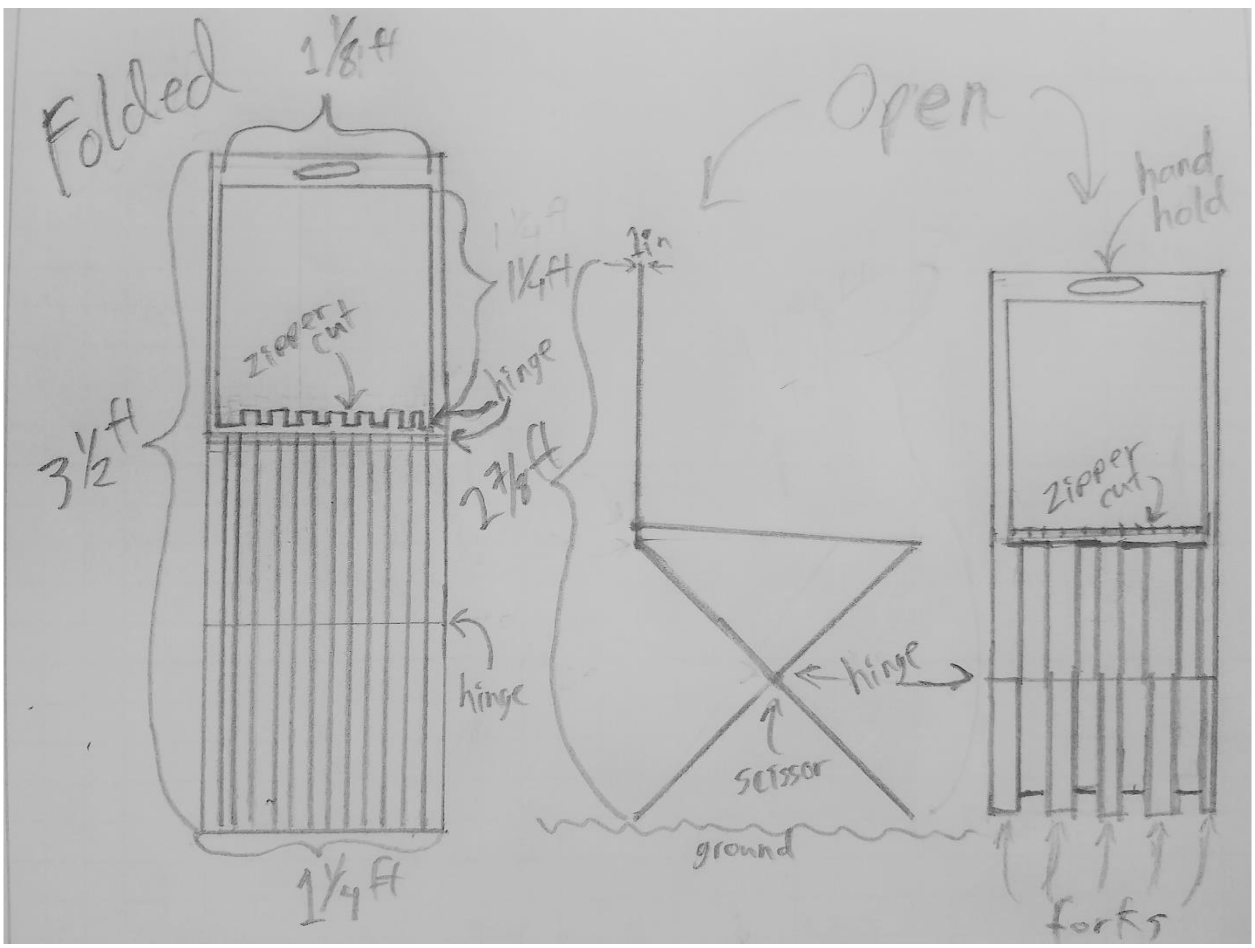

Figure 3.3.4.1: Drawing representing collapsible chair concept. (Vincent Thomas)

3.3.5 Weatherproof Permanent Metal Bench Seating.

The Weatherproof Permanent Metal Bench seating design drawn in Figure 3.3.5.1Figure 3.3.5.1 uses permanently mounted posts in the ground as mounts for a bench. These posts are then reinforced with post-hole cement. At the top of each post, roughly 2 ½ feet above the ground, a cross section with spaces is bolted to the top to create an extremely strong base for the seating platform. Metal rods will run through these spaces, across all the support posts. The end result of this is a series of long metal benches with a strong wooden support post every 4-5 feet. Because of the materials used, this yields a strong weatherproof bench, and depending on the orientation of the supports, this bench could take on a series of shapes, from a parabolic amphitheater shape, to straight traditional classroom seating arrangement.

This design fits the criteria of being safe, due to its solid metal construction and thick heavy support structure, and lack of movable and breakable parts. The bench is also comfortable due to its ergonomic closely placed metal poles. However it most fits the criteria of durability and aesthetics, due to its solid and permanent construction and pleasing customized shape.

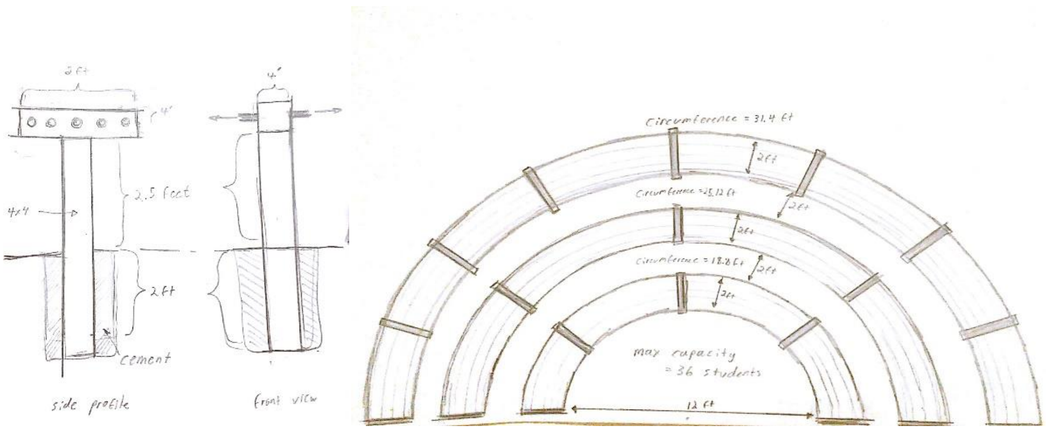

Figure 3.3.5.1: Weatherproof Metal Bench Seating Solution design (Christian Olson).

3.3.6 Peg Seating.

The Peg Seating design, sketched in Figure 3.3.6.1Figure 3.3.6.1, uses metal pipes mounted 2 feet vertically into the ground and cut off at ground level. Each mounted pipe has a corresponding seat with an individual post protruding from the bottom. When the seat's post is placed into the ground, the completed project is a group of individual stools that can swivel but are limited to the number of holes where these seats can be placed. The ability to pull the seats up from the ground allows for easy storage. The easy removal of the seats grounds-keeping does not make grounds-keeping more difficult. The mounting system is easily replicated, should expansion demand additional seating, or arrangements.

This form of seating is highly plastic, being able to be picked up, and moved to any hole in any possible arrangement. It is also very safe, as the seat cannot be tipped, and the peg itself is made of sturdy steel. The utility criteria is also met, as it is easy to use, functional, and can be easily set up.

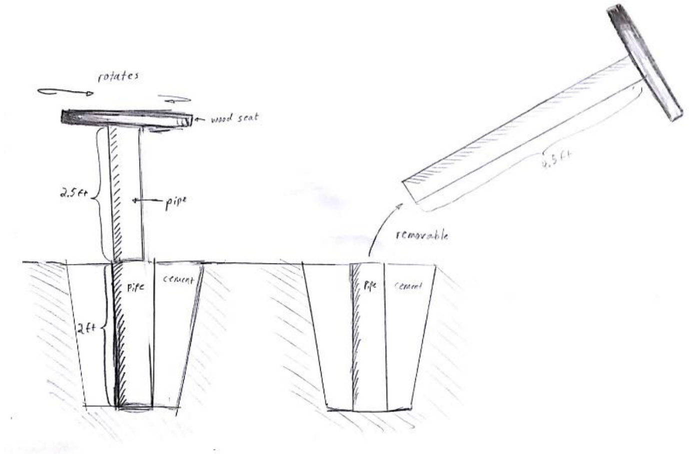

Figure 3.3.6.1: The functionality of the Peg Seating design (Christian Olson).

3.3.7 Cinder block and Brick Amphitheater

The amphitheater, sketched in Figure 3.3.7.1Figure 3.3.7.1, is made primarily of cinder block benches. These benches are then finished with a brick outer layer to create a pleasing exterior. The cinder blocks underneath the brick is to reduce the cost of the project due to materials. Cementing together the base with cinderblocks is relatively easy, whereas laying brick takes some skill to make it aesthetically pleasing. The benches can be made to a variety of different heights allowing for the creation of "standing desks" should the students need them. The benches can be placed in either a semi-circular or in rows depending on need. Extra weather protection may need to be considered as these benches will be exposed to the elements year-round. The distances between the benches may also be adjusted to reflect the clearance needed for the groundskeeper's mower.

