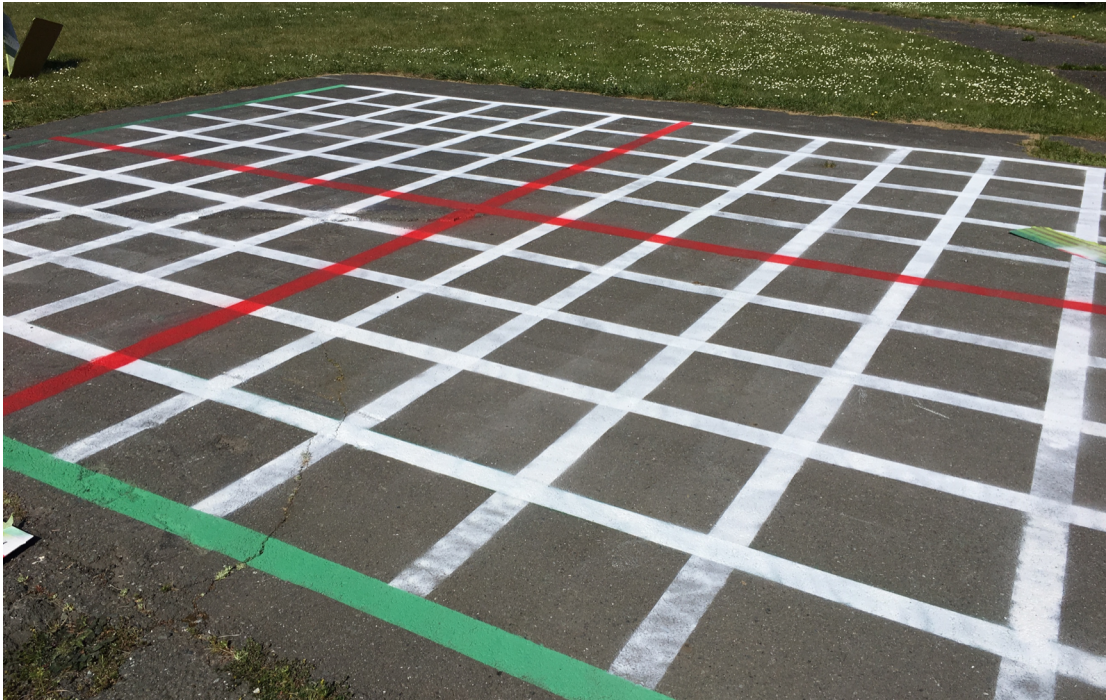


THE BLUE NOTES: OUTDOOR MATH LEARNING SPACE

ENGR215 – Spring 2018



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1 Problem Formulation

1.1 Introduction

Section 1 of this report covers the background of the project, the objective statement, and black box diagram formulated by the Blue Notes design team in phase 1 of the project.

1.2 Background

The Outdoor Math Learning Space is an activity space meant to provide the students of Catherine L. Zane Middle School an interactive space to participate in math based, physically engaging exercises. The client representative advising the Blue Notes on the project was Elizabeth Baker, a math teacher at Zane. Mrs. Baker engages students in many innovative, math-based activities, and is looking for an activity that can get the class outside more often. Only one outside math activity is in use at the time, but is difficult to set up, and so is rarely used. Mrs. Baker is interested in a better, more easily set-up activity for the math classes at Zane Middle School.

1.3 Objective

The objective of the project is to design an outdoor learning space that engages students kinetically and intuitively with mathematics. Figure 1-1 below shows the black box model, which symbolizes what we hope to achieve by completing this project.



Figure 1-1: The black box model symbolically represents the intended goals of the project

2 Problem Analysis and Literature Review

2.1 Introduction to Problem Analysis

The problem analysis lists the specifications given for the project, and discusses considerations made while developing the designs. This section also contains a table of criteria to be considered when making design decisions. The problem analysis also details estimates of yearly usage and production volume involved in the project.

2.1.1 Specifications

The specifications for the Outdoor Math Learning/Activity space were made with input from the client contact, Elizabeth Baker, and must be met in order to satisfy the needs of the school. The specifications for this project are listed below.

- The space will be made for the use of math classes in grades 6 through 8
- The space must accommodate 35 students plus the teacher, including students participating and students in observation “stations” surrounding the activity space
- The observations stations must be facing away from the classroom building to prevent students from being distracted
- The coordinate plane should have twelve points on each axis (six positive and six negative)
- The coordinate plane, number line, and grid must have enough space between marked points for students to stand comfortable
- The client would also like a podium for the teacher, that must be on wheels and with some form of storage

2.1.2 Considerations

The considerations for the project provide additional context that is useful for the design process. Considerations for the Outdoor Math Learning Space were developed together by Team Blue Notes and Beth Baker. The primary consideration for this project is to create an outdoor learning environment for students from 6th to 8th grade. Students must have space in order to be productive. This project should ideally make use of the ample available space outside the math and art classrooms. Creating a learning space that is versatile is very important to the client, and having elements that can be used for more than just the math class would be ideal.

2.1.3 Criteria and Constraints

The criteria and constraints are important when considering the final design. The criteria are weighted and used to make decisions about the design, while constraints are parameters that limit the criteria. Table 2-1 shows the criteria and constraints of this project.

Table 2-1: The criteria and constraints table, with corresponding weights for each criterion.

Criteria	Weight	Constraints
Cost	4	Lower cost is better, maximum spending (not including donations) is \$200
Accessibility	7	More space for students to participate in activities is better. Space for at least 35 students, including observing students.
Durability	8	Must not be destroyed by middle school students.
Safety	9	Must not cause harm in any way to students.
Portability	7	The podium section must be able to move smoothly on the asphalt around the activity space.

Flexibility	6	More possible uses for a feature in the space is better. There must be at least a coordinate plane.
Environmental Impact	4	More environmentally innocuous is better. Must not impose immediate threat to the environment.

2.1.4 Usage

The outdoor math learning space is used during the one hour class periods, two times a week. The interactive components of the learning space allow at least twelve students to participate in desired activities. The spectator portion, that provides ease of access for students to rotate between the spectator area and the participation slots, provides a designated area for the onlookers to watch. There will be around thirty-two students in each class, including those participating in the activity and observers. The portable desk is equipped with storage space to facilitate any detachable figures and it is brought from the indoor classroom to the outdoor learning space.

2.1.5 Production Volume

The outdoor math learning space allows at least twelve students to participate and it provides a large enough area for the rest of the class to comfortably witness the activities with enough space between them to prevent them distracting one another from the lesson. The facility will include a coordinate plane, two circles, a figure projection area, and a number line.

2.2 Introduction to the Literature Review

The literature review contains all of the information gathered during the research phase of the project. A wide array of related topics was researched and relevant information is described here.

2.2.1 Teaching Styles

There are many different reasons for invoking teaching styles other than the conventional approach where students are taught through reading assignments, example problems worked out by a teacher, and the completion of take home assignments. The purpose of this literature review is to present information about kinesthetic and interactive learning styles pertaining to the outdoor math classroom that the Blue notes will be designing for Zane Middle School.

2.2.1.1 *Kinesthetic and Interactive Teaching Styles*

The Blue Notes plan to deliver an interactive outdoor math classroom to Catherine Zane Middle School. In order to do that the blue notes must establish what about interactive outdoor classrooms causes success. Interactive and kinesthetic teaching styles are executed in a manner that allows students to receive information through physical, audio, and visual engaging methods. By engaging in physical activities, students activate skill sets that enhance problem solving abilities because we “retain ninety percent of what we see, hear and do,” according to Jennifer Weilchel’s article, “*What’s Their Learning Style? Part Two: Kinesthetic Learners*” (Weilchel 2016). Andrea Honigsfeld and Rita Dunn say in their piece, *Learning-Style Responsive Approaches for Teaching Typically Performing and At-Risk Adolescents*, that Kinesthetic lessons enhance problem solving skills because “learners’ strongest perceptual

modalities are in the kinesthetic” area (Dunn and Honigsfeld 2009). In conclusion, information delivered through kinesthetic learning styles invoke skills that allow higher retention rates.

