# ENGR 215: Introduction to design

Spring 2019

Zane Middle School


# Team Polaris

Sean Bryant, Jacob Rivera, Kong Vang, Garrett Wendel

# Contents

# 1 Problem Formulation

## 1.1 **Introduction**

Section 1 establishes the background of the problem, Team Polaris' objective and a black box model of the problem.

## 1.2 **Background**

In Eureka, CA, Catherine L. Zane Middle School enrolls over six hundred students. On a daily basis, students learn a variety of subjects ranging from English Literature to Science. In Jeanne Wilhelm's science course, students begin to develop a basic understanding of the universe by analyzing the Solar System. They reference books, pictures, computer models, and mathematics to cultivate knowledge of the Solar System. To help the students grasp the size of humanity in comparison to the scale of the Solar System, the students require a scale model.

## 1.3 **Objective**

Team Polaris' objective is to design and implement a Planetary Scale System to teach the students the vastness of the Solar System and to permanently establish a scale model for long term reference.

## 1.4 **Black Box Model**

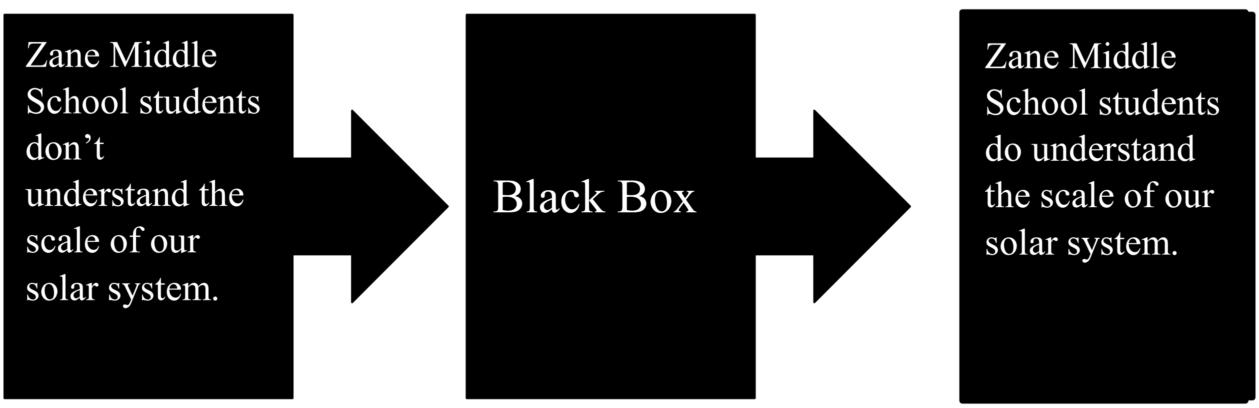


Figure 1-1 Black Box Model

*Figure 1-1: Black Box model of our design problem*

# 2 Problem Analysis

## 2.1 Introduction

The purpose of this problem analysis is to provide a description of the criteria used for the design process and to address constraints for each criterion. The problem analysis includes the specifications, considerations, criteria, usage, and production volume.

### 2.1.1 Specifications

The design of the Planetary Scale Model must follow these specifications listed below in order to meet Zane Middle School's needs.

- Location of the Model:
  Catherine L Zane Middle School

2155 S St, Eureka, CA 95501

- The Model must be safe for students and any personal on the campus.
    - Any installation on the campus grounds cannot be a tripping hazard.
    - Any structure—permanent or temporary—must be secure as to not fall and harm someone.
    - Any paints used must be non-toxic.
    - No sharp edges may be presents
- The Model must be low maintenance.
- The Model should span the length of the campus as to give a proper scale representation.

### 2.1.2 Considerations

The considerations of this project were influenced by the client and through individual research. This model should have educational value for the students and families of Zane Middle School. This model should be aesthetically appealing. Whether the model is portable or permanent, it needs to be able to withstand potential damage from handling and weathering.

### 2.1.3 Criteria and Constraints

The criteria define the scope of the model, while parameters are set by the constraints in order to insure the satisfaction of the client. Table 2-1 shows the criteria and the constraints that were developed through communication with the client.

*Table 2-1: Criteria and constraints for planetary scale model*

| Criteria | Constraints |
|---|---|
| Safety | Model must not harm any person under normal use. |
| Cost | Maximum cost must not exceed $400. |
| Aesthetics | Aesthetics must fit with the themes of the school. |
| Durability | Model must be able to be used for a minimum of 10 years. |
| Ease of Implementation | Model should require no heavy equipment to install. |
| Education | Students must have a better understanding of the scale of the solar system. |

### 2.1.4 Usage

The Planetary Scale Model will be used to demonstrate the scale of the Solar System, in terms of both size of the planets and space between them.

### 2.1.5 Production Volume
Nine "stations" (1 sun and 8 planets) will be marked, and/or constructed, and delivered to the campus of Zane Middle School.

## 2.2 Literature Review
The Purpose of this Literature review is to provide appropriate background information which will be used as a foundation and reference through the design process for Team Polaris' Planetary Scale Model at Zane Middle School. The following topics will be discussed in this Literature Review: The STEM and California Curriculum, Zane Middle School, the Components of the Solar System, Example Planetary Scale Models, and Materials: Metals, Woods, Cements, and Paints.

### 2.2.1 The STEM and STEAM Curriculum
STEM is the category of disciplines that includes Science, Technology, Engineering, and Math. The US government has implemented a learning program for schools, grade k-12, to help implement a higher level of learning and preparation for subjects in the STEM range. STEAM includes these subjects with the addition of the Arts. The world is continually advancing, requiring the advancements of teaching new and upcoming concepts. The goal is to prepare students for the modern world that will require the STEM subjects. The program also collaborates with NASA and the Institute of Museum and Library Services to bring high-quality STEM content and experiences to students (U.S. Department of Education).

### 2.2.2 Zane Middle School
As of fall 2013, Zane Middle School reestablished themselves with a STEAM focused curriculum. There is a heavy emphasis on providing a satisfying experience when learning about subjects that will create the future workforce. Zane has recently created a partnership with Humboldt State University around their STEAM program so that the students will be prepared to become a graduate student in the STEAM subjects (Eureka City Schools).

### 2.2.3 California Curriculum
The California Curriculum is the standard of education the State Government sets and requires of the schools in California to provide to students. The California Department of Education Reposted June 11, 2009 GRADE EIGHT Students know the appearance, general composition, relative position and size, and motion of objects in the solar system, including planets, planetary satellites, comets, and asteroids.( Bruton, S., and Ong, F.) According to the California Department of Education, some major learning outcomes for students, grade 6-8, are the concept of scale, proportion, and quantity. Learning about the difference in size, scales, and magnitudes of properties all correlate with the idea of the dimensions of space

### 2.2.4 The Solar System
#### 2.2.4.1 The Formation of the Solar System
The solar system formed about 4.56 billion years ago from, "the collapse of an interstellar cloud under its own weight." (Russell 2007). This collapse is commonly known as the big bang and it scattered matter across the universe. As bits of matter aggregated, they gained increased gravitational force pulling even more matter into the aggregate. Most of the mass gathered at the epicenter of the explosion forming the sun. Other large masses formed farther out eventually becoming the planets. Over billions of years the planets cooled and changed, becoming what they are today (NASA 2019).

#### 2.2.4.2 The Sun
The sun is a yellow-dwarf star located at the center of the solar system, about 26,000 light years from the galactic center (NASA 2019). The sun is approximately 4.5 billion years old and is the largest celestial

body in the solar system. It has a mass of 1,988,500 Ykg, constituting 99.8% of the mass in the solar system. This mass creates a surface gravity of 274.0 m/s2, a gravity 28 times greater than that of Earth. The sun has a radius of 695,700 km, which is 109.2 times greater than the earths, which is 6,371 km (Williams 2018). The sun is the main source of energy for life on earth, and gives off on average 384.6 Ywatts as a result of the constant nuclear fission occurring in the body of the star (University of Tennessee).

#### 2.2.4.3 Mercury

Mercury is the closest planet to the sun in the solar system. Mercury is named after the messenger to the roman gods who was able to run and incredible speeds. Just like its mythological counterpart, mercury has the fastest orbit of the planets, completing its orbit around the sun in just 88 earth days. Mercury is the closest planet to the sun with an average distance of 36 Mmi (NASA 2018). Mercury is also the smallest of the planets with a radius of 2439.7km and a mass just .0553 times that of earth (Williams, 2018). NASA makes a size comparison stating, "If Earth were the size of a nickel, Mercury would be about as big as a blueberry" (NASA 2018). Due to the small mass mercury has a low surface gravity of 3.7m/s2. Mercury is not capable of sustaining human life. (Williams 2018) The average daily temperature ranges from 800 to -290 degrees Fahrenheit, its atmosphere is too thin to breath, and the sun would be 11 times brighter than it is on earth (NASA 2018).