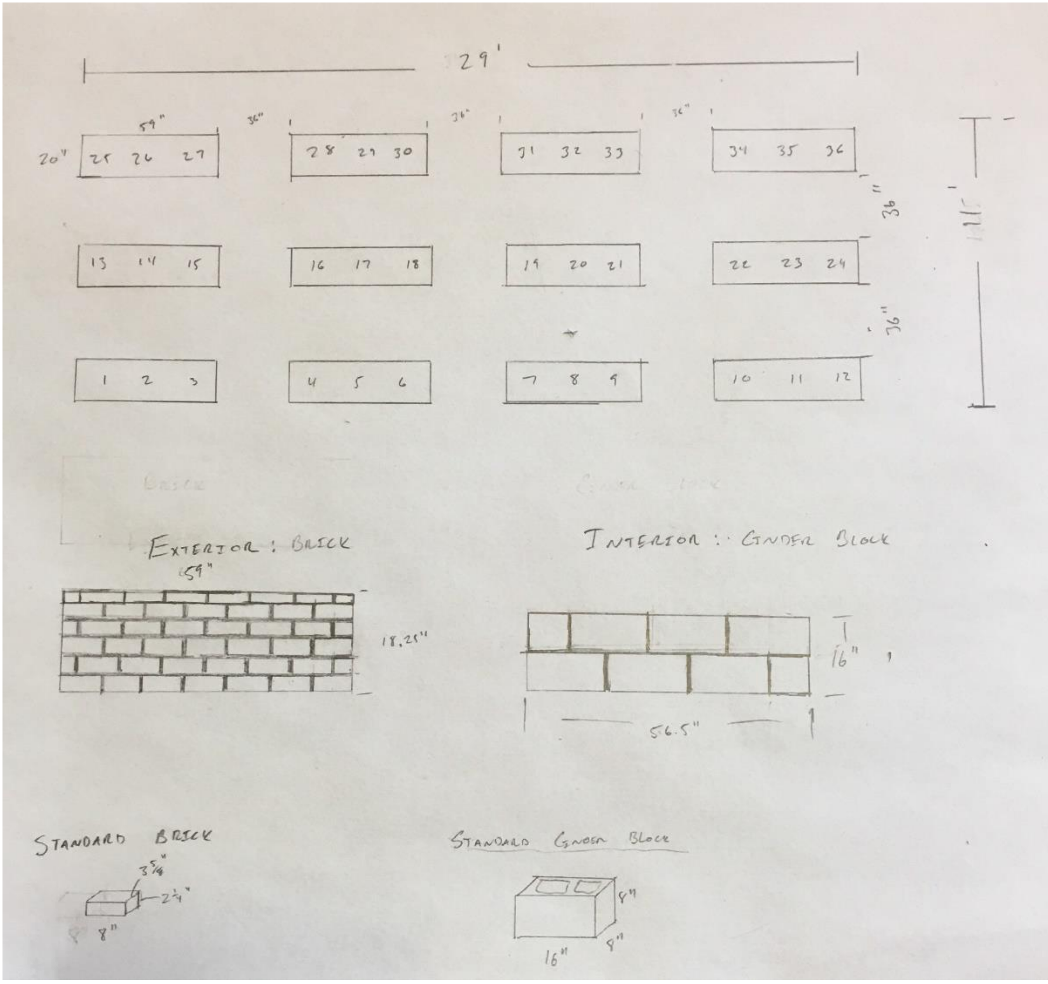

Figure 3.3.7.1: Brick and cinder block benches in row seating (Jonn Geer).

3.3.8 Collapsible Truss Benches

The benches sketched in Figure 3.3.8.1Figure 3.3.8.1 are three-person benches constructed from lumber. The two legs are assembled in Howe or Pratt Truss styles to create a bench capable of supporting a significant amount of weight. The legs are attached to the seating portion via hinges that allow the legs to fold onto the seating surface. The benches can then be stored in a relatively small area to prevent vandalism and excess exposure to weathering. The benches will require a storage space of 15 ft^2 when folded and locked the benches will have handles on either end that will allow students to carry them. These benches are reproducible should repairs or more benches be necessary.

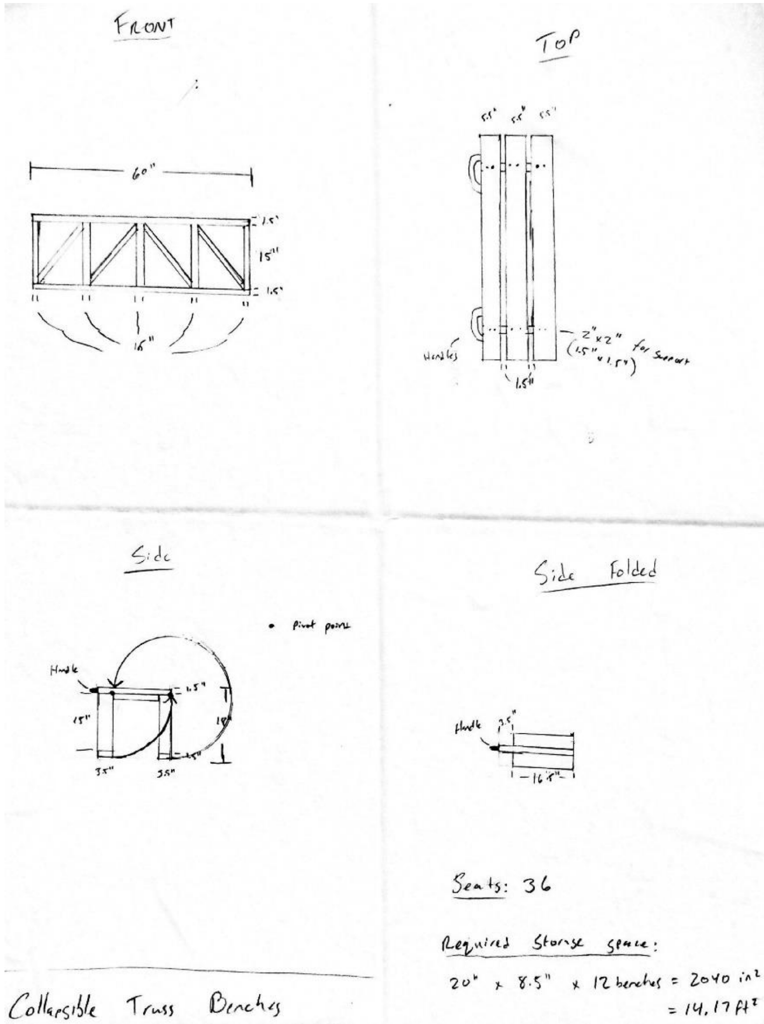

Figure 3.3.8.1: Collapsible truss benches with storage space requirements. (Jonn Geer)

4 Decision Phase

4.1 Introduction

This section is a description of our decision process. Over the course of this section the best seating solutions from Section 3 will be compared using the Delphi Method. This method produces a numerical value for how each solution fares for the various criteria stated in Section 2.

4.2 Criteria Definition

Below are the definitions of the criteria. Each listing has a detailed summary, which is used in the Delphi Method table to ascertain the overall ranking for each solution.

Safety-The level of inability that the structure could harm, or be used to cause harm. This includes swallow-able, detachable, and throw-able elements of the design.

Utility-The structure should function comparably to an indoor classroom. The structure should also be easy and worthwhile to use.

Plasticity-This is the ability of the structure to multitask. The more arrangements or functions it can fulfill, the higher its plasticity is.

Durability-The design must be able to last a long time in weather, adverse conditions, or be easy to clean in the case of graffiti.

Portability-The Structure should be portable and easy to move to other areas of the school, or into cover from the weather. If stored indoors, high portability would enable easy setup outdoors.

Cost-The ideal structure should meet all criteria at some level of proficiency, while having the lowest cost for construction.

Aesthetics-This criterion is best met by a structure that is subjectively more pleasing to look at, or has additional elements that have been implemented to complement the structure's visual appeal.

Storability-If not durable, it is important that a structure is able to be stored in as small of a space as possible. The structure should be able to fold, or stack to decrease the storage space required.

Comfort-Structures should ideally be pleasant to sit on. The Structure should not cause pain or discomfort after prolonged use.

4.3 Decision Process

The design decision process included the use of a Delphi Matrix and communications with the client to come to an agreement on the desired outcome. The Delphi Matrix shown in Table 4.3.1 lists the decided upon criteria that the project must adhere to. Team members collectively decide on a scale of 0-10 how important each criterion is in the overall output of the project, referred to as a weight. A list of the best alternative designs is chosen and listed at the top of the matrix in a row. Each design is then collectively judged and agreed on by the team on a scale of 1-10 how it ranks with each criterion. Criteria weight and the score for each criterion for each alternative design is then multiplied and summed into a total score. The project with the best total score is the design that fits the most with the criteria given.

Table 4.3.1: Delphi matrix used in design decision making process.

Criteria	**Weight (0-10 high)**	**Alternative Solutions (0-10high)**				
		Collapsible Truss	Roll Out Tire	Peg Seating	Permanent Metal Bench	Bench Tires
Safety	10	8 / **80**	9 / **90**	5 / **50**	10 / **100**	10 / **100**
Utility	9	9 / **81**	9 / **81**	9 / **81**	9 / **81**	10 / **90**
Plasticity	7	10 / **70**	10 / **70**	8 / **56**	4 / **28**	5 / **35**
Durability	8	7 / **56**	9 / **72**	8 / **64**	10 / **80**	8 / **64**
Portability	7	6 / **42**	7 / **49**	9 / **63**	0 / **0**	2 / **14**
Cost	9	6 / **54**	9 / **81**	4 / **36**	2 / **18**	8 / **72**
Aesthetics	5	8 / **40**	6 / **30**	8 / **40**	10 / **50**	6 / **30**
Storability	6	8 / **48**	4 / **24**	10 / **60**	0 / **0**	5 / **30**
Comfort	3	7 / **21**	6 / **18**	7 / **21**	5 / **15**	7 / **21**
	Total	**492**	**515**	**471**	**372**	**456**

4.4 Final Decision Justification

The team came to a final decision through the combined input of the client's comments and concerns, the Delphi Matrix in , and internal discussion amongst the team. The team and client came to the final decision through a meeting where criteria, and design plausibility were discussed. After determining the multiple benefits of portable seating, the decision was made to utilize the design described in Section 3.3.8 Collapsible Truss Benches. The benches will use minimal space when stored, while seating three students per bench while in use. When referring to the Delphi Matrix in Table 4.3.1 , the bench scores above a rating of five in all criteria, with cost and portability being its weakest areas. Upon discussing the cost of benches with the client they informed us of being able to purchase discounted lumber from a local supplier. The portability of the benches enables the instructor to arrange seating in a manner conducive to the learning activities to be held on a given day, as well as mitigating issues that may arise with permanent structures like weathering, and vandalism.