2.2.1.2 Consequences of Kinesthetic and Interactive Teaching Styles

Kinesthetic teaching styles improve retention amongst some but others fall behind due to unforeseen disadvantages. In Dena O. Lister’s article, *Effects of Traditional Versus Tactual and Kinesthetic Learning-Style Responsive Instructional Strategies on Bermudian Learning-Support Sixth- Grade Students’ Social Studies Achievement and Attitude-Test Scores*, she explains how kinesthetic teaching styles improve retention amongst students who fall under the categories: Regular Education Students (RED), Learning Support Students (LSS), Higher Achieving (HA), and students with learning disabilities. Lister later mentions “while retention amongst the different categories improved, LSS students and students with learning disabilities were described as less persistent and motivated when compared with HA and RED students because they wanted more supervision from authoritative figures” (Lister 2005). Students apart of the RED group are at a disadvantage because kinesthetic learning styles are distracting to students who benefit in traditional classroom because they are no longer stationary and are therefore susceptible to distractions that were non-existent in the classroom. Students who may have a hard time integrating into kinesthetic teaching styles are students who are uncomfortable interacting with each other and students who become distracted easily. The students who benefit from the outdoor classroom and kinesthetic learning styles build rapport with teachers through the activities because their interest is sparked and they can become infatuated with the planned lessons.

2.2.2 Mathematics

Mathematics is the use of numbers and formulas to solve problems around the world. Mathematics is needed for everyday use. For example, mathematics shows how, where, and why money is used around the world, therefore it is imperative that students understand mathematics as best as possible. To ensure students retain mathematics lessons teachers and faculty alike must develop teaching styles to ensure students understand mathematics because, “Mathematics climbs the ladder of abstraction to see, from sufficient height, common patterns in seemingly different things. Abstraction is what gives mathematics its power; it is what enables methods derived from one context to be applied in others” (Steen 2001).

2.2.2.1 Algebra

Algebra is the branch of mathematics that deals with utilizing letters to represent numbers. Algebra also deals with improper fractions. Fractions can be converted to decimals.

$$2 \frac{3}{4} = \frac{11}{4}$$

Figure 2-1: Conversion of a fraction (Brennan)

2.2.2.2 **Graphs**

Graphing provides a meaningful opportunity for children to represent and communicate important mathematical relationships (Larson). Graphs allow people to visualize functions and plot mathematical relationships. By having input values as (x), the output will be (y) giving a point on a Cartesian graph.

Table 2-2: Basic Point for $y = 2x - 1$ graph

x (Input)	$x \rightarrow \text{FORMULA} \rightarrow y$	y (Output)
-2	$2(-2) - 1 = -5$	-5
-1	$2(-1) - 1 = -3$	-3
0	$2(0) - 1 = -1$	-1
1	$2(1) - 1 = 1$	1
2	$2(2) - 1 = 3$	3

We say that y is a function of x because if you choose any value for x , this formula will give you a unique value of y (Brennan). Graphs are about input and outputs. The function's graph helps find the intersecting points on the x and y axis. Graphs allows people to find intersecting points from two different lines if they cross. Table 1 explains how x values have outputs of y . the inputs and outputs are used to create the graph on corresponding to the x -axis and y -axis.

2.2.2.3 **Geometry**

A branch of mathematics concerned with relations of lines, planes, surfaces and solids. With geometry measuring the circumference of a ball is possible. Shapes and area are important for building. Finding complementary and supplementary angles. Complementary angles are angles that add up to 90 degrees. Supplementary are angles that add up to 180 degrees. Geometry can find similar angles by having parallel planes between the angle.

2.2.2.4 **Eratosthenes**

Eratosthenes made the first measurement of the earth circumference. By finding similar buildings straight under the sun, he could find the length of the shadow of the two buildings. This allowed him to figure out the height of the sun in a certain place. He found the distance between two places and used geometry to find an angle.

2.2.2.5 **Proportional Reasoning**

Proportional reasoning is a mathematical reasoning that involved a sense of multiple comparisons while processing information about the items being used. By using facts and angles, the distances between standing objects can be found. In the figure below the trees height is found by similarities of triangles. Similarities of triangles is used when there is a common angle, therefore a ratio is possible.

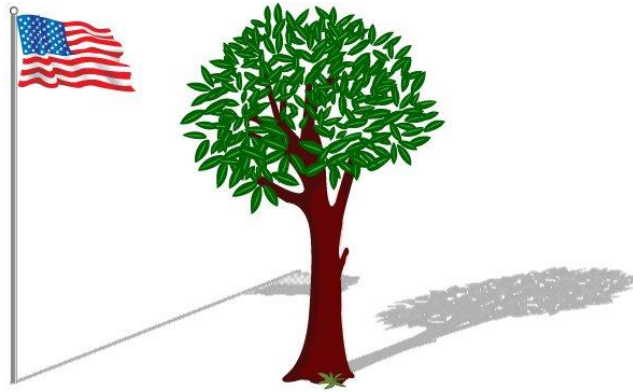


Figure 2-2: Proportional reasoning example (Carbone n.d.)

2.2.3 Building Material

2.2.3.1 Polyvinyl Chloride (PVC)

Polyvinyl Chloride pipes are used around the world for plumbing, they are used to transfer water from the main pipe to the place of the installation. PVC pipes are long lasting in natural environments. The Polyvinyl are exposable after the long-term use. They are safe to recycle. Pipes are not the only use of Polyvinyl chloride, is also used as plastic that is flexible.

2.2.3.2 Wood

Wood is a great resource that comes from trees. Different types of wood are used for different purposes. This is determined on how the wood is cut. There is wood used to build, detailing wood, fire wood, and etc. For building houses, the most common wood is 2'x4'.

2.2.4 Client Interview

The client contact, Beth Baker, is a math teacher at Zane Middle School. She was interviewed on February 17th, 2018 to get information and specifications needed in the design process of the Outdoor Math Learning Space. This section will convey the information gleaned during that interview.

2.2.4.1 Client Specifications

The client asked that any non-permanent installations for the space be easily portable. The client also asked that on any permanent coordinate plane, circles, or number lines, there be enough space so that students can stand comfortably shoulder to shoulder. The client also asked that there be designated marked areas for students who are not participating in the activity to stand and observe. These observations areas have to be far enough apart so that students won't be tempted to distract each other. The client also requested some form of podium or teaching desk that is portable and has some storage in it (Beth Baker, personal communication, February 17, 2018).

2.2.4.2 Existing Outdoor Math Activity at Zane

Currently, the math classes at Zane Middle School rarely participate in outdoor math activities. The activity that the math class has access to is only brought out twice a year because it is

cumbersome and time-consuming for the teacher to set up. It is a coordinate plane set up on two ropes with laminated cards attached, which can be seen in Figure 3. The client informed us that this system is not only difficult to set up, because it gets tangled in storage, but difficult to adapt to different scales (Beth Baker, personal communication, February 17, 2018).



Figure 2-3: Current outdoor math activity at Zane (R. Turlington, unpublished photos, February 2018)

2.2.4.3 The Space

The space that was shown to us by the client contact Beth Baker is an unused parking lot and some sections of grass behind the Zane Middle School math and art classes, which can be seen in Figure 4. In addition to this there is an unused portion of the exterior wall of the math classroom that is available as well. This section is covered by an awning (which can be seen in Figure 5), so that it is protected from the rain and sun.