#### 2.2.4.4 Venus

Venus is the second planet closest to the sun, and being the most bright and visible from earth, is named after the roman goddess of love and beauty (NASA 2018). Size wise, Venus is very similar to earth, with a radius of 6051.8km and a mass 81.5% of earths (Williams 2018)." If earth were a nickel, Venus would also be a nickel, just ever so slightly smaller" (NASA 2018). Venus is 67 million miles from the sun and is the hottest planet in the solar system with a surface temperature of 900 degrees Fahrenheit. Despite there being evidence of water, the extreme temperature in conjunction with the dense toxic atmosphere, volcano strewn landscape, and constant hurricane force winds make Venus an unlikely candidate for life (NASA 2018).

#### 2.2.4.5 Earth

Earth, our home planet, is 93 million miles from the sun, making it the third closest planet to our solar systems center (NASA 2018). Earth has a mass of 5.9723 Ykg, an equatorial radius of 6378.1 km; and is the only planet whose name is Germanic in origin (Williams 2018). Earth has other many unique parameters. It is the only planet that supports known life in the entire universe, the only planet to have known liquid water and an atmosphere that is ideal for life as we know it (NASA 2018). The average temperature of earth is 58.3 degrees Fahrenheit, also optimal for human life (Larson 2014).

#### 2.2.4.6 Mars

At 228 Mkm away from solar system center it is the fourth closest planet to the sun. Mars, the red planet, is named after the roman god of war for its apparent blood color in the night sky. Mars has a radius of 3396.2 km, a little over half of Earth's, and a mass only 10.7% of earths. "If Earth were the size of a nickel, Mars would be about as big as a raspberry" (NASA 2018). The low mass means a surface gravity of only 3.71m/ss (Williams 2018). There has been recent talk in the scientific community about colonizing mars; however, mars is not capable of naturally sustaining human life. (Stoner 2018). Mars does have some life sustain conditions, the temperature ranges from an average of 21.9 degrees Celsius in the warmest months to around -6.4 degrees Celsius in the coldest months which is within acceptable ranges for human life (Climate Data 2015). Mars also has $H_2O$ on the surface, although the vast majority of it is frozen in the polar ice caps. Mars' atmosphere is also too thin to breathe or block out solar radiation, making the planet uninhabitable without the assistance of a man made atmosphere (NASA 2018).

#### 2.2.4.7 Jupiter

Jupiter is the fifth planet in the solar system. Jupiter in roman mythology was the supreme king of the gods, an apt name for this gas giant with its radius of 74,482 Km making it over 11 times greater than Earths. It also has more than twice the mass of all other planets combined, according to NASA, with a staggering mass of 1,898.2 Ykg. This mass results in a gravity of 24.79 m/s2 (Williams 2018). “If Earth were the size of a nickel, Jupiter would be about as big as a basketball” (NASA 2018). Since Jupiter is a gas giant, the planet does not have a solid crust like Mercury, Venus, Earth, and Mars and instead is more of a very dense gas mixture, mostly hydrogen and helium, with liquid elements closer to the planets center due to the immense pressure. Due to the intense pressure, >>1000bar, Jupiter may have a solid core, but it is still unknown; another theory is that at the planets center a thick hydrogen “soup” is present and could have temperatures reaching 90,032 degrees Fahrenheit (Williams 2018). The gas portion of Jupiter is home to many storms. Jupiter’s largest storm, called “The Great Red Spot”, is a massive gas hurricane that has been raging for over 150 years. The storm is twice as wide as earth and has sustained winds of over 400mph, smaller storms can be seen from Jupiter’s orbit. Jupiter is not capable of sustaining life, however some of its 79 moons have sub-surface oceans that may contain life (NASA 2018).

#### 2.2.4.8 Saturn

With a distance of 886 Mmi, Saturn is the 6th closet planet from the sun. Perhaps best known for its glorious rings, Saturn is named after the god of wealth and harvest in roman mythology. Saturn is slightly smaller than Jupiter, “If Earth were the size of a nickel, Saturn would be about as big as a volleyball” (NASA 2018). Like Jupiter, Saturn is a gas giant made up of mostly gaseous hydrogen and helium with liquid states of these elements at closer to the planets center. Unlike Jupiter, Saturn is confirmed to have a solid core of iron and nickel covered with a coat of rock (NASA 2018). Saturn is the second largest planet with a radius of 60,268 km, a mass of 568.34 Ykg, a surface pressure of >>1000bar, and a surface gravity of 10.44 m/s2 (Williams 2018). As a gas giant, Saturn is not capable of sustaining life, however, one of its 53 moons may contain life in sub-surface oceans (NASA 2018).

#### 2.2.4.9 Uranus

At 1.8 billion miles from the sun Uranus is the 7th farthest planet from the sun. Named after the roman god of the sky Uranus is the third largest planet in the solar system with a radius of 15,759.2 miles and a mass of 86.8 Ykg (Williams 2018). “If Earth was the size of a nickel, Uranus would be about as big as a softball” (NASA 2018). Unlike Saturn and Jupiter, Uranus is known as an Ice Giant due to its composition of an icy dense fluid of water, methane and ammonia. Aside from the inner core, Uranus is very cold, reaching temperatures of -224.2 degrees Celsius. Like Saturn, Uranus also has sets of rings, although they are not as obvious to observers. The composition, temperature and pressure make Uranus virtually uninhabitable for all life, it is also unlikely that any of Uranus’ 27 moons support life (NASA 2018).

#### 2.2.4.10 Neptune

Neptune is 2.8 billion miles from the sun, making it the most distant true planet in the solar system. Neptune is dark blue in color and deservingly gets its name from the roman god of the sea. Neptune’s year is equivalent to 165 earth years and has only completed a full revolution around the sun once since its initial discovery (NASA 2018). Like Uranus, Neptune is a massive ice giant boasting a radius of 15,299.4 miles and a mass of 102.413 Ykg (Williams 2018). “If Earth were the size of a nickel, Neptune would be about as big as a baseball” (NASA 2018). Neptune’s composition is similar to Uranus with most of the planet being made from an icy fluid of water, methane and ammonia. It is believed that Neptune has a super-hot ocean of water closer to the planets core that is kept in place by the extreme atmospheric pressure. Neptune is not capable of sustaining life and it is unlikely that its moons are life sustaining (NASA 2018).

### 2.2.5 Planetary Models

Planetary scale models are two or three dimensional exhibits that display the size of the planets and the distance between them at a smaller scale. These exhibits help people comprehend the scope of the solar system.

#### 2.2.5.1 Voyage Scale Model Solar System

The Voyage Exhibit is a 1 to 10 billion scale model of the solar system that opened in 2001, located in the National Mall in Washington D.C. The exhibit is 2,000 feet long, located between the Capital Building and the Washington Monument. The Voyage exhibit consists of thirteen 8-feet tall stainless steel stations: The Sun, each planet, Pluto and other solar bodies. Each of these stations has models, text, and images of their respective body. Voyage represents the space between each body to scale, as well as their respective size (Voyage, 2018). Figure 2-1 shows children on a field trip looking at the Sun station of the Voyage Exhibit.


*Figure 2-1: Children on a field trip to the Voyage Exhibit looking at the Sun station.*

#### 2.2.5.2 Colorado Scale Model Solar System

The Colorado Scale Model Solar System is a 1 ten billionth scale model of our solar system. It shows relative scale in both distance between solar bodies and their size. This scale model was put up in 1991 on the Boulder Campus of the University of Colorado. The exhibit features ten granite pedestals with informational plagues mounted on them. These plagues feature text, images, and diagrams about their respective planet (Bennett). Figure 2-2 shows the pedestals of the inner planets and the Sun.

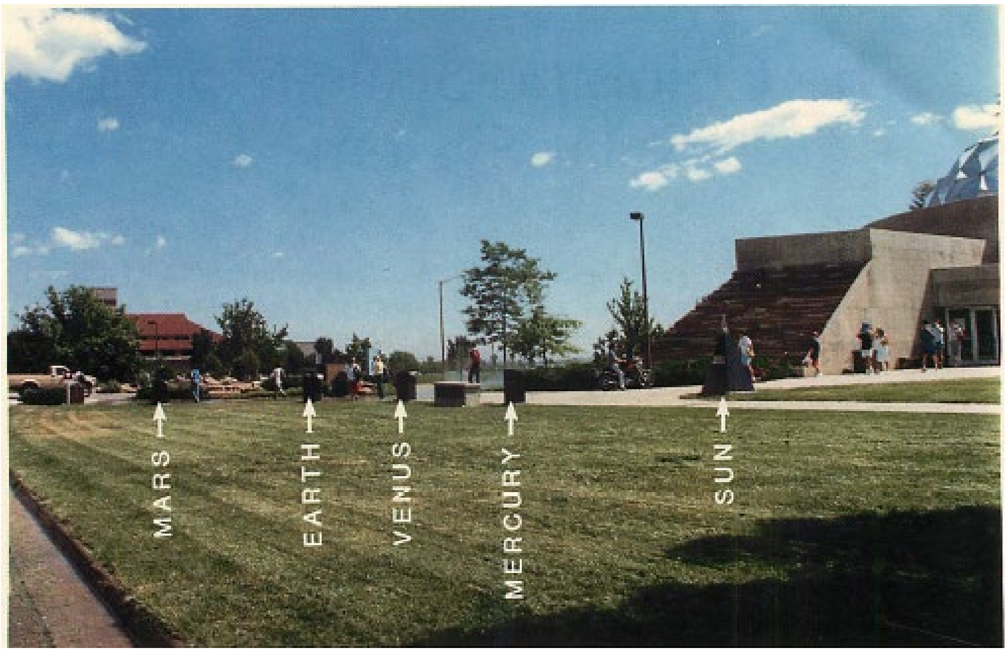


*Figure 2-2: The pedestals of the inner planets in relation to the Sun (Bennett, 2018).*

### 2.2.6 Materials

#### 2.2.6.1 Metals

A durable material composed of the "metal" group of chemical elements arranged in a crystalline lattice structure. Metals have been used for construction for centuries. This section will discuss Galvanized Steel, Aluminum, and Stainless Steel.