5 Specification of Solution

5.1 Introduction

Section 5 showcases the details of the Zane Middle School outdoor classroom, and its various components. This section chronicles the instructions for implementation, use, and maintenance of the design. Accompanying the details of the design itself are analyses of costs including capital, labor, and the predicted costs of maintenance. Prototype history, iterations, and progressions may be found in this section as well.

5.2 Design Description

5.2.1 Classroom Arrangement

The portable bench design's transportability makes it apt for multiple seating arrangements. Zane Middle School has an area set aside for the class to be set up. Various arrangements are indicated by the different colors red, yellow, and blue indicating parabolic, pod, and circular seating arrangements respectively. Figure 5.2.2.1 displays the various arrangements superimposed over a view of the class space. Benches align with the front side on the line for quick and easy set-up.

Figure 5.2.1.1: AutoCAD markup of proposed classroom arrangements superimposed over an aerial view.

5.2.2 Seating

A simple AutoCAD of our final design has been provided for dimensional reference. The width of the main truss support and the folding wings can be seen in Figure 5.2.2.1 A. In Figure 5.2.2.1 B the width and depth of the bench and each individual seating board dimensions are shown. The bench is shown completely folded and partially folded in Figure 5.2.2.1 C and D. More in-depth dimensions are described in Section 5.4: Construction.

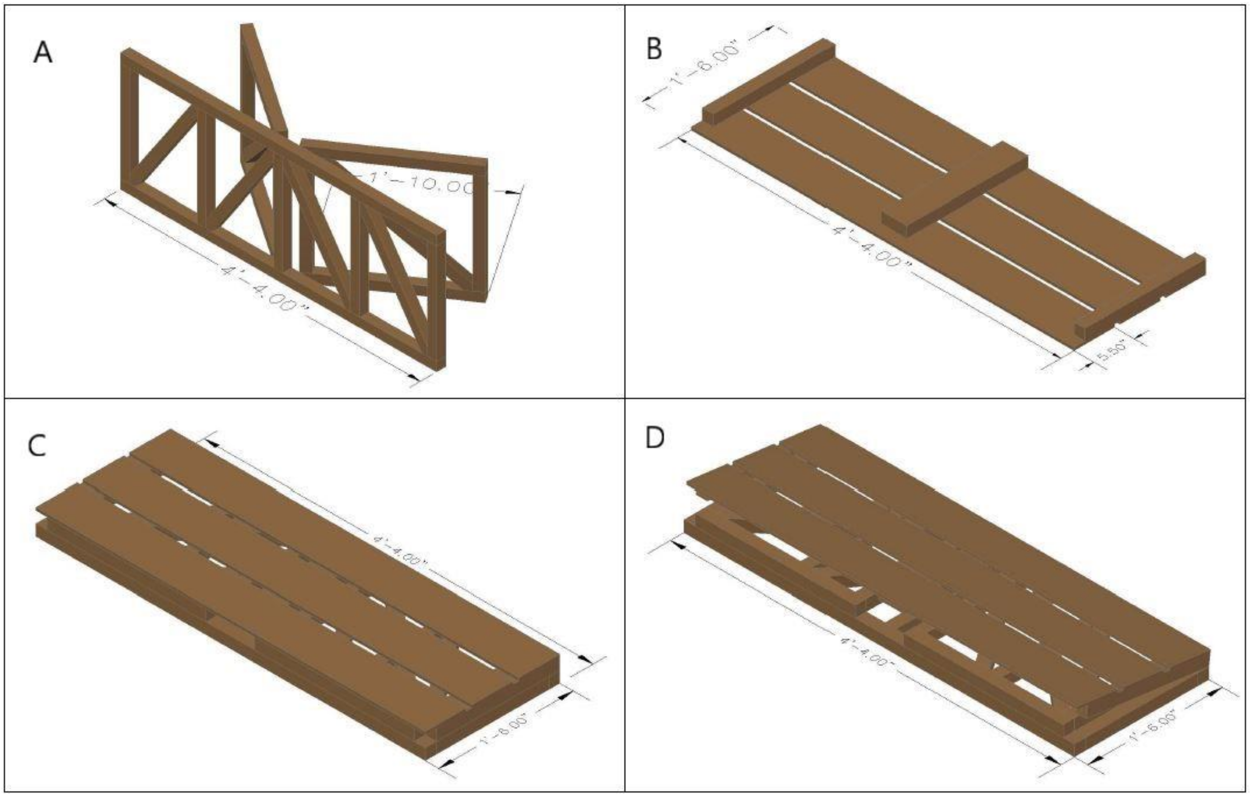

Figure 5.2.2.1: AutoCAD of bench supports, top, and folded position.

5.2.3 Writing Surfaces

Writing surfaces are comprised of a clipboard with a whiteboard applique applied to the side that does not have the clipping apparatus. Writing surfaces offer student a rigid area with which to take notes as well as an interactive learning tool on the reverse side.

5.3 Cost Analysis

This section breaks down the costs associated with the design and implementation of the outdoor classroom seating at Zane Middle School. The total cost of the project is broken down into two categories, time and materials.

5.3.1 Design Time

The total time spent on the project was 277 hours and is broken down by phase in Figure 5.3.1.1. Over 50% of the design time is attributed to Phase 5: Specification of Solution. This section comprised the physical implementation of our solution from prototype to final product. The other sections comprise many hours of research, brainstorming, consultation and drafting. The implementation of the project required extra hands and community volunteers were sought. 22.5 hours were donated by the community. The donated time was not included in the design costs breakdown, but deserved an honorable mention.

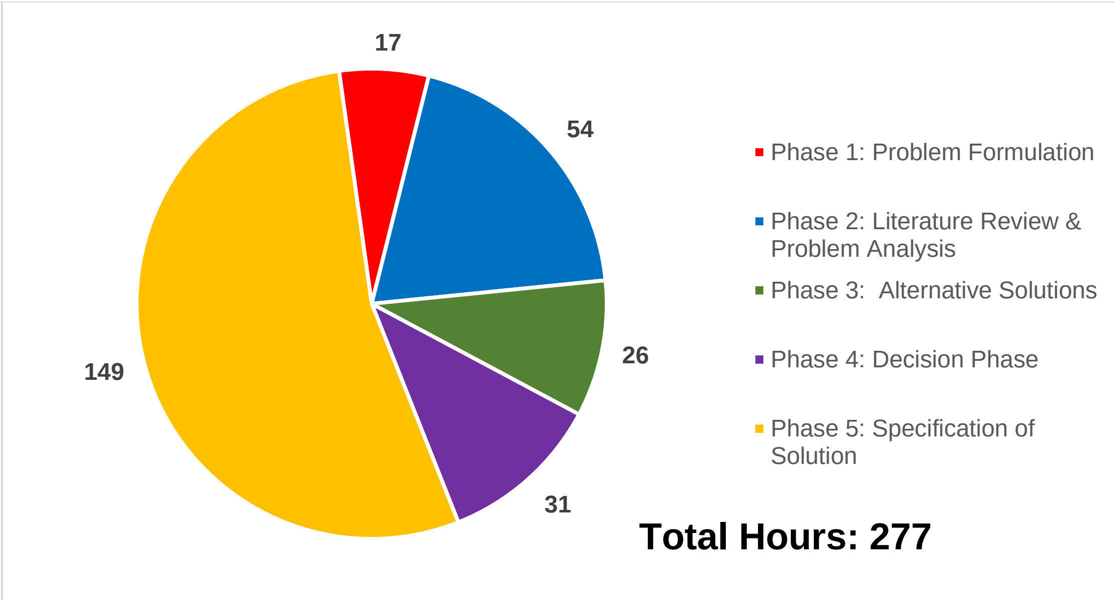

Figure 5.3.1.1 Cumulative design hours spent in each phase.

5.3.2 Cost of Materials

The total amount of money spent on the final materials was $532.22. The materials for 11 benches were generously discounted by Tanka Chase of The Mill Yard in Arcata, CA. The construction redwood and hinges comprised over 85% of our budget. The remaining budget was for the white board material used on the donated clipboards. Individual lumber specifications and an itemized list can be found in Table 6.2.2, a brief cost breakdown is shown below in Table 5.3.1.

Table 5.3.1: Brief cost analysis

Material	Material Value	Our Cost
Bench Lumber	788.39	349.26
Bench Hardware	160.26	116.93
Clipboards	36	0
Whiteboard Material	66.03	66.03
Total	**1050.68**	**532.22**

5.4 Construction

Construction of the benches is relatively simple in nature, with the most difficult part being the construction of the cross members, as they are odd angle cuts. Tools needed will be protective eye wear, a pencil or marker, a cut saw, a power drill with a Phillip's head drill bit and smaller drill bit for pilot holes, around 1/8", a Phillip's head screw driver, measuring tape, straight edge, speed square, and a power sander. Other recommended, but not needed, materials are a belt sander, gloves, and hearing protection. Materials required for constructing benches are 2"x2" posts, 2"x4" studs, 6' fence boards, 2" deck screws, 2-1/2" deck screws, 2" strap hinges, and handles. Materials for the writing surfaces are clipboards, whiteboard applique, and cutting tools. Materials needed for the shadowbox outline are a stencil forming an 8"x8"x2" L-shape, some type of rope, and paints of the desired colors.