Figure 2-4: Space Available at Zane Middle School (R. Turlington, unpublished photos, February 20



Figure 2-5: Available wall outside of math classroom (R. Turlington, unpublished photos, February 2018)

2.2.5 Paint

Paint is the most important material to look at when considering this project. There are environmental and health concerns that must be considered where paint is concerned. There are two categories of paint, water-based, and oil-based and there are four components common to both types of paint. Solvents keep the paint liquid until it dries. Binders make up the outer coating of the paint after it dries, and differ depending on the type paint (oil- or water-based). Pigments add color as well as opacity to the paint. The final component in paints are additives, which are meant to enhance the paints performance but can be toxic and contribute to volatile organic compounds (VOCs) in the air (Marinelli 1995). The make-up of the paint, and the

presence chemicals harmful to the environment or health of students is important when looking in to how we pick the paint to use in the project. Most paints will not adhere to asphalt at all. For this reason, there are a narrower set of options for painting asphalt. There are chlorinated rubber paints, which are very durable and hold up well in colder climates, but are more expensive than the other options. There are solvent paints that contain alkyd binders, which also hold up well in cold conditions, but may bleed if the asphalt has been treated with coal tar emulsion. There are also latex paints, which don't dry as quickly under wet conditions. Typical water-based paints will last for between 1 and 2 years (Thompson 2004).

2.2.6 Examples of Outdoor Math Activities

There are many examples of outdoor math activities on the internet. For middle school activities, this mostly involves coordinate planes and trigonometry. Figures 6 and 7 shows an example of the concept of Pi, and how it might be demonstrated in an outdoor setting. The circumference of a 1 unit in diameter circle is equal to Pi units, so this can be easily shown by marking a 1 ft or 10 ft in diameter circle on the ground and then using a string marked at every 1 or 10 ft can be lead around the circumference of the circle a little over three times (Pierce 2017). Figure 8 shows a trigonometry based outdoor math activity. This one allows for students to find the height of a tall structure or object by measuring its shadow, and then measuring the height and length of the shadow of a student, or fence post and then comparing the measurements using the idea that they are creating similar triangles, since the angle of the sun is the same hitting both the large and smaller object (Mathspig 2014).

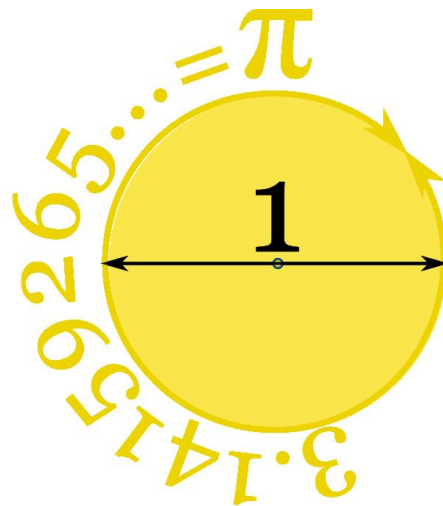


Figure 2-6: A circle 1 unit in diameter (Pierce 2017)

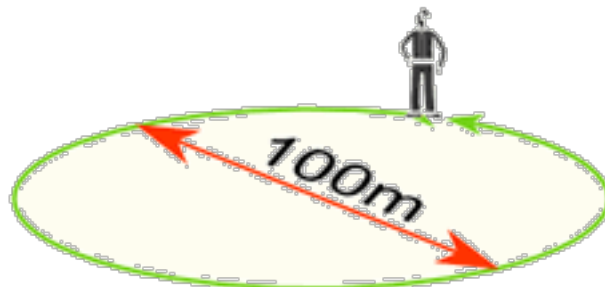


Figure 2-7: A figure on a 100m diameter circle (Pierce 2017)

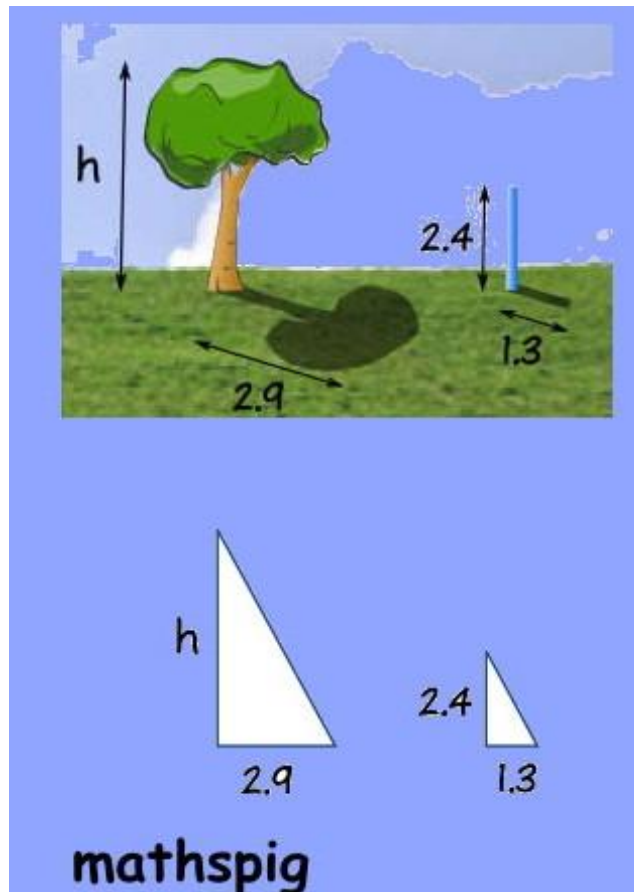


Figure 2-8: Using similar triangles to find the height of a tree (Mathspig 2014)

3 Alternative Solutions

3.1 Introduction

Alternative Solutions contains narrative details of two brainstorming sessions held by Team Blue Notes, on March 1st and March 2nd, 2018. Also included are the nine alternative solutions for the Outdoor Math Learning Space that were generated during those brainstorming sessions.

3.2 Brainstorming

The Blue Notes separated the brainstorming into two separate sessions. On March 1st, 2018, we held a structured brainstorming session. We filled a white board with ideas related to each aspect of the learning space. The end result of this brainstorming session can be seen below in Figures 3-1 through 3-5. On March 2nd, 2018, we followed up the structured session with an unstructured brainstorm. We started with a structured brainstorm because we felt we already had a foundation to jump off from, so we held our unstructured session the next to do allow for a completely open forum in which to throw out ideas. This, too, generated ideas that informed our synthesis of alternative solutions. The results of this, shorter session can be seen in Figures 3-6 and 3-7.

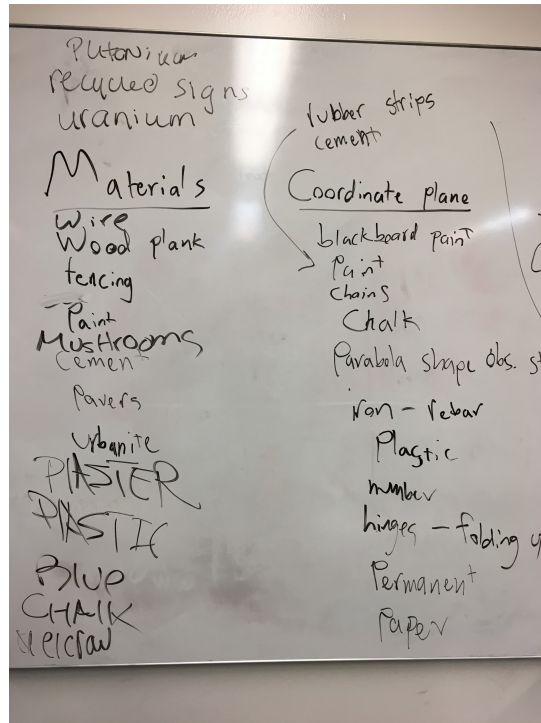


Figure 3-1: Results of Structured Brainstorm Part 1 (R. Turlington, unpublished photos, March 2018)