##### *2.2.6.1.1 Galvanized Steel*

Galvanized steel is steel treated in a hot bath of Zinc, in order to form oxide barrier galvanic coating (Shibli 2008). The galvanic coating is a protective layer for the steel. Zinc quickly oxidizes and creates a corroded layer to prevent further corrosion of the steel. Galvanization prevents the steel from weakening through corrosion and, and prevents the steel from rusting, thus extending its lifetime.

##### *2.2.6.1.2 Aluminum*

Aluminum is an element, number thirteen on the periodic table. It is highly reactive and easily oxidized. Due to its chemical properties, aluminum creates an oxide film which protects the underlying metal from further corrosion (King 1987). Aluminum is used to coat and protect other metals in commercial use.

##### *2.2.6.1.3 Stainless Steel*

Stainless steel is a steel alloy with a large amount of chromium. Stainless steel must have a minimum of ten percent chromium to be considered stainless. The chromium found in stainless steel allows it to develop a passive film, similar to Zinc and Aluminum, which protects the steel from further corrosion. Stainless steel is superior to all other materials in terms of corrosion resistance (Budinski 2002).

### 2.2.6.2 Woods

Wood is a firm organic material that comes from the trunk of trees. It has been used for construction for thousands of years. This section will discuss Solid Wood, Particle Wood, and Wood Treatments.

#### *2.2.6.2.1 Solid Wood*

Solid wood is wood that does not require any glue to hold its structure. Solid wood has different densities depending on its composition and moisture content. Solid wood has multiple uses such as construction, tools, furniture and more. It is expensive because of its strength and versatility. In its raw form, a fresh piece of timber is composed of sapwood and heartwood. The heartwood is located in the middle of the timber and provides structure to the tree. The sapwood is softer, more absorbent and transports sap from the roots to the leaves. Sapwood is often attacked by fungi and insects despite its strength similarity to heartwood. However, sapwood's absorbent property allows it to be treated more effectively with preservatives for weather protection (Levin 1972).

#### *2.2.6.2.2 Particle Wood*

Particle wood is wood chips and sawdust bonded together using synthetic or organic glue. Its applications range from furniture to house projects such as flooring. It must be stored lying flat or risk deformation. Particle wood is typically obtained in sheets of various sizes, densities, and is less expensive than solid wood (Levin 1972).

#### *2.2.6.2.3 Preservative Wood Treatment*

Preservative wood treatment is used to prevent wood from decaying. Prior to treatment, fresh timber must always be dried at equilibrium with the humidity conditions, or seasoned. If the fresh timber is not properly seasoned prior to treatment, the timber will warp in various ways as it reaches equilibrium. Any solid wood labeled durable is resistant to preservative treatments and may be used liberally without treatment. However, if any sapwood is present, it is recommended that preservative treatment is applied to the sapwood to prevent fungi and insects from destroying it (Levin 1972).

### 2.2.6.3 Cement

Cement is a powdered form of limestone and clay that can mixed with water to form a mortar binding agent. It can be mixed with sand, gravel, and water to make a durable construction material, called concrete, that is easily poured into molds before setting and hardening, resembling stone. Different mixes provide different features and contain unique compositions. Portland cement is one of the most common mixes used in construction and small projects. Portland cement is made by heating limestone and clay to one thousand four hundred degrees Celsius in a kiln (Claude Aïtcin 2016). Portland cement undergoes a chemical reaction, hydration, after contact with water. The calcium bonds to the oxygen granting it sturdiness (Brehm 2009).

### 2.2.6.4 Cob

Cob (also spelled cobb) is an earthen construction material that has been in use for many centuries. It is generally made by mixing soil, sand, clay, straw, and water. Straw is added to give the mixture tensile strength and help bind layers together. The exact amount of each material in the recipe can may vary greatly. This allows for versatility if there is a shortage of materials. The simple material is mixed together by hand—often times by feet through stomping—and requires no heavy machinery to apply. Most of the construction work is also done by hand or simple hand tools. In addition to cob's straightforward and flexible production, cob structures are durable in a wide range of climates. Cob structure can withstand the harsh winds and rain of coastal Great Britain, as well as the temperate rain forests of Oregon (Chiras 2000). This is due to the cob taking on a hardness similar to stone when dried. Figure 2-3 shows a bench made out of cob in Arcata, California.

*Figure 2-3: Bench in Arcata, California (Appropedia 2013).*

The construction of cob starts with having or creating a strong foundation. Cob is durable when built on concrete or stone. Once the foundation has been laid, the cob should be constructed layer by layer until the structure is complete. It is advised to build each layer no higher than 1 foot at a time. After one layer is applied, the cob should dry completely before adding additional layers (Appropedia 2017). Drying the layers may take a few hours if the weather permits, but generally a full day is needed before another layer can be applied.

Cob is simple to make and apply. It is both labor and time intensive, making the process quite slow. The simplicity of cob does allow for people of all ages to use it. The end product is a strong, weather and fire proof material that is cost efficient and has a low impact on the environment.

#### 2.2.6.5 Paints

Paints are liquid coatings applied to a surface for protective and aesthetic reasons. Paints are made from four main components: Binders, Solvents, Pigments, and Additives. These components can be seen in figure 2-4. Binders help adhere the paint to the surface. Solvents are the medium in which the paint is held before application. Solvents can be used to modify the paint’s viscosity to allow for different methods of application. These methods may include rolling, brushing spraying, or dipping. The pigment of a paint gives the paint its color along with other properties. UV-protection, gloss and hardness can be characteristics of different pigments. Additives are any other component added to the paint. This may include driers, which accelerate how quickly the solvent evaporates, plasticisers, which gives the paint flexibility, or pesticides (Subtech 2014). There are multiple different types of paints.

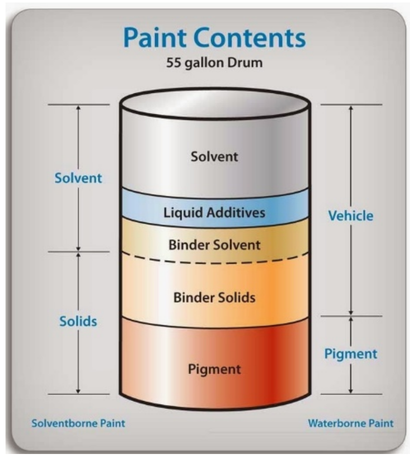


*Figure 2-4: Visual representation of the composition of paint (Red Devil Home Improvement 2014).*

#### *2.2.6.5.1 Latex Paints*

Latex paints have water solvents and acrylic binders. Latex paints emit Volatile Organic Compounds (VOCs) which may be harmful if inhaled. "Low-VOC" Latex paints often contain synthetic compounds that may be harmful or difficult to dispose (Wilhide 2003). These paints are easy to apply because the surface does not have to be fully dry. Latex paints are quick to dry, decreasing the likelihood that dirt and insects will get caught and dry in the paint. Their quickness to dry also allows for more coats to be applied quicker (Reader's Digest 1981). Latex paints are good for wood, brick, concrete, and metals, such as steel, iron, and aluminum.

#### *2.2.6.5.2 Oil-Based Paints*

Oil-based paints have petroleum-product solvents. They are more adhesive than latex paints and will hold more firmly to the surface they are applied to. The oil bases in the paints make them difficult to handle and dispose. Oil-based paints emit more VOCs than Latex paints (Wilhide 2003). Oil-based paints can be applied to all the same surfaces that latex paints can: wood, brick, concrete, and metal. Oil-based paints typically need a layer of primer on the surface before application.

#### *2.2.6.5.3 Natural Paints*

Natural Paints contain solvents, binders, and pigments that are all sourced from plants and minerals. Figure 2-5 shows a student at HSU painting the interior of the Campus Center for Appropriate Technology (CCAT) using a natural egg-based paint. Vegetable pigments often fade with time. Mineral pigments are more intense and are more durable. Natural paints are more difficult to apply than latex paints and have a longer drying time. Natural paints contain significantly less, if any, VOCs. Precautions must be taken if the paint contains the mineral lime. Lime is very caustic which means it is able to burn or corrode organic tissue (Wilhide 2003). Other elements that need to be taken into consideration are Iron, which can cause eye defects if Iron-containing-pigments come in contact and remain in eye tissue. Pigments containing lead or arsenic also threaten the health and safety of individuals and the environment (Abagale 2013). Natural paints can be more or less expensive than synthetic paints depending on if they are purchased or created by the user.