Construction instructions are divided up amongst the various components of the benches and writing surfaces. Section 5.4.4 deals with the final assembly of the benches when the various components are completed. below denotes the amount of materials used per bench. Sections 5.4.1-5.4.4 should be repeated as needed to meet the number of benches need, in the case of this project, twelve benches were constructed. Lastly, it is recommended that after completion of Sections 5.4.1-5.4.3 that the components are sanded. Sanding instructions will not be given in any of the sections below, nor will staining, finishing, or other aesthetic modifications post-construction.

Table 5.4.1: Materials and their respective dimensions needed to produce one bench.

Component	**Item**	**Quantity**
Bench Top	52”x6”x5/8” fence boards	3
	16-½”x2”x2”	2
	16-½”x2”x4”	1
	2” Screws	18
Folding legs (Two)	21-¼”x2”x2”	4
	15”x2”x2”	4
	24”x2”x2”	2
	2-½” Screws	12
Truss Section	52”x2”x2”	2
	15”x2”x2”	5
	20”x2”x2”	4
	2-½” Screws	18
Various Hardware	2” Strap Hinges	4
	Handles	2
	Velcro (Male and female)	3”

5.4.1 Bench Top

1. Take a 6’ fence board, measure 52”, and mark line to denote your desired length. Repeat two more times each with a new fence board.
2. Take a 2”x2” post, measure 16-½”, and mark your post. Measure from the opposite end of the same 2”x2”, measure, and mark the same distance.
3. Take a 2”x4”, measure 16-½” from the end, and make a mark.
4. Power on the cut saw and cut along the marks until all cuts are made and you are left with three 52” fence boards, two 16-½” long pieces of 2”x2”, and one 16-½” piece of 2”x4”.
5. Position a 16-½” 2”x2” one-and-a-half inches from the corner of a fence board, and clamp the two pieces together.
6. With the power drill, drill two pilot holes centered on the 2”x2” 1” from the end and 1” away from the first mark. Change drill bits to the Phillip’s head and drill a 2” deck screw into both pilot holes. Figure 5.4.1.1 displays what the completion of this step prior to the screws should reflect.

Figure 5.4.1.1: After the first two pilot holes are drilled.

7. Repeat this Steps 5 and 6 on the opposite side.
8. Line up the 2”x2” posts on the ends of another fence board so that it is flush on both sides.
9. Clamp the 2”x2” to the new fence board and repeat Step 6. Perform once again on the opposite side.
10. Position the third fence board equidistant from the ends of the other two, approximately ¾”.
11. Clamp a 2”x2” on one side and repeat Step 6 for both sides. Figure 5.4.1.2 demonstrates the completion of this step.

Figure 5.4.1.2: Completion of 2”x2” attachment.

12. Measure and mark lengthwise on the end fence boards at the 24/-¼" and 27-¾".
13. Position the remaining 16-½" 2"x4" section and position it along those marks.
14. Drill the pilot holes in the 2"x4" and secure it to each fence board as described in Step 6.

Figure 5.4.1.3: Finished bench top.

5.4.2 Folding Legs

1. Take a 2"x2" post, measure, and mark a 21-¼" section from either end. With another piece of 2"x2" measure and mark two 15" sections. Lastly with a final piece of 2"x2" measure and mark a 24" section.
2. Power on the cut saw, and cut along the lines marked in Step 1.

3. Form a joint with the ends of a 21-¼” piece and a 15” piece, with long piece on top.
4. Drill a pilot hole about ¾” from the end. See Figure 5.4.2.1 for clarification.
5. Replace the drill bit with Phillip’s head bit and drill a 2-½” deck screw into the pilot hole joining the two pieces.

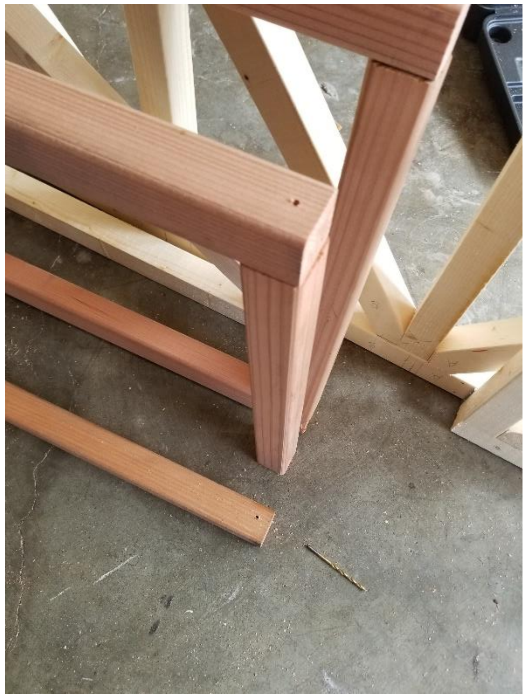

Figure 5.4.2.1: The joint created screwing a 21-¼” and 15” section together.

6. On the opposite end of the 15” section place the other 21-¼” piece, and repeat Steps 4 and 5.
7. Complete the rectangle by inserting the second 15” section, and repeating Steps 4 and 5 again.
8. Taking the 24” section and speed square, measure and mark the centerline on the piece of wood. The mark should be about ¾” from the edges. Make sure the mark is straight and about 3” long as shown in Figure 5.4.2.2. Repeat this on the opposite side, and same face as the first mark.

Figure 5.4.2.2: Center-line marking on 24”x2”x2”

9. Line the two center lines up along the center of the inside joints created by the rectangle made in Steps 1-7. Mark lines parallel to the posts that create the joint, and repeat on the opposite side. The two lines marked should be perpendicular to each other as reflected in Figure 5.4.2.3. **Use only the frame that the cross-member will go in to mark. All angle cuts will be unique due to a small amount of human error.**
10. Using the cut saw, cut along the lines marked. The lines are not perfect angles to line up with the cut saw, so it is best to angle by hand instead of rotating the saw. **Make first cuts sparingly until the ability to get quality angle cuts has been developed.**
11. Place cross members in the rectangle and drill pilot holes into them from the 21-¼“ side, approximately an inch from the first screw. Replace the drill bit, and using a 2-½“ deck screw join the two members together. Repeat on the opposite side. The member should fit snug, but not need excessive force to fit. The completed joints should look similar to Figure 5.4.2.3.

Figure 5.4.2.3: Proper installation of a cross-member joint, and perpendicular angle cut.

12. Repeat steps 1-11 once more to have a total of two folding legs. It is recommended that measurements and cuts be made for both legs at the same time.
13. Refer to Figure 5.4.2.4 for a reference image of a completed folding leg.

Figure 5.4.2.4: Completed folding leg.

5.4.3 Truss section

1. Using all 2"x2" measure and mark two 52" sections, five 15" sections, and four 20" sections.
2. Power on the cut saw, and cut along the marks.
3. On the 52" sections measure at mark at ¾" from both ends as well as at 13", 26", and 39".
4. Place a 15" section underneath the corner of the 52", drill a pilot hole, and join the members with a 2-½" deck screw. Repeat on the opposite end.
5. Flip the three-sided frame over, and connect the other 52" section to the end pieces and complete the rectangle.
6. Using a speed square, position another 15" member centered on the 26" mark, drill a pilot hole, and join the members together with a 2-½" deck screw. Repeat at the 13" mark, and the 39" mark.
7. Flip the frame over to the opposite side, drill the pilot holes marked, and join the pieces in the order described in Step 6.
8. With the 20" sections, mark a 3" center-line as described in Step 8 in Section Folding Legs5.4.2. Mark corners unique to each joint on both the cross member and frame (Ex.: A, B, C, etc.).
9. Line the two center lines up along the center of the inside joints created by the rectangle made in Steps 1-7. Mark lines parallel to the posts that create the joint, and repeat on the opposite side. The two lines marked should be perpendicular to each other as reflected in Figure 5.4.2.3. The cross members should be symmetric about the center vertical member. **Use only the frame that the cross-member will go in to mark. All angle cuts will be unique due to a small amount of human error.**
10. Using the cut saw, cut along the lines marked. The lines are not perfect angles to line up with the cut saw, so it is best to angle by hand instead of rotating the saw. **Make first cuts sparingly until the ability to get quality angle cuts has been developed.**
11. Place cross members in their respective frames and drill pilot holes into them from the 52" side, approximately an inch from screw joining vertical members. Replace the drill bit, and using a 2-½" deck screw join the two members together. Repeat for each frame. The member should fit snug, but not need excessive force to fit. The completed joints should look similar to Figure 5.4.2.3. Figure 5.4.3.1 reflects the symmetry described in Step 9, and the completion of the truss section.

Figure 5.4.3.1: The completed Truss Section.

5.4.4 Assembly

1. Take both wing legs and the strap hinges. Position the strap hinges as seen in Figure 5.4.4.1. Ensure that the bulged portion of the hinge will face away from the truss section when attached.

Figure 5.4.4.1: Proper positioning of the strap hinge, and drilling of pilot-holes.

2. Drill pilot holes, shown in Figure 5.4.4.1., in the wing leg, and swap drill bits to the Phillip's head. With the screws provided in the strap hinge packaging, screw the hinge onto the wing leg. Repeat Steps 1 and 2 on the bottom side of that same vertical member.

3. Take the completed truss section, and two folding legs, and place the truss section flat on the ground. Place each wing long-ways along the truss section approximately 2” from the end of the truss section, and flush with the top and bottom.as demonstrated in Figure 5.4.4.2.