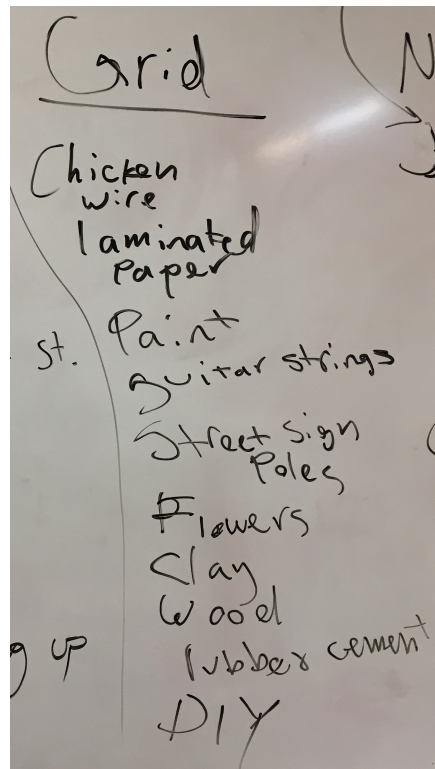


Figure 3-2: Results of Structured Brainstorm Part 2 (R. Turlington, unpublished photos, March 2018)

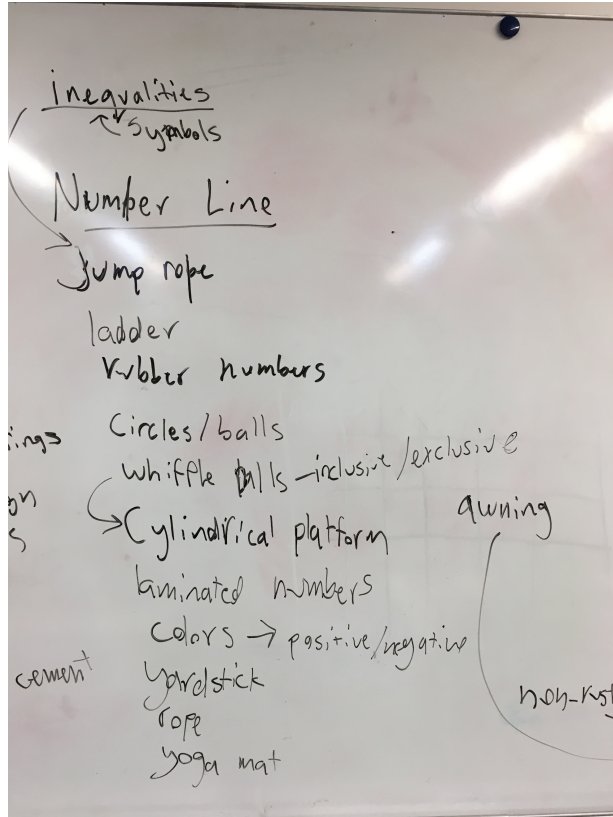


Figure 3-3: Results of Structured Brainstorm Part 3 (R. Turlington, unpublished photos, March 2018)

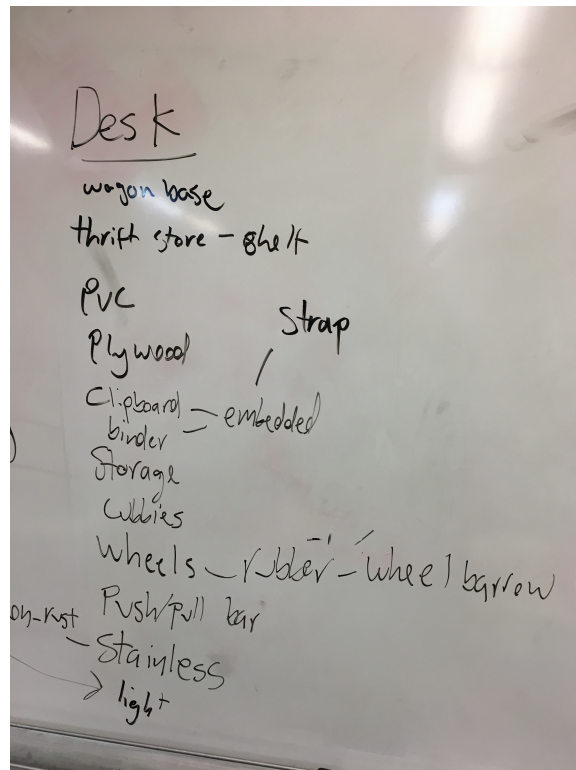


Figure 3-4: Results of Structured Brainstorming Part 4 (R. Turlington, unpublished photos, March 2018)

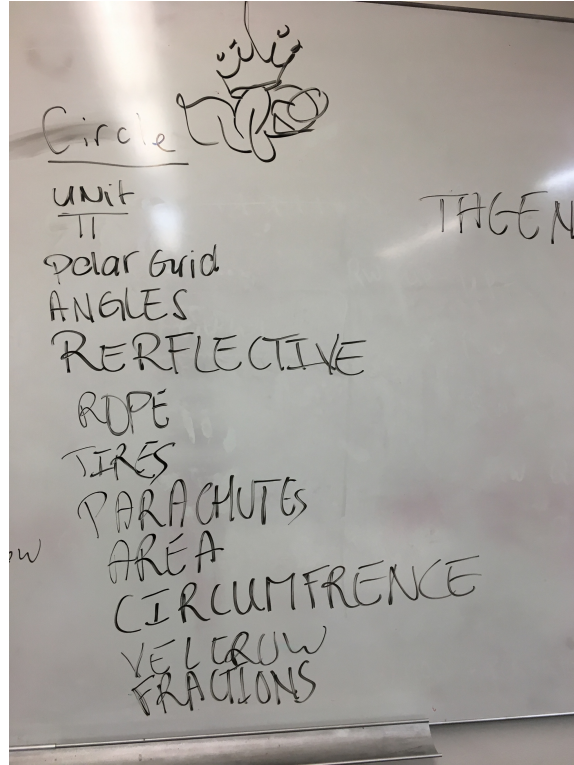


Figure 3-5: Results of Structured Brainstorming Part 5 (R. Turlington, unpublished photos, March 2018)

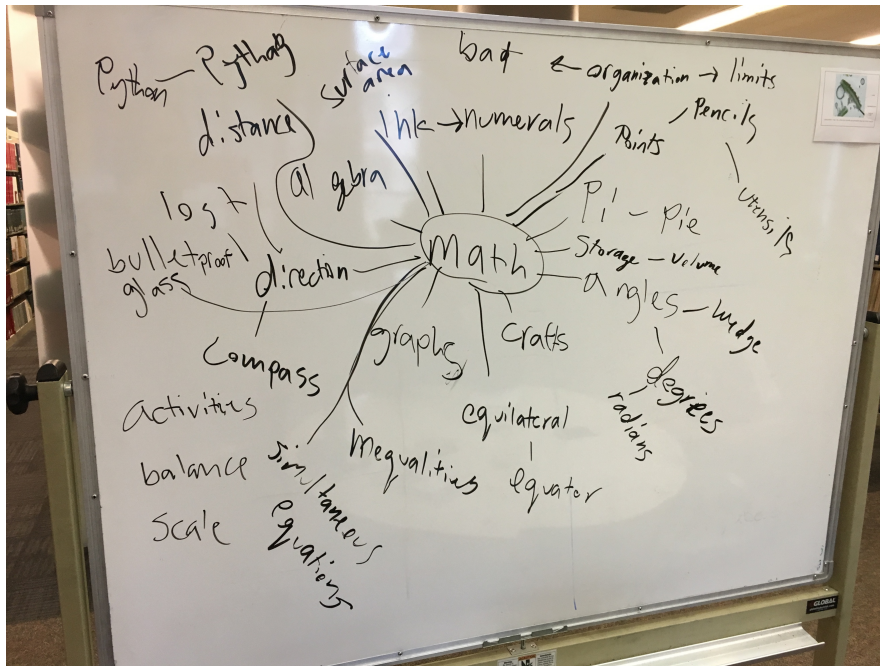


Figure 3-6: Results of Unstructured Brainstorm Part 1 (R. Turlington, unpublished photos, March 2018)