*Figure 2-5: Student painting CCAT interior using egg-based paint (Appropedia 2012).*

# 3 Alternative Solutions

## 3.1 Introduction

Section 3 contains the brainstorming process which led to the alternative solutions which would satisfy Zane Middle School's need for a planetary scale model. These solutions are described generally with more specific details discussed in the adopted design section.

## 3.2 Brainstorming

The first stage of brainstorming was an informal idea generation over the course of a couple weeks. We met with our client and discussed some ideas that became integrated into our alternatives list. After this meeting, as a team, we conducted a more formal brainstorming to ideate other alternatives. These ideas were recorded with pencil on paper. Our alternatives consist of a wide range of ideas, each having their respective pros and cons. Our specifications and considerations outlined in Section 2.1 focused our brainstorming. The notes and sketches from our brainstorming can be found in the Appendix.

The list of Alternatives is as follows, proceeded by a detailed description.

- Submerged Planets
- Ground Paintings
- Pedestals
- Lockable Flag Pole Holders
- Tile Mosaic
- Mounted Paintings/Murals
- Augmented Reality

## 3.3 Submerged Planets

Submerged Plants involves removing paved areas of Zane middle school and replacing them with a slightly raised spherical cap (dome) of cement. These domes would be of varying sizes and scaled so that they accurately model the size of the planets relative to each other. Distances of these domes would also be such so that the distance between the planets would be to scale with the solar system. I.e. the planet sizes and distances are scaled down from their actual dimensions but the relative size and distances of the planets is preserved, thus making submerged planet option an accurate model solar system. They cement domes would be painted to provide a more appealing aesthetic and increase contrast with the surrounding area.

A small plaque containing information about the planet, such as actual size, distance, a size comparison to earth, how long it would take humans to reach the planet, where the planet gets its name, who discovered it and number of moons. This plaque would either be inlayed into the ground by the planet, or on a small stand in the same location. The plaque would serve as a learning aid and a source of supplemental education of the Zane students.

## 3.4 Painted Model

The paint model is a simpler version of the submerged planets alternative. The paint model entails painting the planets on already paved areas of Zane. Like the submerged planets model the size of the painted area will be scaled so the relative planets sizes are accurate and the distances between the planets will be scaled as well. Due to this scaling, the paint model will be an accurate representation of the solar system. The paint will provide an aesthetic appeal and serve as a visualization aid for the students at Zane.

A small plaque containing information about the planet, such as actual size, distance, a size comparison to earth, how long it would take humans to reach the planet, where the planet gets its name, who discovered it and number of moons. This plaque would either be inlayed into the ground by the planet, or on a small stand in the same location. The plaque would serve as a learning aid and a source of supplemental education of the Zane students.

## 3.5 Pedestals

The Pedestals Design would include nine pedestals, one for the sun and eight for the planets. Each pedestal would be made either of metal of poured concrete and would include an informational plaque on the top face. The overall design of the pedestals would be kept simple and elegant, similar to the pedestals used for the Colorado Scale Model shown by Figure 3-1. These pedestals would be placed along the length of Zane Middle School's paved area. This will allow the display to grasp the scale of the solar system as much as possible The plaques would include specific measurements about the body, including diameter, distance from the sun, distance from earth and a size comparison to earth. They can also include general information about each planet, such as composition, date of discovery and discoverer, and any relevant studies NASA has conducted on said planet, ideally any satellites or rovers NASA has sent to collect data. Installation of this design would require the breaking up of nine sections of the pavement at Zane in order to lay a foundation for each pedestal.

*Figure 3-1 Example pedestal from the Colorado Scale Model Solar System (Bennet, 2018)*

## 3.6 Planet Flag Poles

The Planet Flag Pole Design includes eight portable bases that would support a pole with a model of each planet on top of it. These holders would most likely be made of a light weight material, and when not in use, be stowed away out of sight. When in use, the models will be placed on preset markers placed around Zane Middle school's paved section as to give the true scale of the solar system. . Each planet pole would be roughly eye level with the children so they can really take in the scale of the planets in comparison to each other. The sun will not be included on one of these poles due to the fact that the sun's scale compared to the other planets is too large and would either result in the planets being too small to see, or the sun being way too large to put on a movable pole. An alternative plan for the sun's scale would be to paint it on a side of building or paint it on wood planks and mount it to wall. This way the true scale can still be maintained. This design allows for flexibility because it is non-permanent and requires no breaking of the paved areas.

## 3.7 Lockable Flag Pole Holders

The Lockable Flag Pole Holder Design includes eight flag pole-like holes in the ground that would support a pole with a model of each planet on top of it. These holders would most likely be made of metal pipe. When not in use, the planet poles can be removed and a cover can be placed over the hole and locked in order to prevent tampering with the hole. The cover for the hole would include an indented section in the middle so that the lock used to secure the lid shut would be able to lay flush with the ground in order to not be a tripping hazard. The covers could be made of metal, treated wood, or concrete. A schematic of this is shown in figure 3-2. These coverable holes will be placed along the length of Zane Middle school's paved section as to give the true scale of the distance between the planets. Each planet pole would be roughly eye level with the children so they can really take in the scale of the planets in comparison to each other. The sun will not be included on one of these poles due to the fact that the sun's scale compared to the other planets is too large and would either result in the planets being too small to see, or the sun being way too large to put on a movable pole. An alternative plan for the sun's scale would be to paint it on a side of building or paint it on wood planks and mount it to wall. This way the true scale can still be maintained. This design gives the model versatility and would require less breaking of the current paved section of Zane then the Pedestal Design. It would still require breaking some of the paved section in order to install the pole holders.

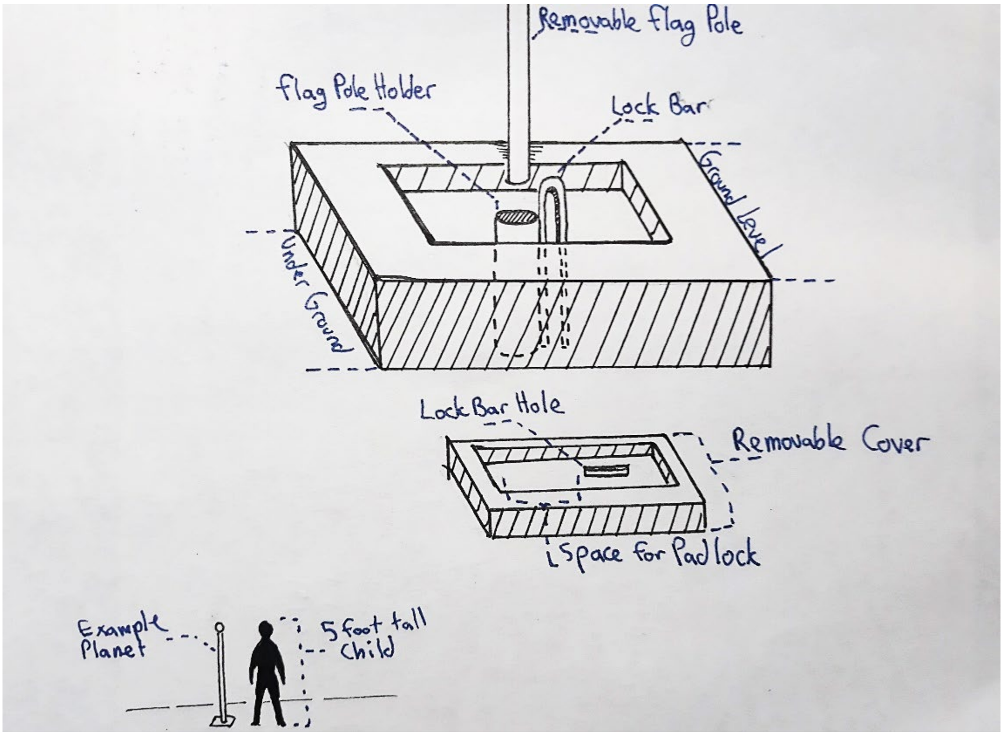


*Figure 3-2 Preliminary sketch of Lockable Pole Holder from team brainstorming (Team Polaris brainstorm, 2019)*

## 3.8 Mosaic

A Mosaic Design would depict the sun as well as the eight planets to the sun in a very decorative and elegant fashion. The mosaic design would require that either glass or stone pieces be placed within the ground and then cemented in place. These pieces of glass or stone are typically small, smooth and often square shaped and can also be a multitude of different colors known as tesserae. The mosaic design would be dispersed throughout the school campus to represent the scale distance of the planets within the solar system, and it would be most appropriate to locate the designs within a concrete walkway or on a sidewalk. These mosaic designs would not only serve as a scale model and as an art piece, as the mosaic design is intended to be durable and last for long periods of time. In order to implement this design, it would be necessary to break up the pavement at Zane enough for the glass or stone pieces to be flush with the rest of the sidewalk and prevent any hazards when walking. In between each piece of stone or glass is an adhesive used to set the pieces in place which can take up to 72 hours for it to completely dry.