Figure 5.4.4.2: Proper positioning of wing leg on top of the truss section.

4. Ensuring that the wing leg is flush with the truss section, open the strap hinge and drill pilot holes for it into the truss section. Change to the Phillip’s head drill bit and secure the strap hinge to the truss section, demonstrated in Figure 5.4.4.3.

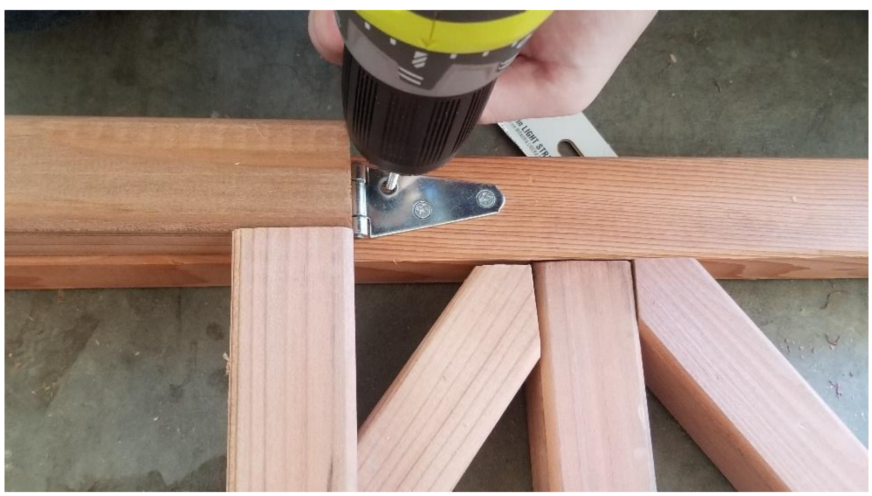

Figure 5.4.4.3: Securing the strap hinge, and wing leg to the truss section.

5. Repeat Step 4 for the second strap hinge.
6. Repeat Step 1 through Step 5 for the second wing leg. Ensure that the cross members are oriented in the same direction for appearances. Refer to Figure 5.4.4.4 for the completed leg assembly.

Figure 5.4.4.4: Completed leg assembly

7. Fold the legs flat and place the bench top on top of the leg assembly, demonstrated in Figure 5.4.4.5. The bench is now completed and should reflect that seen in Figure 5.4.4.6.

Figure 5.4.4.5: Collapsed bench.

Figure 5.4.4.6: Completed bench.

5.4.5 Layout Painting

5.4.5.1 Non-Circular Layouts

1. Organize the completed benches into the desired arrangement. Figure 5.4.5.1 demonstrates the arrangement used for this project, and is a hybrid of parabolic, and row seating.

Figure 5.4.5.1: Arrangement of desired seating layout.

2. At each bench, using sidewalk chalk, mark on the pavement where the front corners are located, about 6” in each direction forming an L-shape.
3. Move the benches away from the area.
4. Taking the stencil, shown in Figure 5.4.5.2, place the stencil on top of the corners marked in chalk, and using the spray paint, paint the area of the stencil on top of the chalk. Be careful not to use an excessive amount of paint otherwise the stencil will bleed and look messy.

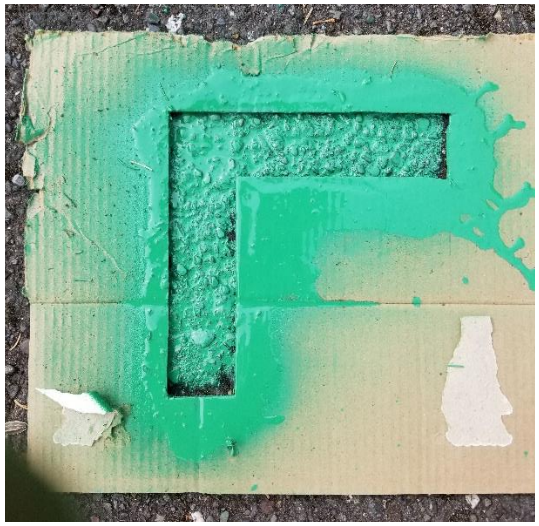

Figure 5.4.5.2: 8”x8”x2” Stencil and painting over the marked chalk.

5. Repeat Step 4 for all chalk marks made, until classroom layout is complete

5.4.5.2 Circular Layouts

1. Determine the circumference of circle that would be able to accommodate all the benches using Equation 5.1 and rounding up to the nearest whole foot.

$$Circumference = B \times 5'$$

Equation 5.1: Circumference is determined by multiplying the number of benches (B) by 5’ (a length slightly larger than the benches).

2. Next determine the radius that a circle with the circumference determined in Step 1 would need using Equation 5.2 and rounding up to the nearest half foot.

$$r = \frac{C}{2\pi}$$

Equation 5.2: Solving the circumference equation for the radius (r) in feet. Circumference is denoted as (C) in feet.

3. Next, taking a rope measure out the length of the radius needed with approximately six inches of excess on either side. With the excess tie a knot on either side, demonstrated in Figure 5.4.5.3.

Figure 5.4.5.3: One of two knots needed for drawing the circular layout.

4. Locate where the center of the circle will be, ensuring that there is adequate space at the desired location, and mark the center. Place an anchor point at the center such as a chair, or something heavy that will not move once tension is placed on the rope.
5. Secure one side of the rope to the anchor as shown in Figure 5.4.5.4.

Figure 5.4.5.4: Securing the rope to the centered anchor point.

6. Now taking the marking chalk, and the other end of the rope, walk away from the center until the rope is full extended to the calculated radius. Place the chalk through the loop made by the second knot and begin marking lines approximately six inches long spaced one to two feet apart as shown in Figure 5.4.5.5.

Figure 5.4.5.5: Proper chalk-marking of the circular layout.

7. Continue making marks for the entire circumference of the circle. If using a chair make sure to pivot the chair periodically to not shorten the radius by curving the rope around the legs of the chair.
8. With the circular layout completed take stencil mentioned from Section 5.4.5.1, and modify it to make an 8”x2” line instead of an L-shape shown in Figure 5.4.5.6.

Figure 5.4.5.6: Modified Circular layout stencil.

9. Place the stencil over one of the chalk marks and cover the stencil area with the paint color of choice, demonstrated in Figure 5.4.5.7.

Figure 5.4.5.7: Painting of the circular layout.

10. Repeat Step 9 until all chalk marks have been painted.
11. If the area of the circle will intersect with the layout painted in Section 5.4.5.1, then 8” line should be reduced to four inches to reduce confusion of set-up with the non-circular layout.

5.4.5.3 Completed Layout(s)

Completed layouts should reflect that seen in Figure 5.4.5.8.

Figure 5.4.5.8: Completed semi-parabolic and circular layouts.

5.4.6 Writing Surfaces

1. Purchase the number of clipboards and applique needed. Using Equation 5.3 determine the total area of the clipboards to assess the proper amount of whiteboard applique to purchase.

$$A = L \times W \times N$$

Equation 5.3: Taking the area of the face of the clipboard by multiplying length (L) and width (W) by the number of writing surfaces to be made (N).

2. After purchasing the needed material wipe the smooth reverse side of the clipboard with a damp towel to remove any dust.
3. Next unroll some of the applique and place the flat side of the clipboard on top. Cut the applique to the shape of the clipboard plus a small amount of excess, as shown in Figure 5.4.6.1.

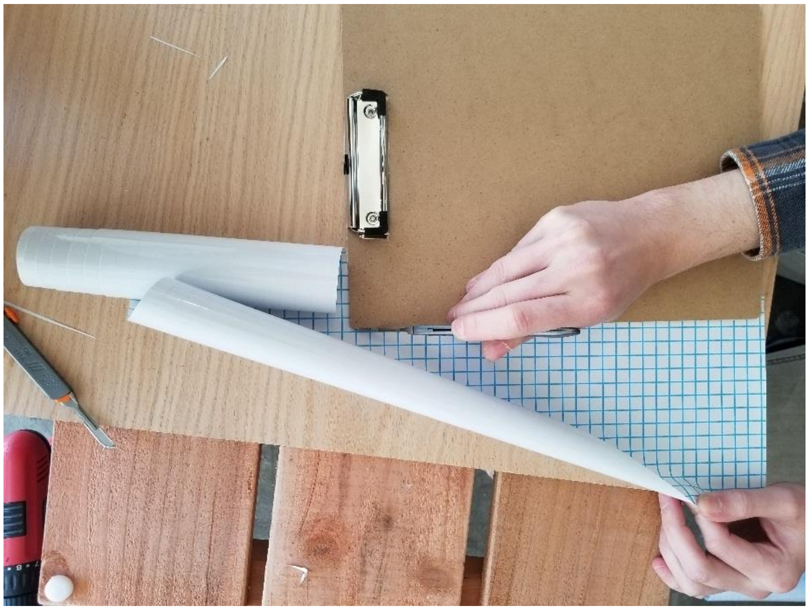

Figure 5.4.6.1:Proper placement of clipboard on applique and cutting of proper dimensions.

4. Flip over the clipboard so the flat surface is face-up. Peeling the applique from its backing, place it on the flat side of the clipboard and smooth it out using a plastic card, such as an ID, as demonstrated in Figure 5.4.6.2.