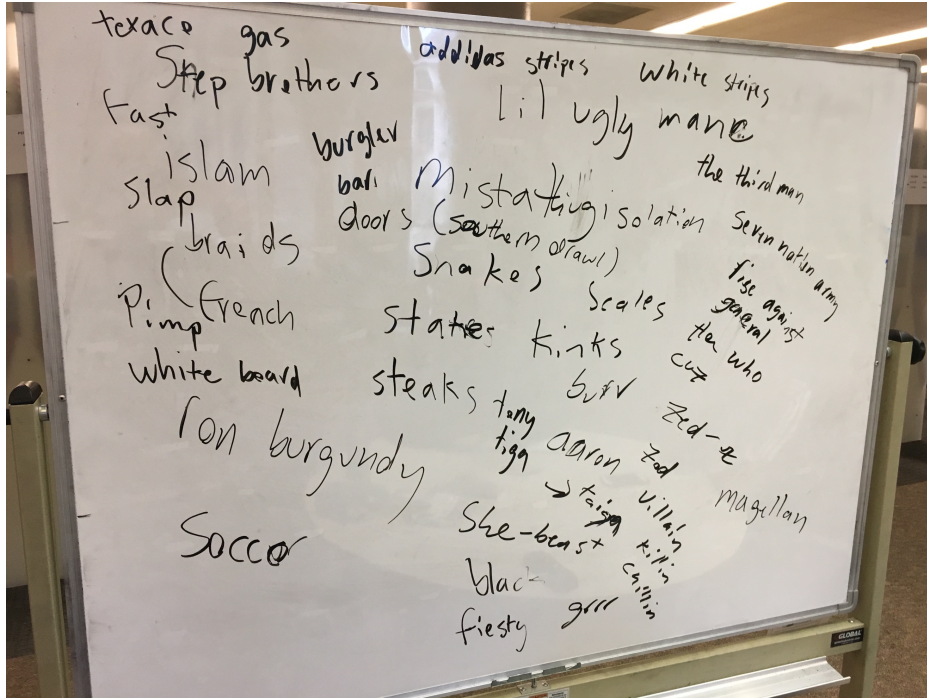


Figure 3-7: Results of Unstructured Brainstorming Part 2 (R. Turlington, unpublished photos, March 2018)

3.3 Alternative Solutions

There are nine solutions contained in the following section. Each one was created after two brainstorming sessions. Each solution is accompanied by a sketch, done by hand or on a computer. In addition, each solution will include at least a coordinate plane, a number line, and a portable podium for the client to teach from. The following solutions detail various methods for creating those three features, as well as other possible elements to be added.

3.3.1 Painted Activity Spaces

The Painted Activity Spaces include a coordinate plane, with six positive and six negative marked points on each axis, painted in the asphalt parking lot outside of the math classroom at Zane Middle School. This coordinate plane, which can be seen in Figure 3-8, is painted in between the grassy area and the concrete immediately outside the art classroom. To the right of this is a painted, 12x12 grid. Between the grid and the grassy area is a number line, 13 spaces across. To the right of both the grid and number line there are two circles painted onto the asphalt. One is marked with a diameter of 1 meter, and with the number Pi painted into the edge of the circumference. The other circle is larger than 1 meter diameter and is left unmarked. There are twelve marked squares that indicate a space for pairs of observing students to stand these squares will be as spread out as allowed by the space. The squares are at least 1 meter apart. For each marked “point” on the coordinate plane, as well as the edge of the grid, and the number line, a small box is painted so that different numbers can be marked in chalk. This allows the scale of these features to be changed to accommodate different functions that are being plotted. This solution can be completed for less than \$200 or even \$100, depending on the cost of the podium.

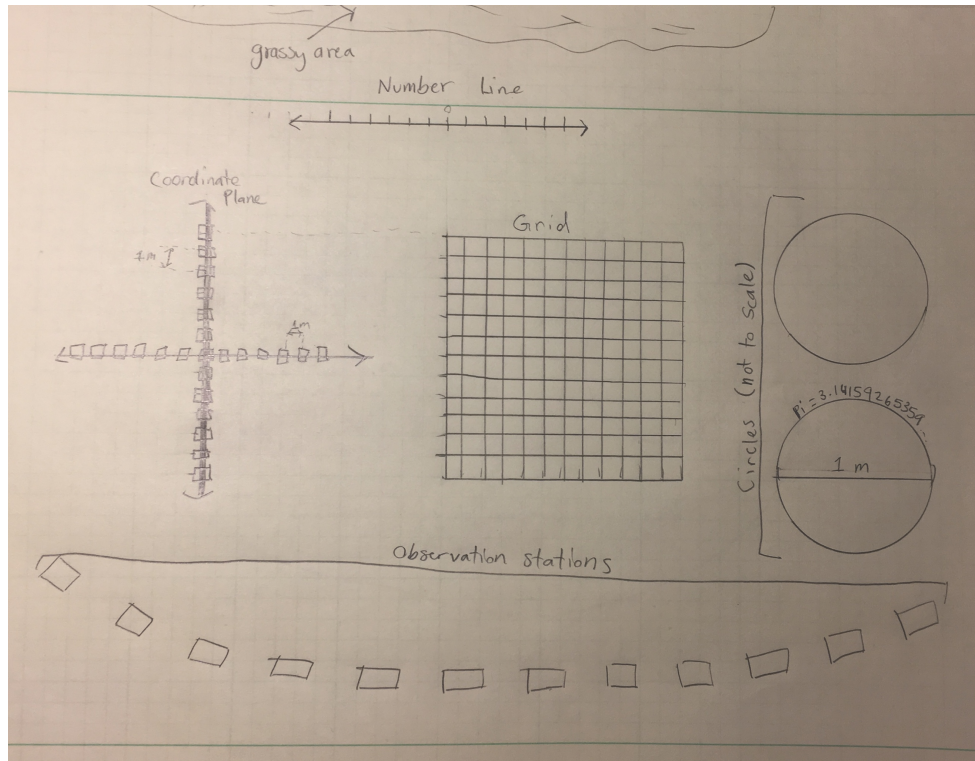


Figure 3-8: Sketch of the Painted Outdoor Learning Space (R. Turlington, unpublished drawings, March 2018)

3.3.2 Portable PVC with Hinges

The Portable PVC with Hinges design includes a coordinate plane, including gridlines, created with pieces of PVC pipe that are attached to a central axis, made of whole PVC pipe. This coordinate grid has 3 hinges along the X-axis, and folds in half so that it may be stored, which is illustrated in Figure 3-9. The points in this grid are painted onto the PVC axis at the center. There is also a number line, made from 3 pieces of PVC pipe that are cut in half and hinged at the two joints between PVC pipes. This number line is also painted with numbers, and can fold for storage. These features may be placed in the grassy area, or on the asphalt. This design will use 2" and 1" PVC pipe.