## 3.9 Murals

A mural design would be used to depict a scaled size comparison of the eight planets compared to the sun. This mural design will be located on the side of a building where the actual art depiction will be painted either directly onto the wall or onto a piece of plywood and then mounted to the wall. The important aspect of this design would be to depict the massive size difference, seen in figure 1, that the sun has compared to the rest of the planets. In order to accomplish the mural design a primer will need to be set onto the surface for the paint to stick on to. Once the primer is set and dried it is also important to create an underpainting or create the general composition of the mural with main colors, using an eggshell sheen due to its ability to be cleaned and accept more layers of paint on top of it. Once this underpainting is handled higher quality acrylic paints can be used to create the small details within the mural to depict the planets shape and distinctive features.

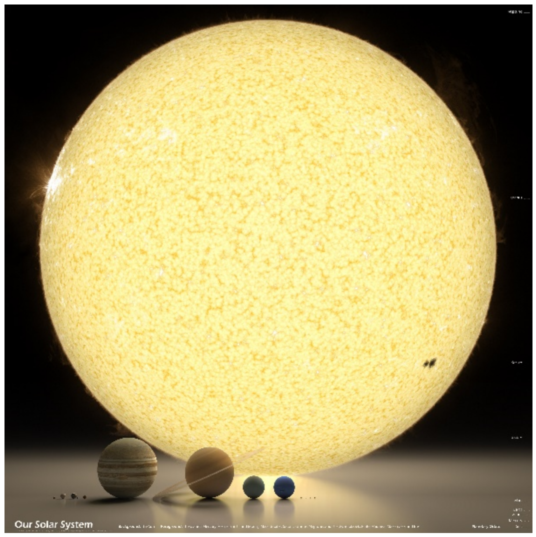


*Figure 3-3 Size of the planets in comparison to the sun (Ziche, 2014).*

## 3.10 Augmented Reality Scaled Solar System

Augmented Reality (AR) is using computer generated images or 3D models and superimposing them onto reality through software, computers and cameras. An open source software for Augmented Reality would be utilized for the project to save time. Utilizing AR would drastically reduce material cost, carbon footprint and invasive construction. However due to strict timeline limitations and lack of prior knowledge for coding, the idea has been set aside. If AR had been implemented into the project, markers, which contain an image code, would be used to identify each of the eight planets and the sun. A computer-generated 3D model of the planet or sun would be linked to its respective marker. When a marker is scanned with the appropriate application using live feed imagery, the computer-generated 3D model linked to the marker will display itself. The generation of the 3D model would be superimposed onto reality. The medium used to view the image would have to be a modern smartphone. The smart phone must have a gyroscope to detect orientation and use a camera to layer the live image feed with the 3D model. Each marker may be designed in a practical way such as a card containing its respective extraterrestrial body. In addition to the 3D model, information about the model may also be coded on to the display with its respective model. Each marker would then be placed at a scaled distance from each other during lessons and then users may then utilize smartphone technology along with a software application to generate one model at a time.

# 4 Decision Process

## 4.1 Introduction

Section 4 reviews all the alternative solutions for the Scaled Planetary System and drives the decision process. The Delphi method determines the best alternative solution for implementation based on the best correspondence with the set criteria.

## 4.2 Criteria

The criteria that informed the final design are listed and defined below.

**Safety** – The inability to be harm any person.

**Cost** – The total amount of money spent on materials and tools in order to complete the design.

**Aesthetic –** The ability to match the overall themes of the school.

**Durability –**The ability to withstand weather and repeated use.

**Ease of Implementation** – The ability to be installed without an excessive increase of cost and time.

**Educational** –The ability to provide learning opportunities for all persons who use and see it.

## 4.3 Solutions

Listed below are all alternative designs presented to the client.

- Painted ground
- Submerged Planets
- Pedestals
- Covered Pole Holders
- Tile Mosaic
- Mounted Paintings/ Murals
- Augmented Reality

For detailed descriptions of each alternative, please refer to Section 3.

## 4.4 Decision Process

This project was first discussed with the client representative and there was not a specific design in mind besides painting the planets on the ground. This idea was kept in mind but also gave the group opportunity to think of various designs. In total there were eight alternative designs that were reviewed based off the criteria in Table 4-1 below with a rating of 0-10 with 10 being the highest.

*Table 4-1: Criteria and weights*

| Criteria | Weight (0-10) |
|---|---|
| Safety | 10 |
| Cost | 10 |
| Aesthetics | 10 |
| Durability | 9 |
| Ease of Implementation | 6 |
| Educational | 5 |

The decision was made based off the Delphi chart, shown in Table 4-2, which used each criterion as a multiplied factor towards the scores given to each alternative design. The scores are added up for each criterion and the design with the highest value is the best overall choice for the specific criterions list as shown in the figure below. Cost, aesthetic, safety, and durability had the most weight and the most influence on our final decision process.

*Table 4-2: The Delphi matrix used for design selection*

| Delphi Decision Method | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (0-10) | Alternative Solutions (0-50) | | | | | | | |
| Critera | Weight | Painted Ground | Submerged Planets | Pedestals | Planet Flag Poles | Covered Pole Holders | Tile Mosiac | Mounted Paintings/ Murals | Augmented Reality |
| Cost | 10 | 50 / 500 | 20 / 200 | 20 / 200 | 40 / 400 | 35 / 350 | 25 / 250 | 45 / 450 | 40 / 400 |
| Aesthetic | 10 | 15 / 150 | 10 / 100 | 25 / 250 | 300 | 30 / 300 | 35 / 350 | 15 / 150 | 10 / 100 |
| Educational | 5 | 10 / 50 | 45 / 225 | 45 / 225 | 15 / 75 | 15 / 75 | 10 / 50 | 10 / 50 | 10 / 50 |
| Safe | 10 | 50 / 500 | 10 / 100 | 40 / 400 | 45 / 450 | 45 / 450 | 40 / 400 | 40 / 400 | 50 / 500 |
| Durability | 9 | 5 / 45 | 5 / 45 | 40 / 360 | 50 / 450 | 50 / 450 | 30 / 270 | 35 / 315 | 40 / 360 |
| Implementaion | 6 | 45 / 270 | 10 / 60 | 15 / 90 | 50 / 300 | 30 / 180 | 5 / 30 | 20 / 120 | 10 / 60 |
| **Total** | | **1515** | **730** | **1525** | **1975** | **1805** | **1350** | **1485** | **1470** |

## 4.5 Final Decision

The final decision is Planet Flag Poles as shown by the Delphi chart (see table 4-2). The solution with the highest total score was covered pole holders, and as such the team agreed that this will be the final design. This solution was inspired by Trevor, a client representative, team brainstorming and a tour of the school. The Planet Flag Poles will have relatively low cost, and ease of implementation while maximizing aesthetics, educational value, safety and durability. For a detailed description of the Planet Flag Poles solution, see section 3.8.

# 5 Final Design

## 5.1 Introduction

Section 5 reviews the specifications for the Planetary Scale Model final design. This section contains a complete description of the design along with analyses of cost, labor, and maintenance.

## 5.2 Description of Final Design

The design of the planet models are split into two groups: the inner four rock planets and the outer four gas planets. The model also includes markers to represent the planets painted on the ground as well as a plywood mural of the sun mounted to an external wall.

### 5.2.1 2D Markers

Each planet has a 2D marker painted onto the paved area of the campus, which are shown in Figure 5-2.. These markers are placed apart with the scaled distance between them. Each marker is scaled in size to its respective planet. Figure 5-1 shows an aerial map of Zane's campus with each marker location.


*Figure 5-1: Aerial view of 2D marker layout across Zane campus.*


*Figure 5-2: 2D markers of all eight planets.*

### 5.2.2 Rock Planets

The inners planets are much smaller, allowing them to be represented by truth spheres. Mercury and Mars are painted marbles, shown in Figure 5-5, while Earth and Venus are painted ping pong balls. Each of these spheres are attached to a 3 inch length of ¾ inch wooden dowel using a two part epoxy called PC7. This dowel is then inserted into the 3 ½ foot length of 1 inch PCV pipe and attached using PC7.Plans for these models can be seen in Figures 5-3 and 5-4. Each model is painted to represent their respective planet. The PCV poles and bases are painted black to represent space. Figure 5-6 shows the four rock planet models.