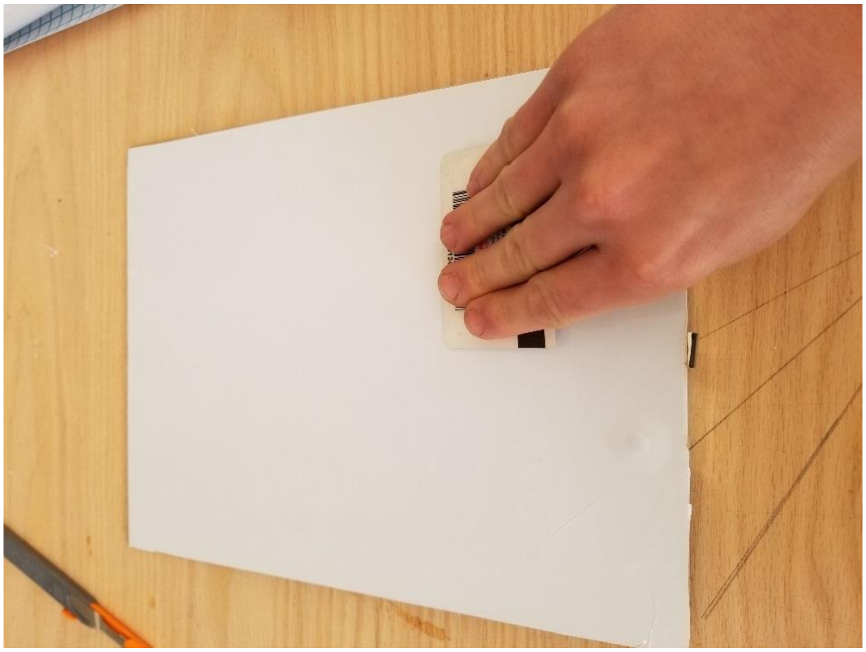

Figure 5.4.6.2: Smoothing out the applique.

5. Cut off any excess that may be hanging from the corners, and the writing surface is complete, and should reflect that seen in Figure 5.4.6.3.

Figure 5.4.6.3: Completed writing surface with whiteboard applique.

6. Repeat Steps 1 through 5 until the desired number of writing surfaces has been obtained.

5.5 Maintenance

Apart from damaging or extreme incidents, these benches should last for a period of 5 to six years. This duration can be extended with a stain and sealant. While not a requirement, this may be necessary to extend the life of the benches. It may also be necessary to sand the benches every 3-4 years, to remove all possibility of splinters.

Table 5.5.1 Breakdown of maintenance tasks and their respected temporal and financial costs.

Maintenance Tasks	Frequency	Projected Cost/yr ($)	Projected cost (hrs)
Water proofing	1 yr	$20	8 hrs
sanding	3 yrs	$15	14 hrs

5.6 Implementation Instructions

The truss bench design for the Outdoor Classroom is a two-piece collapsible bench, to set up the bench for class, students will need to transport the bench, separate the two-piece design, and set up the bench for use.

Implementation of the collapsible truss bench begins with the transportation the benches to a designated shadow box. Three students will be required in the transport and set up of the bench. Two of the students will carry the short ends of the bench while the third student carries the bench in an area that needs support as determined by the strengths of the first two students. The students will travel from the benches storage area with the bench to the numbered shadow boxes for set up of the bench.

Once the collapsed bench is set down and laid next to the shadow box one student will unlatch the top piece of the bench with the bottom piece. Two students will pick up the top piece and move it to the side for later assembly. Two students will unfold the two hinged legs from the bottom piece and tilt the bottom piece into an upright position. Two students will pick up the top piece of the bench and lay it down on the upright bottom piece with the guidance of the third student. After the top piece has been placed one or two students will adjust and angle the legs of the bottom piece to best support the top piece. The bench set up is complete and can now be used to sit on.

The process to take down and store the bench can be done by the same process in reverse. A visual step by step process can be seen in **figure ()**.

5.7 Prototype Performance

5.7.1 Prototype 1

Our first prototype used mainly two by fours and two by twos. It used a heavy 2 x 4 seating position hinged onto the front truss structure. The rear of the seating platform used 2 x 4 pegs to hold up the back of the seating platform. This prototype worked as a bench, but was very heavy, and difficult to assemble due to the pegs.

Figure 5.7.1.1: This is an image of the bench upside down, for a better view of the peg legs.

5.7.2 Prototype 2

This prototype was a modified version of the first prototype. Instead of pegs it had two hinged frames that can swing out from the front truss structure, and support an independent seating platform. This was a very rough draft of our final design, and was wobbly due to cheap hinges and quickly made weak hinged frames. This prototype was a simple proof of concept design, and proved that even when not constructed well, it could still work as a functional bench.

Figure 5.7.2.1: An image of the second prototype set up and folded.

5.7.3 Final Prototype

This prototype was a vastly improved version of prototype 2, and it used mostly 2x2 construction for the truss structure and the hinged frames. For the seating platform we used 5x1 fence boards. Additionally, we added 2x2 sections to the end of the platform, so that when folded the hinged frames would fit within the lid, giving the entire bench a much more compact folded size.

Figure 5.7.3.1: Final Prototype folded and assembled.

5.7.4 Portable Writing Surfaces Prototype

Portable writing surface are included in the design to include a surface for writing as well as a means of increasing participation in class. The portable writing surface was pulled from Section 3.3.2 “The Tire Solution.” The design utilizes clipboards as the base, and a whiteboard applique applied on the bottom of the board for participatory exercises. Figure 5.7.4.1 indicates the boards are numbered, and pinstripes are painted in school colors for a subtle aesthetic treatment.

Figure 5.7.4.1: Prototype clipboard writing surfaces

6 Appendices:

6.1 A. References

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6.2 Design Costs

Table 6.2.1: Time spent per phase broken down by member.

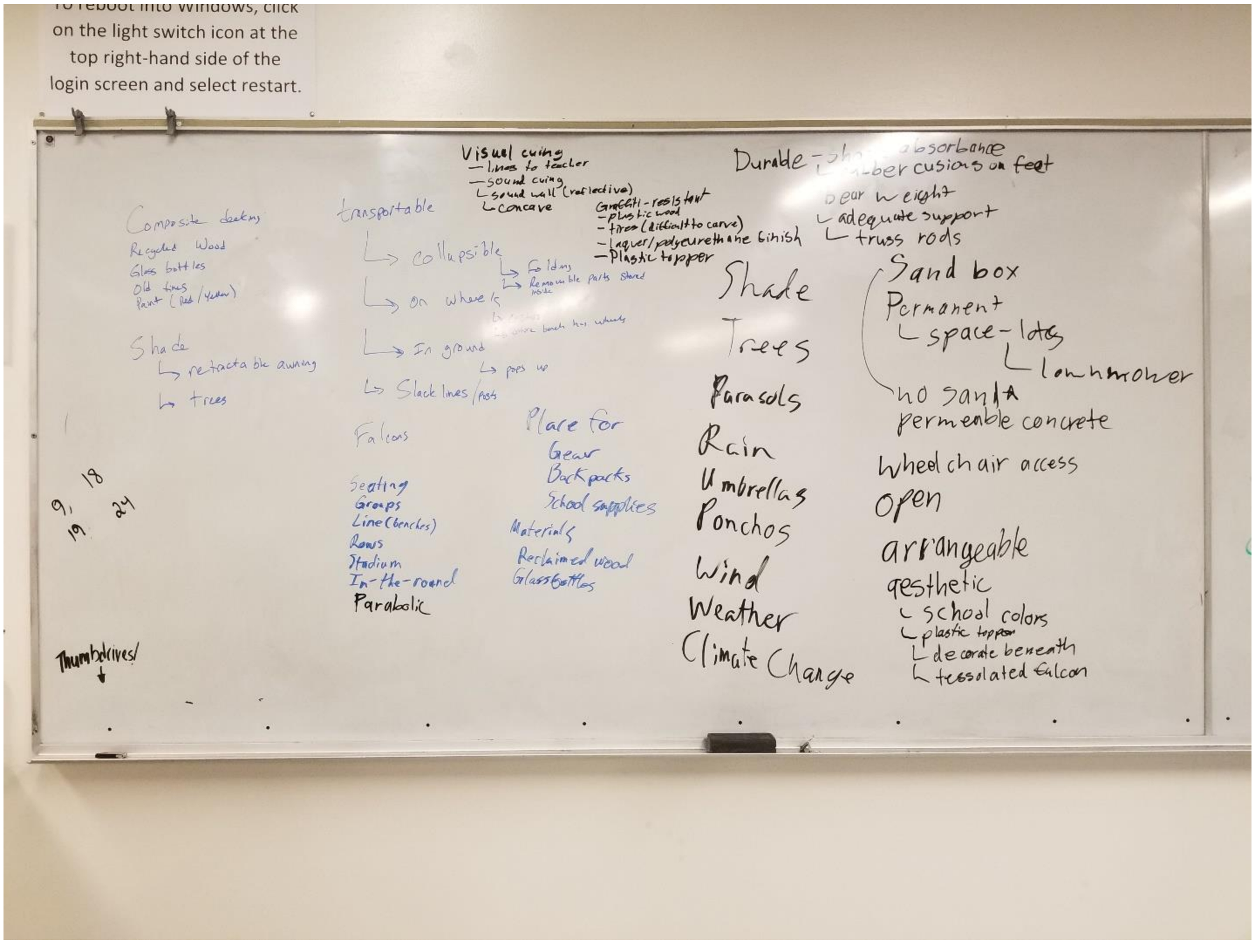
Phase	Jonn Geer	Christian Olson	Vincent Thomas	Richard Cupp	Phase Total
Phase 1: Problem Formulation	0	11	4	2	17
Phase 2: Literature Review & Problem Analysis	11	9	16	18	54