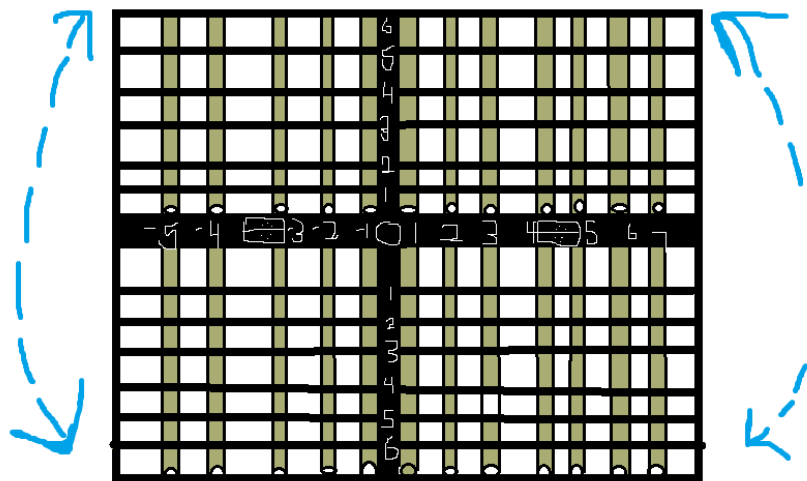


Figure 3-9: Drawing of a Portable PVC Coordinate Grid (I. Duque, unpublished drawings, March 2018)

3.3.3 Semi-permanent Lawn Installation

A circle is laid out in rope in the grassy area outside of the math classroom. The rope is staked into the ground with metal stakes, or croquet wickets, which are noted in the sketch in Figure 3-10. There are at least eight stakes holding down the rope circle. Next to the roped circle, there is also a 12x12 grid made with staked in rope. The grid will have stakes at each intersection of gridlines. A number line is also laid out in rope and staked into the ground. This is a very cheap solution, and can surely be completed for under \$100, including the cost of the teaching podium.

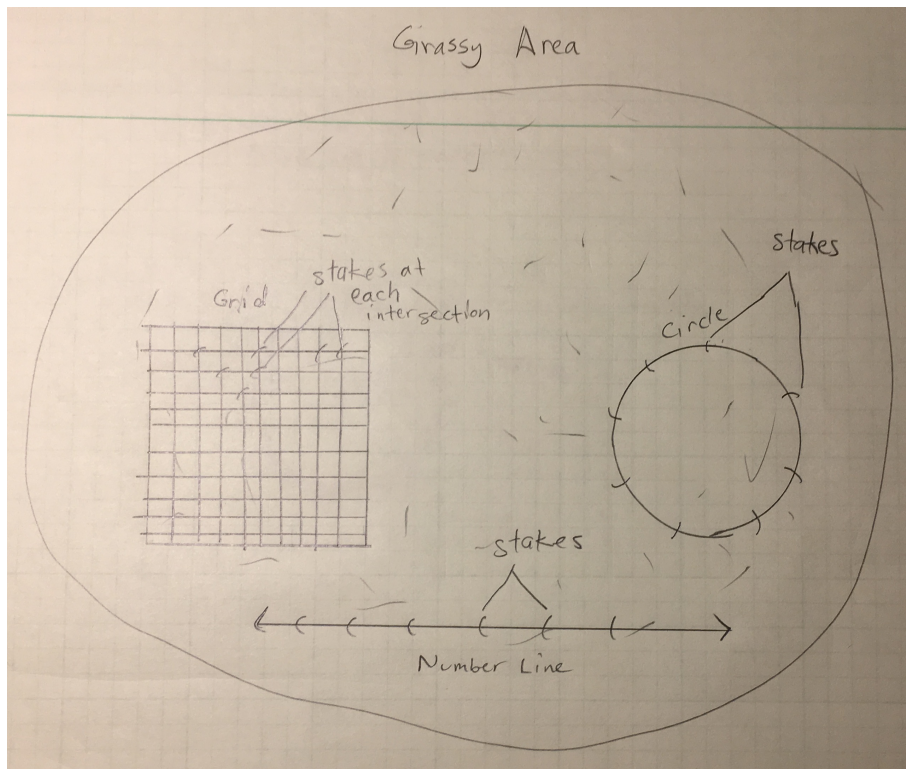


Figure 3-10: Sketch of the lawn installation (R. Turlington, unpublished drawings, March 2018)

3.3.4 Portable Graph Connected to Podium

The portable teaching podium has four wood veneer panels attached at the base. These panels mark the axis lines of the coordinate plane, and can be seen in Figure 3-11. The veneer panels will be hinged in two places so that they fold up and may be stored on the side of the teaching podium. The podium has two wheels on one side of its base, and two pegs on the other side working as stands. On the top of the podium there is a handle, so that it may be pulled or pushed around on the wheels. The veneer panels will have numbers painted onto them, with six spots on each half-axis.

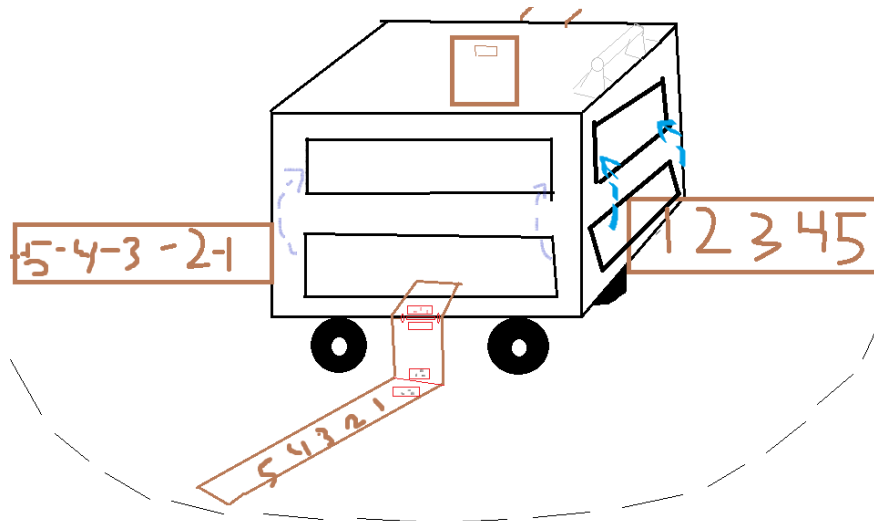


Figure 3-11: Drawing of the Coordinate Plane attached to the Podium (I. Duque, unpublished drawings, March 2018)

3.3.5 Folding Portable Grid

A wooden frame, large enough to encompass a 12x12 grid, is hinged at the center, so that it may fold in half. The open view of this grid may be seen in Figure 3-12, and the closed view is visible in Figure 3-13. On top of the frame is a grid made of halved PVC pipes laid vertically. Laid on top of the PVC horizontally are pool noodles that are cut at each PVC pipe so that they lie flat on top.

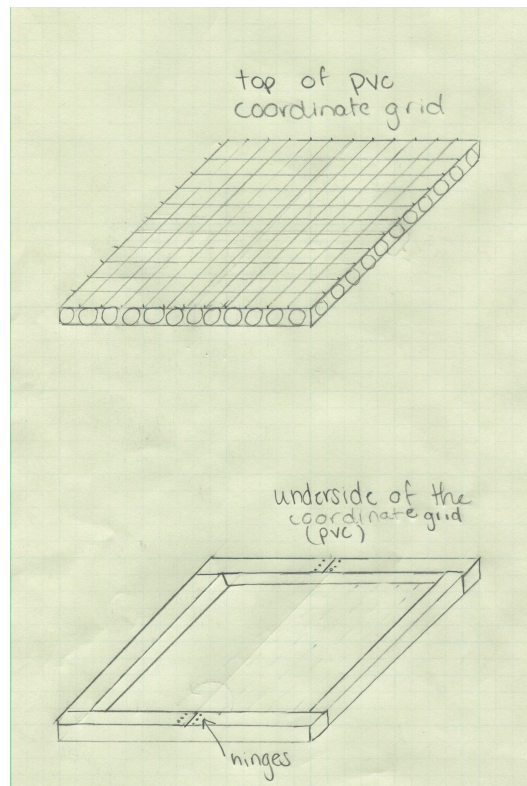


Figure 3-12: Sketch of the frame of the collapsible grid (J. Reid, unpublished drawings, March 2018)