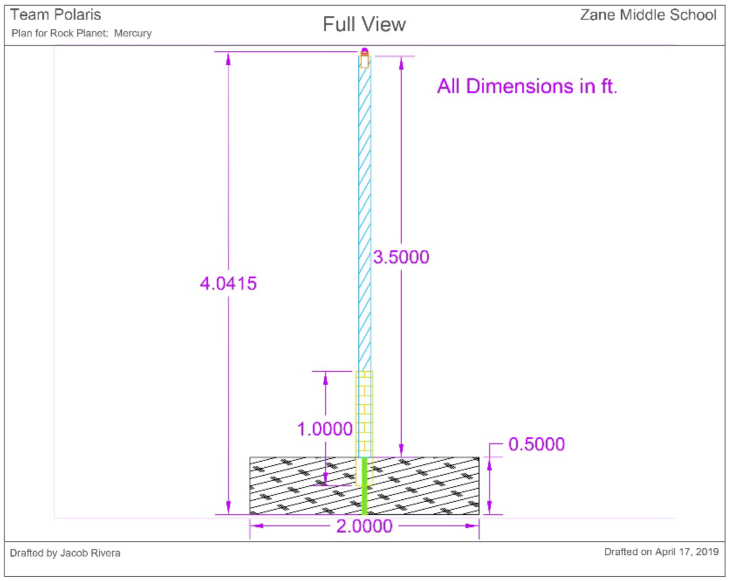


*Figure 5-3: Full view plan of rock planet model (Mercury model).*

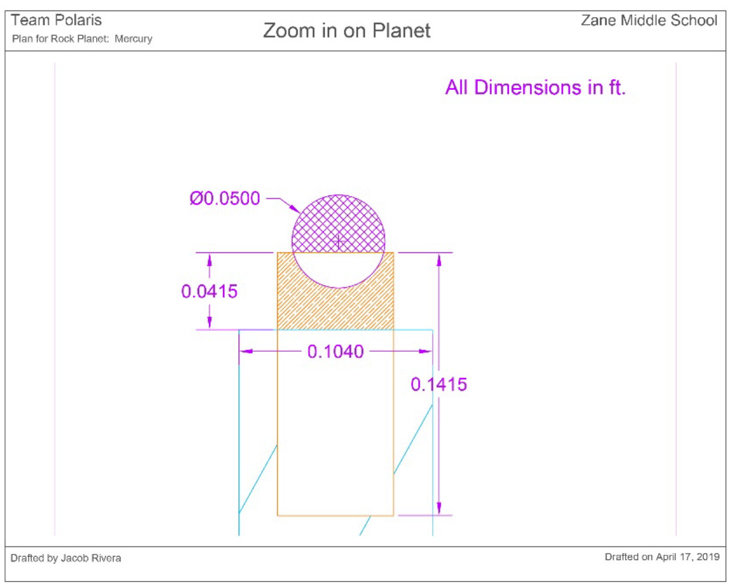


*Figure 5-4: Close up on rock planet model (Mercury model).*


*Figure 5-5: Close view of finished Mars model.*


*Figure 5-6: All four finished rock planet models.*

### 5.2.3 Gas Planets

The outer planets are too large to be true spheres mounted on the PCV pole. Instead they are constructed from two interlocking disks cut from ¼ inch plywood, making a pseudo sphere. The Neptune and Uranus models are small enough to have the two disks permanently adhered together using PC7. These pseudo spheres are also adhered to a 3 inch section of wooden dowel that has an X cut across one of the faces as to hold the bottom joined disks. This dowel segment is then inserted into the PCV pole as with the Inner planet models.

The larger Jupiter and Saturn pseudo spheres are not permanently adhered so that they can be collapsible and easy to stow away. This is demonstrated in Figure 5-8 with the Jupiter moodel. Only one disk is adhered to a 9 inch segment of dowel that has a 6 inch long section cut down its center. The remaining 3 inches are fixed into the PVC pole. Figure 5-7 shows the four gas planets models.


*Figure 5-7: All four finished gas planet model.*

*Figure 5-8: Jupiter model being assembled.*

### 5.2.4 Bases

A total of eight bases were produced. Each base is comprised of three separate piece: Base A, Base B, and the Holder. Both Base A and Base B are made from ½ inch plywood cut to 24 inches long and 5 inches high. As shown in Figure: 5-9, Base A has a ¾ inch long and 2 ¼ inch deep slot cut from the center of the bottom side of the plank. Two additional ½ inch wide by 2 inch deep slots are cut ¼ inch to the right and left of the center slot on the top side of the plank. Base B has identical slots, except all three are cut on the top side of the plank. Base A and Base B are assembled by aligning A perpendicular to B, and inserting the center slot of A into the center slot of B. The Holder is a 1 foot length of 1 ¼ inch PVC pole that gets inserted into the four open slots on the assembled Base A and B. This PVC Holder supports the planet poles. An example of a disassembled base is shown in Figure 5-10 and an example of an assembled base is shown in Figure 5-11.

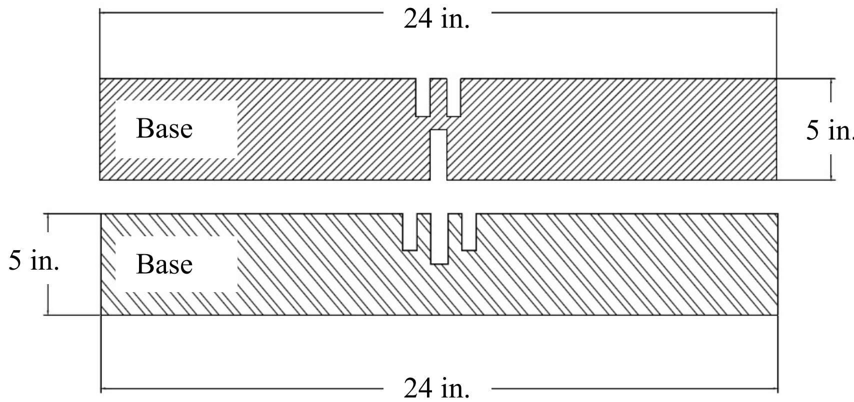


*Figure 5-9: Specifications for Base A and Base B.*

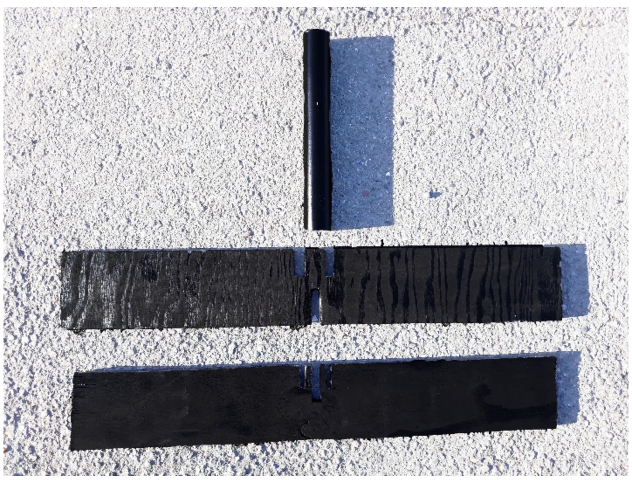

*Figure 5-10: Disassembled base.*

*Figure 5-11: Assembled base.*

### 5.2.5 Sun

The sun model is a mural painted onto ¼ inch plywood. Due to its large stature at this scale, the sun is a 12 foot wide, 6 foot tall half circle cut from four panels of 3 foot by 6 foot ¼ inch plywood. This mural is mounted onto a 2x4 frame that will be fixed to the external wall adjacent to classroom 13 on the west side of campus. The mural will be fixed to the wall by the grounds team at Zane as per a previous agreement. The original mock-up for the Sun's design is shown in Figure 5-12.