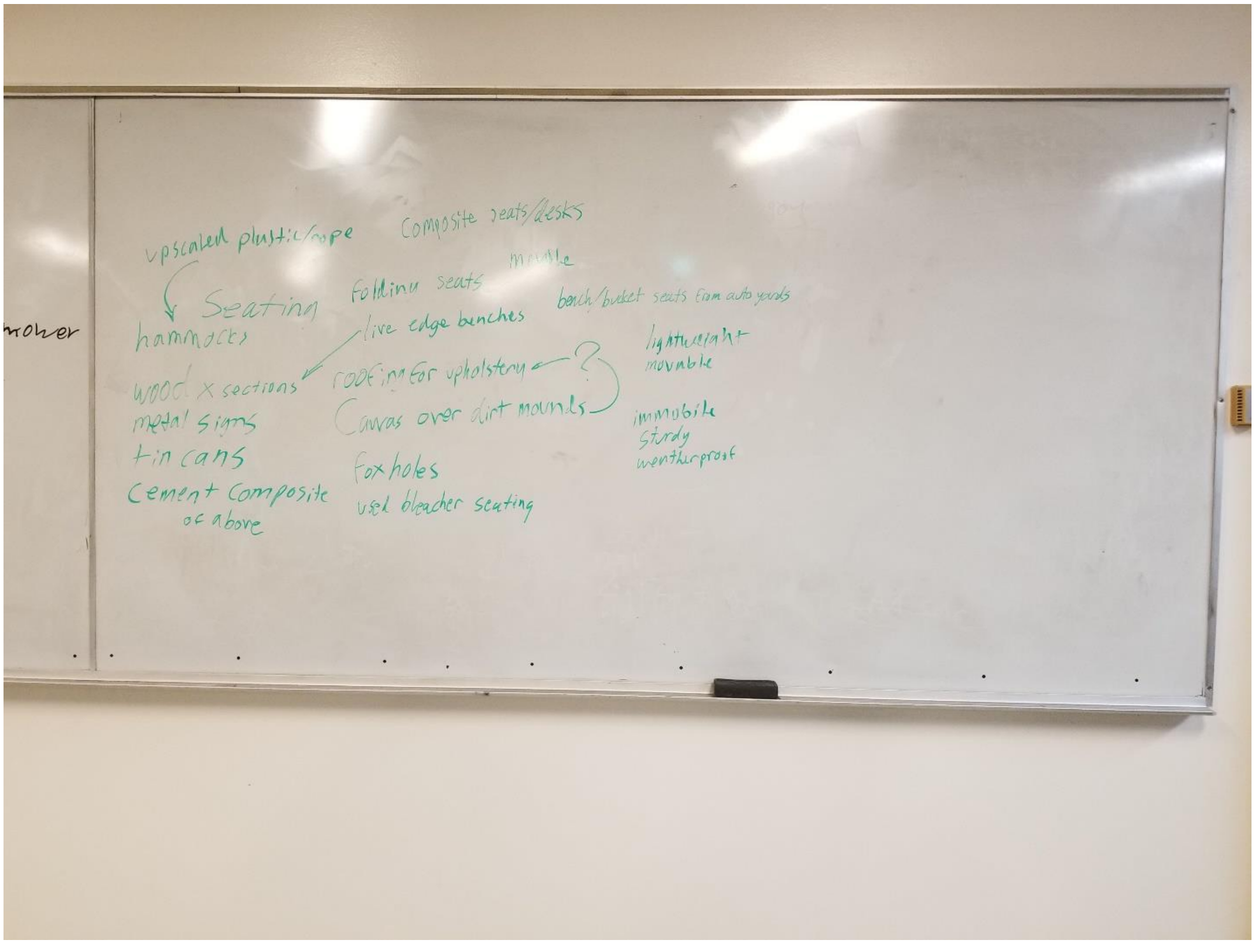
Phase 3: Alternative Solutions	6	11	5	4	26
Phase 4: Decision Phase	3	20	3	5	31
Phase 5: Specification of Solution	49	22	24	54	149
				Total Hours:	**277**

Table 6.2.2: Material list and associated costs.

Materials	Quantity	Unit ($)	Value ($)	Cost ($)
1"x6"x6' Redwood Fence Board	33	5.29	188.53	300
2"x4"x8' Construction Redwood	3	22.37	72.47	
2"x2"x3' Construction Redwood	33	2.5	89.1	
2"x2"x4' Construction Redwood	66	3.33	237.36	
2"x2"x6' Construction Redwood	22	5.5	130.68	
2" Strap Hinge 2 pk	10	3.69	39.85	
2" Strap Hinge 2 pk	12	3.69	47.82	44.28
2"x2"x8' Furring Strip	9	3.49	33.92	31.41
1"x6"x6' Cedar Fence Board	3	3.78	12.24	11.34
2"x4"x8' Framing Stud	2	3.87	8.35	7.74
2"x6"x8' Lumber	2	7.27	15.70	14.54
1.5" Brass Hinges 2 pk	2	2.49	5.37	4.98
Exterior Wood Screws 1 lb. Box	8	4.49	33.94	35.92
White Nylon Floor Protector 100 pk	2	7.99	17.25	15.98
White Board Paint	1	22.02	23.78	22.02
White Board Applique	3	13.04	42.24	39.12
Clipboards	36	1	38.88	0
Road Paint	2	8	17.28	0
		Total:	188.53	527.33

6.3 C. Brainstorming Sessions


To reboot into Windows, click on the light switch icon at the top right-hand side of the login screen and select restart.
Composite decking
Recycled Wood
Glass bottles
Old tires
Paint (Red/Yellow)
Shade
retractable awning
trees
transportable
collapsible
Folding
Removable parts
on wheels
In ground
pies up
Slack lines/posts
Falcons
Seating
Groups
Line (benches)
Rows
Stadium
In-the-round
Parabolic
Place for
Gear
Backpacks
School supplies
Materials
Reclaimed wood
Glass bottles
Visual cuing
– lines to teacher
– sound cuing
sound wall (reflective)
concave
Graffiti-resistant
– plastic wood
– tires (difficult to carve)
– laquer/polyeurethane finish
– Plastic topper
Shade
Trees
Parasols
Rain
Umbrellas
Ponchos
Wind
Weather
Climate Change
Durable
absorbance
rubber cusions on feet
bear weight
adequate support
truss rods
Sand box
Permanent
space-lots
lawnmower
no sand
permeable concrete
Wheelchair access
open
arrangeable
aesthetic
school colors
plastic topper
decorate beneath
tessolated falcon
9, 18
19, 24
Thumbdrives!