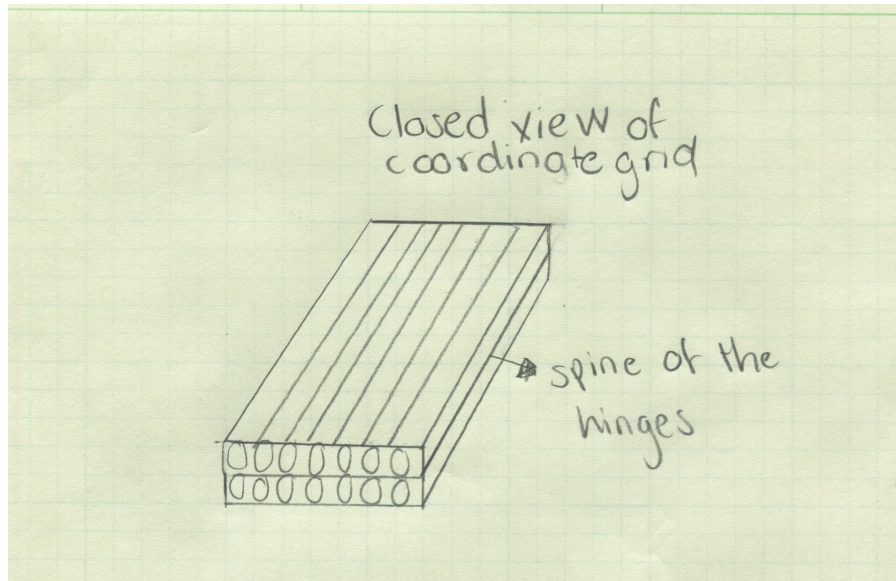


Figure 3-13: Sketch of the collapsed grid (J. Reid, unpublished drawings, March 2018)

3.3.6 Repurposed Shelf/Chest of Drawers for Podium

A shelf, or a chest of drawers, is found at a thrift store or elsewhere, and attached at the base are two wheels and two pegs to allow the podium to stand. The wheels attached are at least 5" in diameter, attached at either side of the base of the podium, as can be seen in Figure 3-14. A handle is attached at the top of the podium so that it may be pushed or pulled around the asphalt and grassy area. On top of the podium, there are two elastic bands attached at the side, spaced to accommodate a clipboard. If a shelf is used, then wood and hinges, or canvas is used to cover the shelf in order to safely store supplies.

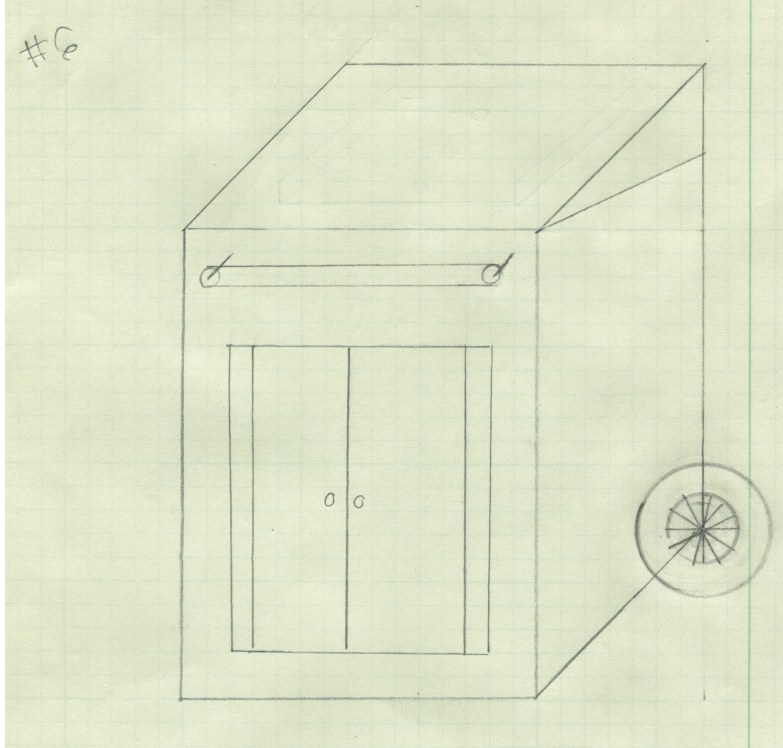


Figure 3-14: Sketch of the repurposed chest of drawers (J. Reid, unpublished drawings, March 2018)

3.3.7 Number Line for Inequalities

A number line that is 13 points-wide (including the zero point) has a PVC cylinder at each point. Included in the podium are 13 whiffle balls. A whiffle ball is placed inside the cylinder at each point where a number is to be filled in during an exercise plotting inequalities. The PVC cylinders are staked into the ground in the grassy area along with the number line made of rope. Each of the PVC cylinders is marked with a number along the line. This is also a very cost-effective solution, most likely \$100 or less including the podium. This solution is shown in Figure 3-15.

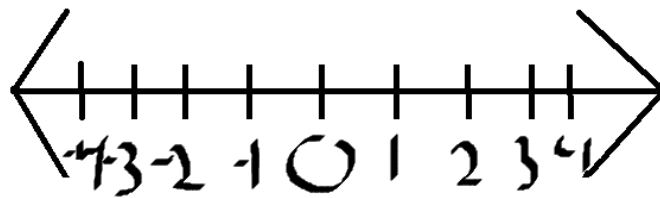


Figure 3-15: Drawing of a number line (I. Duque, unpublished drawings, March 2018)

3.3.8 Proportional Reasoning Pole

A tall PVC pipe pole is set in an umbrella stand. This pole is made from two pieces of PVC pipe, 3 feet each, and joined together in the center with a PVC joint. The total height of the pole is marked on the side of the pipe. In the stand, or base of the pole, there is a hole cut in the side of the pipe. Stored inside the pipe is a tape measure. The pull tab for the tape measure is outside

the pipe. This tape measure may be pulled out so that the shadow cast by the pole may be measured by students during a proportional reasoning exercise. This solution will not add much cost to the project, and including the podium and other features should be under \$200. This solution is shown in Figure 3-16.

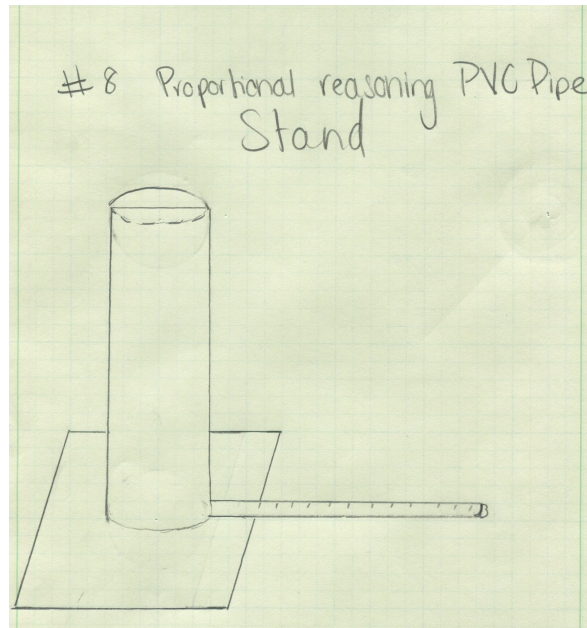


Figure 3-16: Sketch of a PVC pole used for proportional reasoning exercises (J. Reid, unpublished drawings, March 2018)

3.3.9 Pi Circle and Tangent Number Line

A number line, containing 13 points including the zero point, is painted on the asphalt. At the zero point of the number line, immediately underneath the line is a circle. This circle is painted to be 1 meter in diameter. The length of the diameter is painted onto the center of the circle. The number line is painted so that it is tangent to the circle. Included in the podium supplies is a length of rope that is cut to fit the circumference of the circle. This rope may be shown to be the length of the circumference, and then may be laid out along the number line so that it can be shown to be equal to just over 3 meters, demonstrating that the formula for the circumference of a circle is Pi times the diameter. This solution does not add any cost to the project, but just reorganizes the space to add functionality to the circle and number line. This solution is shown in Figure 3-17.