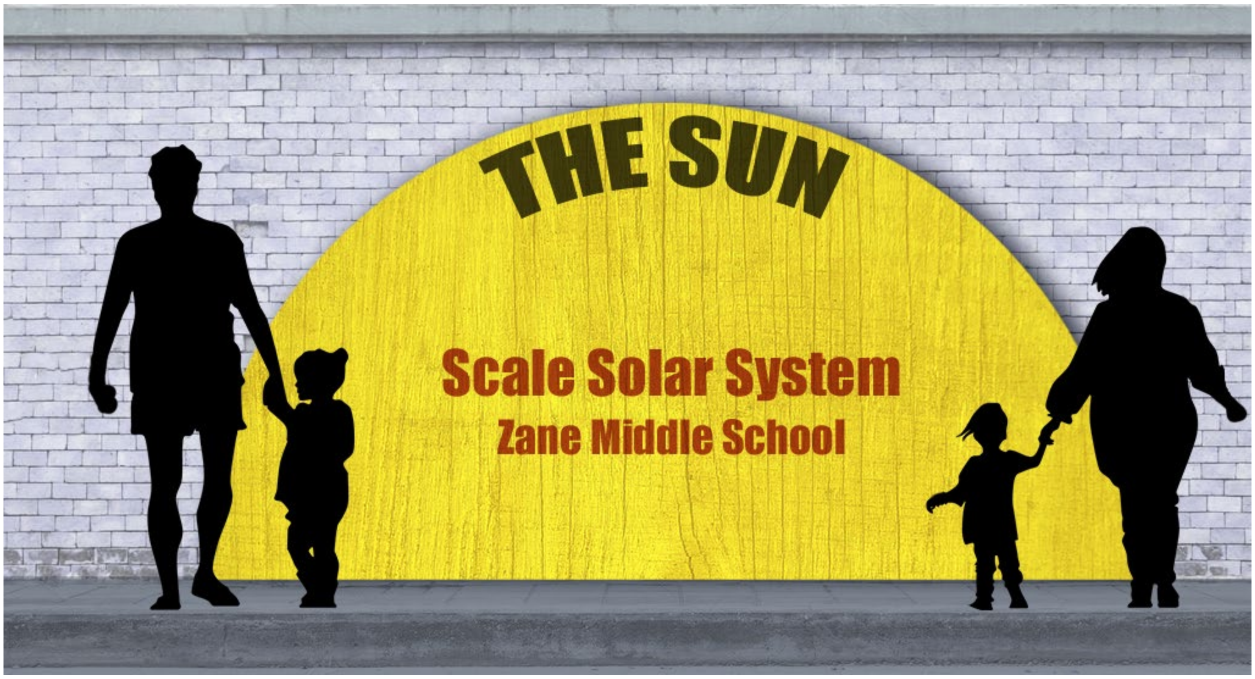


*Figure 5-12: Mock-up of Sun display.*

## 5.3 Cost Analysis

This section provides an analysis of the total cost of implementing this design at Zane Middle School. The cost is divided into total design hours, cost of implementation, and projected cost of maintenance.

### 5.3.1 Total Design Hours

A total of 180 human hours were spent through the course of this design. A majority of hours were spent on the construction of the models and implementation at the campus. A visual representation of the breakdown of design hours is shown in Figure 5-13.

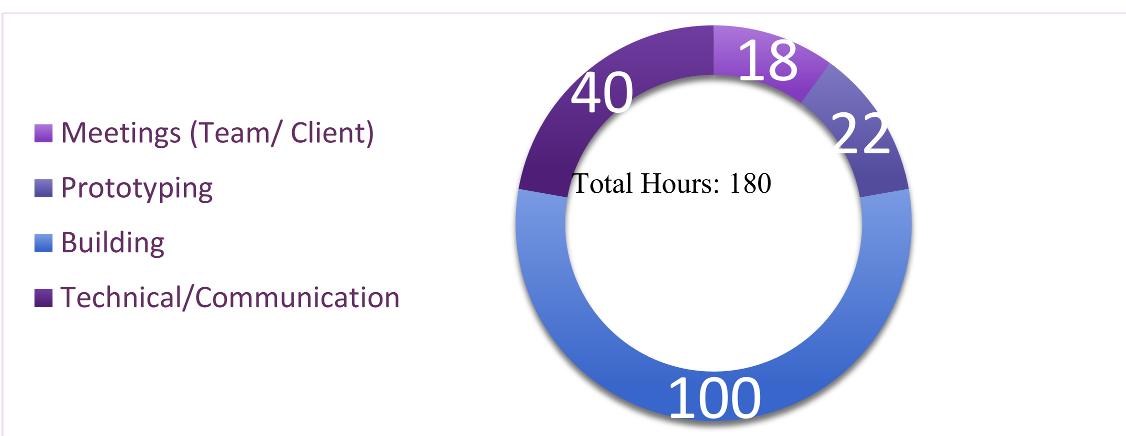


*Figure 5-13: Visual breakdown of total design hours.*

### 5.3.2 Cost of Construction

The total cost to implement the design was $320.24 not including tax. The total cost with tax was $371.94, which was under the $400 budget. An itemized breakdown of the materials and cost is shown below in Table 5-1.

*Table 5-1: Breakdown of all materials and capitol cost of implementing solar system model.*

| Material | Cost |
|---|---|
| Brushes | $6.84 |
| Bucket | $7.56 |
| Glue | $6.64 |
| KrudKutter | $14.99 |
| Masking Tape | $8.72 |
| Paint | $105.94 |
| PC7 Epoxy | $13.28 |
| Plywood | $102.51 |
| Poster Board | $8.94 |
| PVC | $14.46 |
| Sandpaper | $4.74 |
| Screws | $3.70 |
| Spraypaint | $16.23 |
| Wooden Dowel | $5.69 |
| Total | $320.24 |

### 5.3.3 Maintenance Cost

The maintenance required for this design is very minimal resulting in a low upkeep. The 3D models will be used 1 to 2 days out of the year. The paint on the 2D and 3D models will degrade over time. Total cost and hours of maintenance for this design is $20 every five years.

## 5.4 Prototyping

Before the final decision was made to pursue the Planet Flag Pole design, a prototype for a locking cover for the Covered Flag Pole design was made. This prototype was presented to the client and feedback about the cost and implementaion of this design helped guide the final decision away from from the Covered Flag Poles. Images of this prototype can be seen in figures 5-14 through 5-16.

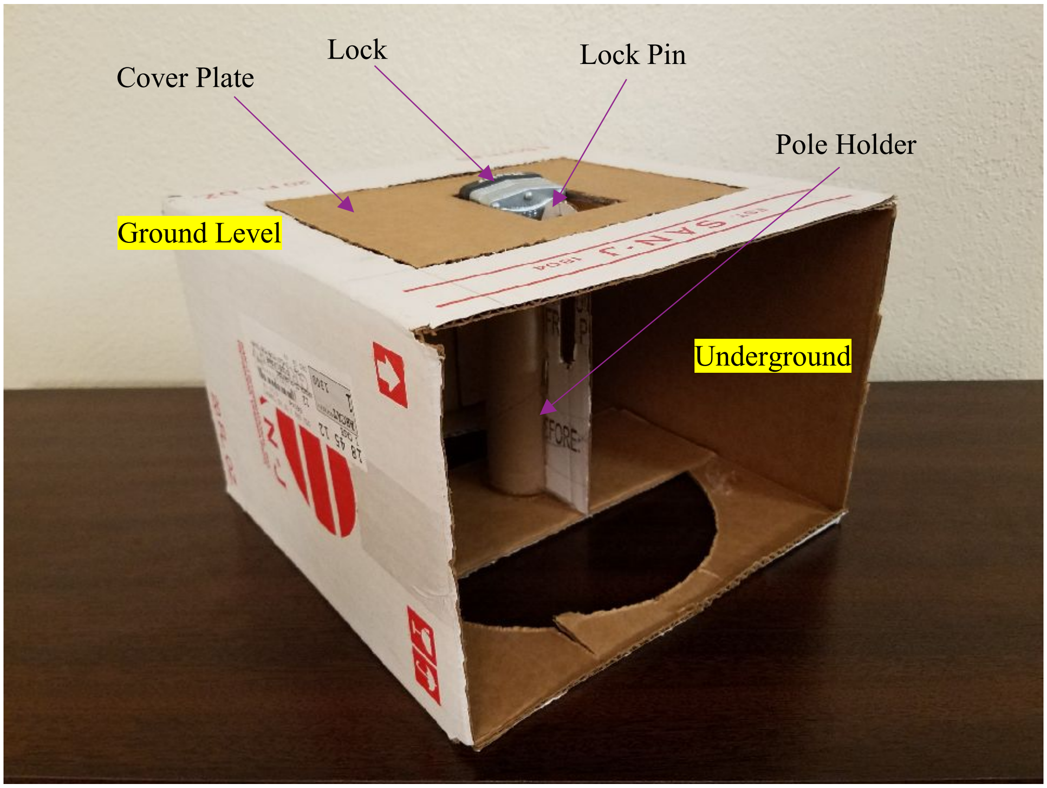


*Figure 5-14: Original prototype of Covered Flag Pole design.*


*Figure 5-15: Top view of Covered Flag Pole prototype.*

*Figure 5-16: Inside view of Covered Flag Pole prototype.*

Once the Planet Flag Poles design was decided upon, a prototype of Mercury and Jupiter were constructed. These prototypes are shown in figures 5-17 through 5-20. These prototypes were shown to the client and were approved. Feedback was given and all aspects of the model were carried through to the final design except for the height of the poles. They were reduced from 5 feet to 3 ½ feet for the final design.