upscaled plastic/rope
Composite seats/desks
movable
Seating
folding seats
bench/bucket seats from auto yards
hammocks
live edge benches
lightweight
movable
wood x sections
roofing for upholstery
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metal signs
Canvas over dirt mounds
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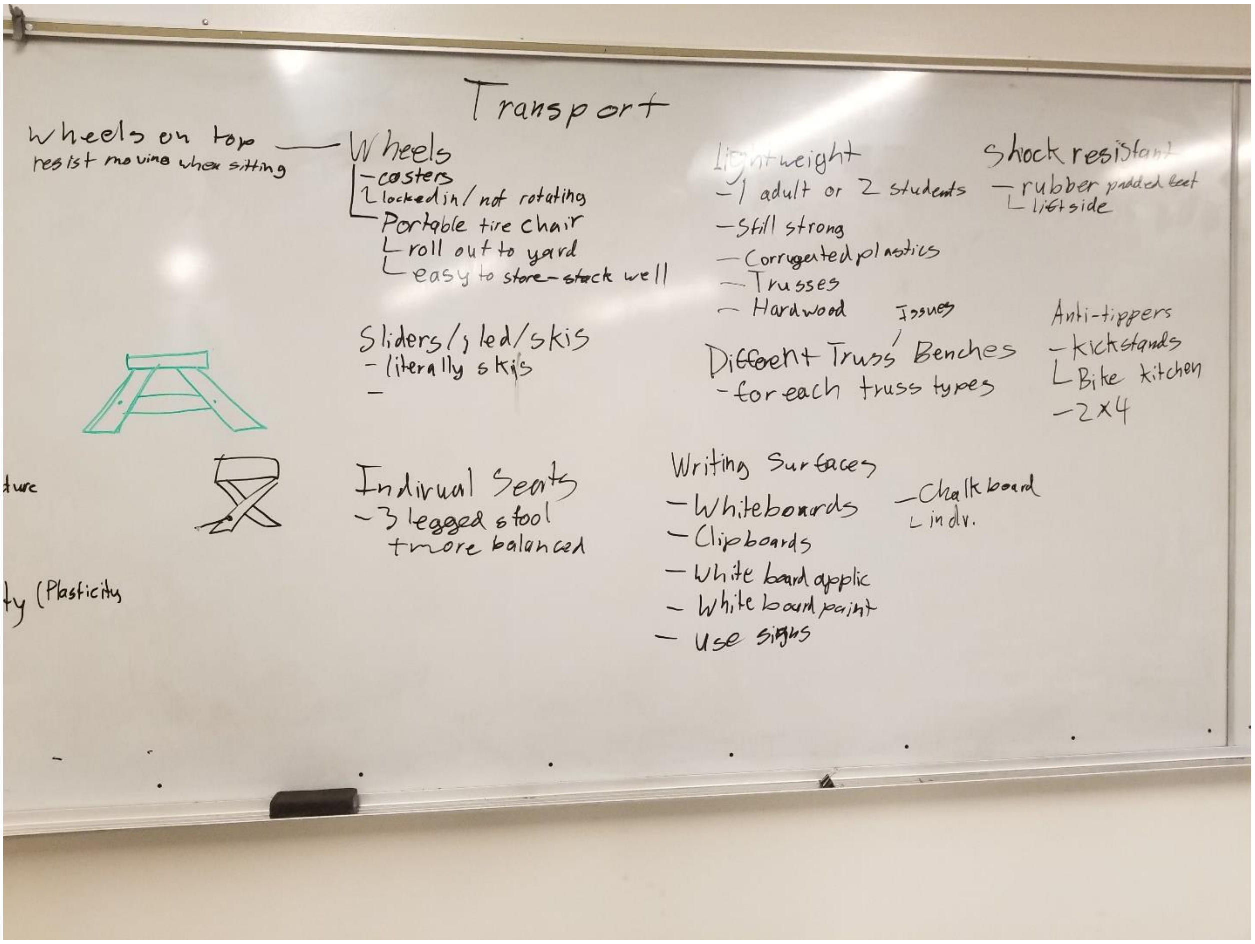
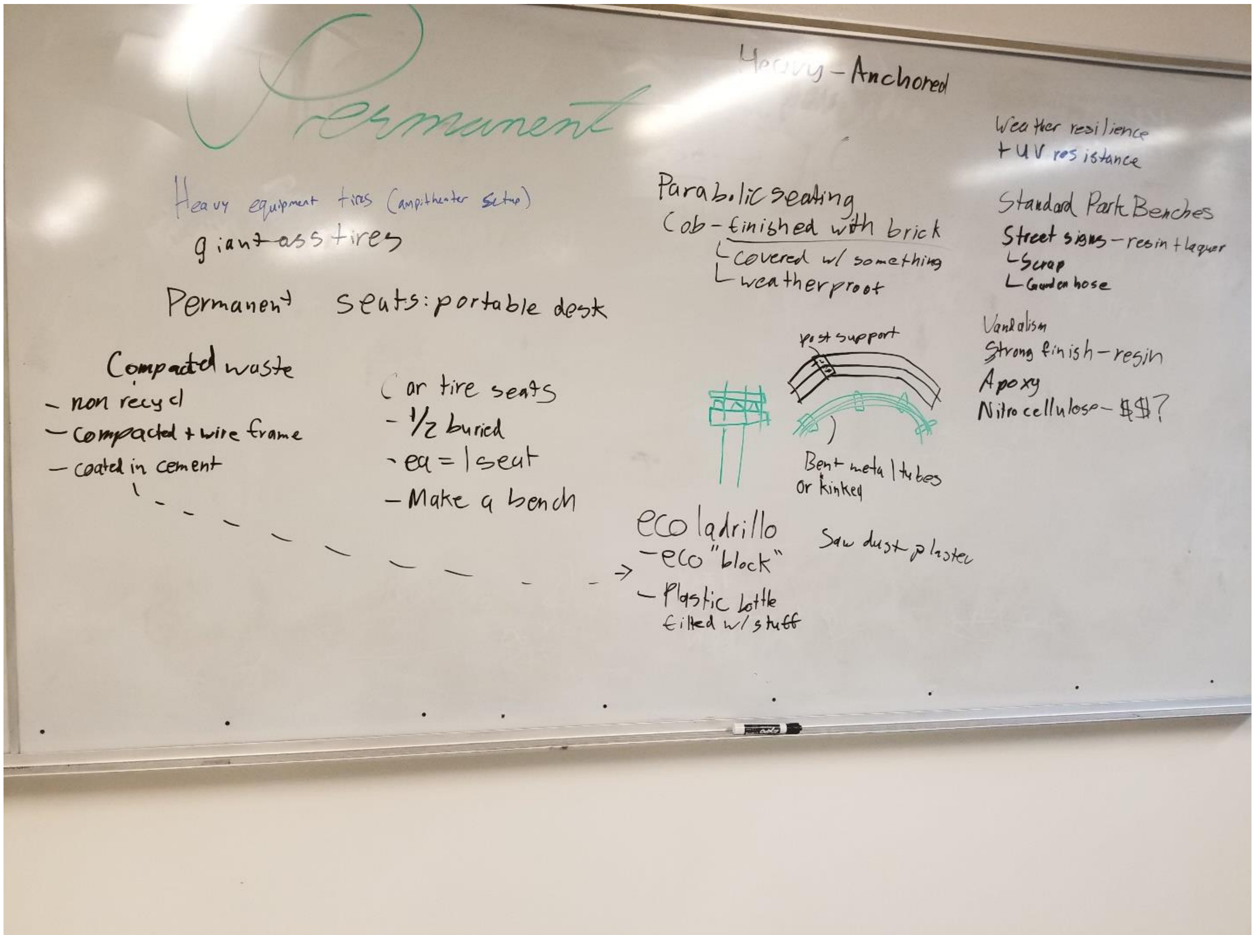
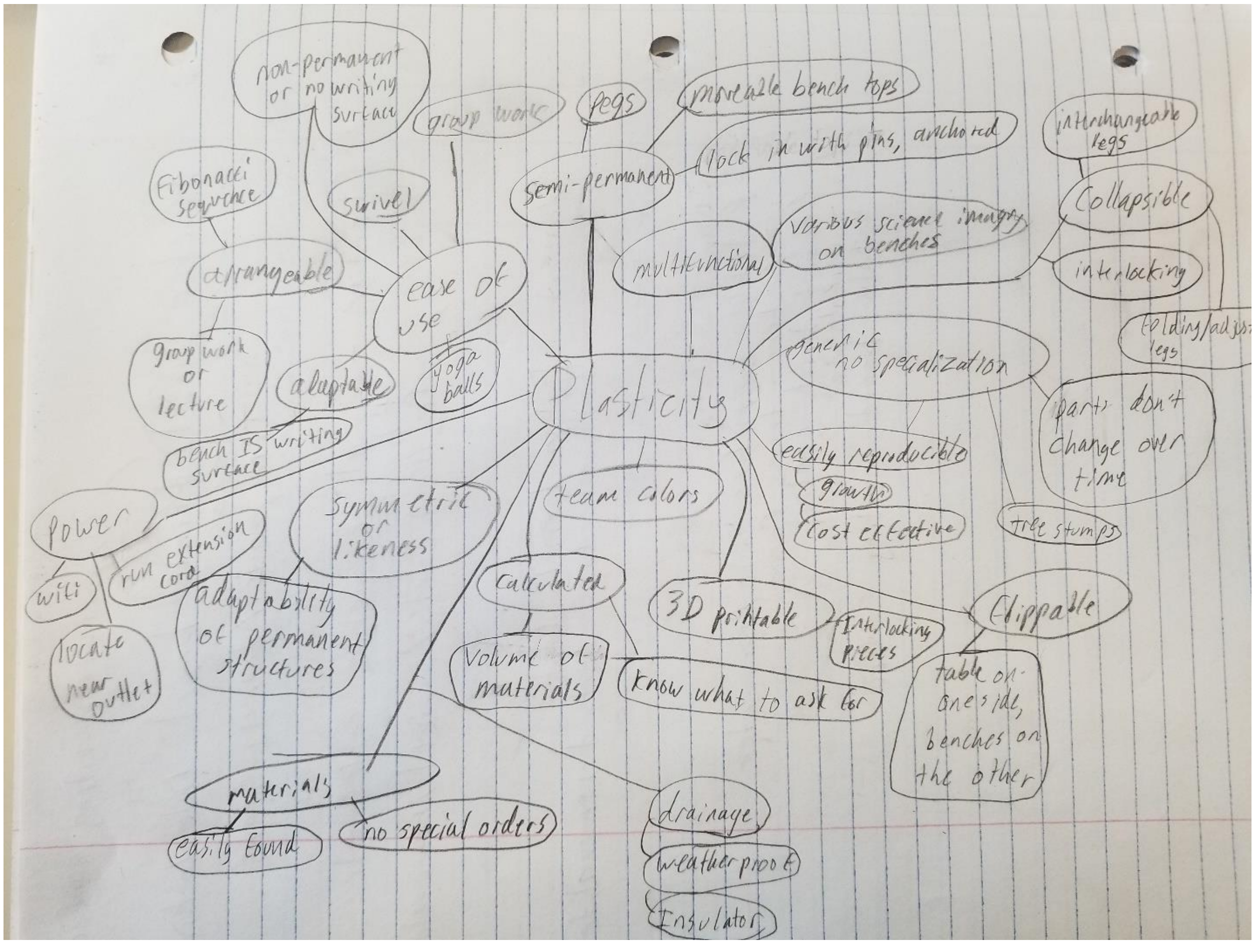
sturdy
weatherproof
tin cans
fox holes
Cement Composite
of above
used bleacher seating


Transport
wheels on top
resist moving when sitting
Wheels
-casters
locked in / not rotating
Portable tire chair
roll out to yard
easy to store - stack well
Lightweight
-1 adult or 2 students
-Still strong
-Corrugated plastics
-Trusses
-Hardwood
Shock resistant
-rubber padded feet
Issues
Sliders/sled/skis
-literally skis
Different Truss Benches
-for each truss types
Anti-tippers
-kickstands
Bike kitchen
-2x4
Indivual Seats
-3 legged stool
more balanced
Writing Surfaces
-Whiteboards
-Clipboards
-White board applic
-White board paint
-use signs
-Chalk board
indv.
(Plasticity


Permanent
Heavy - Anchored
Weather resilience
+ UV resistance
Heavy equipment tires (ampitheater setup)
giant ass tires
Parabolic seating
Cob - finished with brick
covered w/ something
weatherproof
Standard Park Benches
Street signs - resin + laquer
Scrap
Garden hose
Permanent seats: portable desk
Compacted waste
- non recycl
- compacted + wire frame
- coated in cement
Car tire seats
- 1/2 buried
- ea = 1 seat
- Make a bench
post support
Bent metal tubes
or kinked
Vandalism
Strong finish - resin
Apoxy
Nitro cellulose - $$?
eco ladrillo
- eco "block"
- Plastic bottle
filled w/ stuff
Saw dust plaster



6.4 C.

Maybe put in later