*Figure 5-17: Full view of Mercury model prototype.*

*Figure 5-18: Close view of Mercury model prototype.*

*Figure 5-20: Full view of Jupiter model prototype.*

*Figure 5-19: Close view of Jupiter model prototype.*

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# 7 Appendix

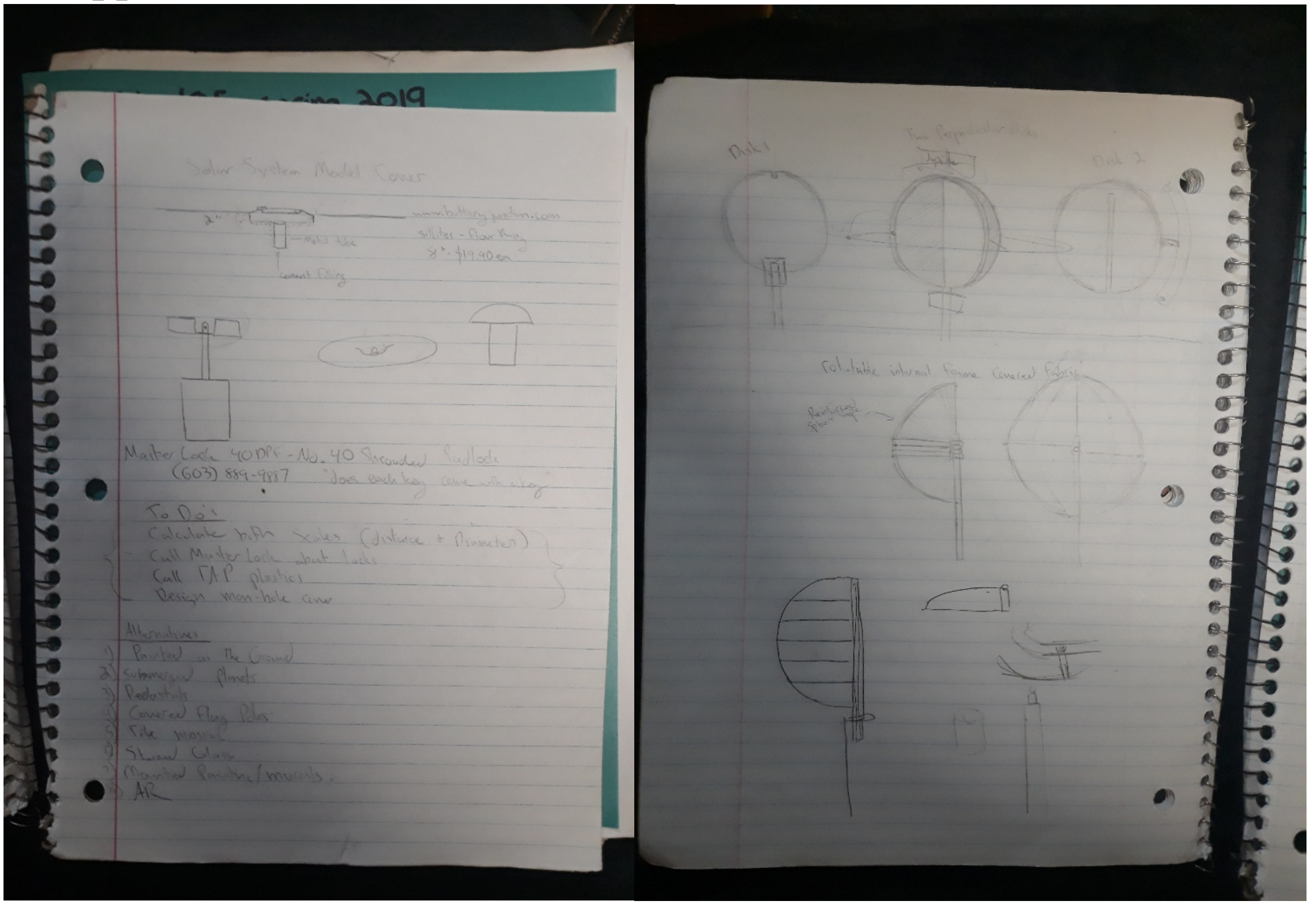

*Figure 7-1: Initial brainstorming about Alternatives and 3D models.*

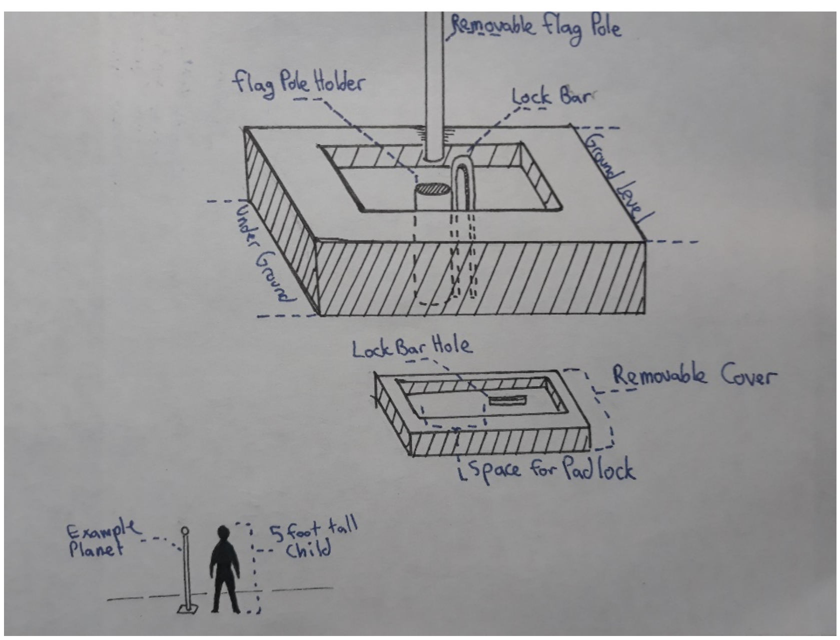


*Figure 7-2: Initial sketch of Covered Flag Pole Design.*

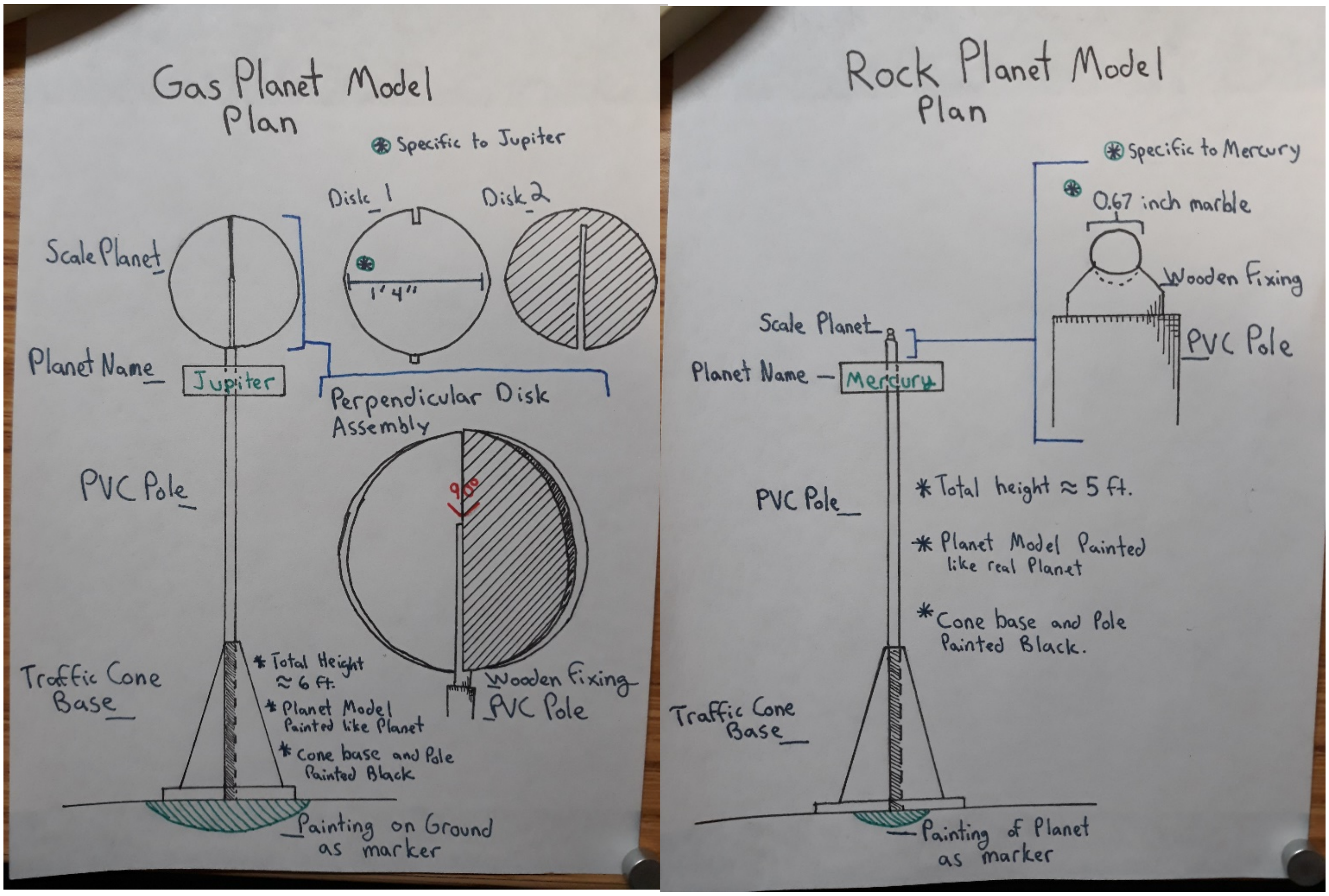


*Figure 7-3: Initial sketches of Planet Flag Pole design for both Gas and Rock models.*

*Figure 7-4: Picture of final 3D models with client representative Jeanne Wilhem.*