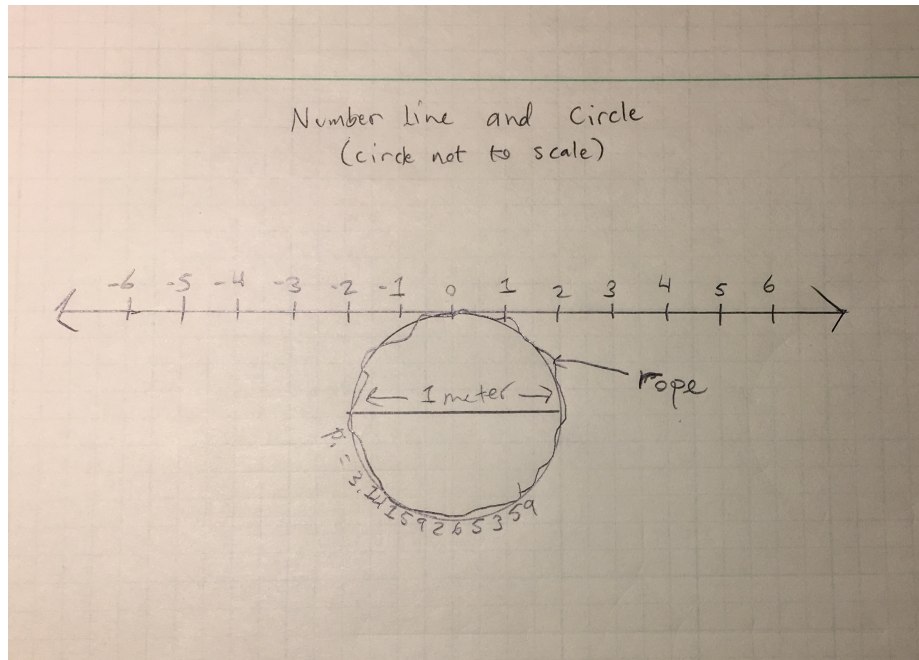


Figure 3-17: Sketch of the Pi circle and tangent number line (R. Turlington, unpublished drawings, March 2018)

4 Decision Phase

4.1 Introduction

The Decision Phase is used to decide which of the alternative designs, stated in section III, are to be built for the client. The criteria presented in the section II are used as multiples in the Delphi Method to select the solutions that best meet the client's needs.

4.2 Decision Criteria

The criteria listed and defined below was established in section II.

Cost- Mrs. Beth Baker, the client, has agreed to contribute \$100 towards the project and the Blue Note members have agreed to spend a maximum of \$75 each

Accessibility- It is important that tall students and Mrs. Baker can maneuver throughout the built solution easily so the lessons can be executed effortlessly and the students can retain the information conveyed.

Portability- The students must be able to walk on and through the solution so they can partake in certain mathematical executions, giving them the opportunity to convert what they've physically done into information they need to learn.

Safety- Students have to work on and around the solution(s) so it is important that they stay safe. It is the Blue Notes duty to ensure they provide a solution that doesn't pose: chemical, biological, ergonomic, or, physical hazards.

Durability- Due to the harsh weather conditions in Humboldt County the solution must be able to withstand hectic conditions. The solution executed must also be able to withstand the transportation due to its being moved from the classroom to its designated area.

Portability- It is essential that the solution is easily transported. The solution should be something that may be moved and set up in a matter of minutes because the Mrs. Baker must work efficiently.

Flexibility- The design must be able to work well in different situations. Therefore, Mrs. Baker should be able to apply different lessons to the same solution.

Environmental Impact- The design that is chosen should be environmentally friendly because it is going to be outside.

4.3 Solutions

Five of the alternative solutions described in Section III were picked to be tested by the Delphi Matrix.

- Pi Circle Number Line
- Proportional Reasoning
- Painted Activity Space
- Podium with Coordinate Plane
- Portable Grid

4.4 Decision Process

The decision process consisted with collaborating with the client and receiving feedback for the alternative solutions. The solutions put through the Delphi Matrix were chosen to represent as many different ideas developed during the solution phase are represented. Both two-dimensional painted features are represented, as well as more three-dimensional features, and so that portable features are represented along with more permanent solutions. Based on the feedback the alternative solutions were able to be evaluated based on the criteria in section 4-1. The criteria are being based on the importance to design. The criteria are based on a scale from 0 to 10. The higher the number, the more important it will be to the overall process. The criteria are listed again below in Table 4-1 in order of greatest to least weight.

Table 4-1: Table of criterion listed with associated weights

Criteria	Weight (0 – 10 high)
Safety	9
Durability	8
Accessibility	7

Flexibility	6
Portability	5
Cost	4
Environmental Impact	4

For the second part of the Delphi Matrix, the alternative solutions were ranked on a scale of 0 to 50. 50 meaning the solution meets the criteria. The Delphi Matrix in Table 4-2, was created to create a stepping stool in the decision making. Each alternative solution was scored accordingly as a group. The final scores will be used to finalize the group’s decision.

Table 4-2: Delphi Matrix used for the decision process

Criteria	Weight (0-10)	Alternative Solutions (0-50)				
		Pi Circle Number Line	Proportional Reasoning	Painted Activity Space	Podium with Coord Plane	Folding Portable Grid
Cost	4	35 140	45 180	30 120	40 160	35 140
Accessibility	7	45 315	20 140	40 280	30 210	25 175
Durability	8	40 320	35 280	40 320	25 200	30 240
Safety	9	45 405	35 315	45 405	35 315	25 225
Portability	5	0 0	30 150	0 0	45 225	30 150
Flexibility	6	30 180	20 120	40 240	25 150	25 150
Environmental Impact	4	40 160	45 180	35 140	40 160	35 140
		1520	1365	1505	1420	1220

4.5 Final Decision Justification

The final decision was based on two small projects and a major project. The “Pi Circle Number Line” solution is the highest scoring design on the Delphi Matrix. The other two elements are “Painted Activity Space” and “Podium with coordinate plane” that scored second and third highest. The design will consist of painting coordinate planes and number lines as well as building a portable podium. The client, Elizabeth input helped the group improve the alternative designs to reach the final decision. The reason for three elements is that podium was a good idea, but did not score high enough in the durability and accessibility. After the feedback from the client, the podium is good enough to keep for the final decision. In order to incorporate each of the three designs in the final project, the individual designs as described in section 3 were altered. The attached coordinate axes from “Podium with coordinate plane” were removed,

and the design was altered to only include the portable podium as a teaching station with some storage for necessary activity materials. The “Painted Activity Space” was altered to include a multi-use coordinate plane, which has gridlines, as well as a marked x- and y-axis. The “Pi Circle Number Line” no longer includes a PVC feature. In addition, this number line was made incorporated into the painted features, and is painted permanently on the ground, not laid out in rope on the grass.

5 Specification of Solution

5.1 Introduction

The Specification of Solution describes how the chosen solution, detailed in section 4, was implemented at Zane Middle School. This section contains a description of each of the three features included in the final decision. It also provides a cost and maintenance analysis of the entire project.

5.2 The Podium

5.2.1 Skeleton of the Podium

The perimeter of the base is connected at the corners by 1” 3-way elbow joints resulting in a rectangle with dimensions 24” by 18”. To provide stability, at the center of each base, there are 1” 4-way joints that extend to the midpoints of each side of the rectangle. The two bases are joined by PVC via the vertical orifice of the 3-way elbow joints, resulting in the 42” height of the skeletal system. On the inner ends of the opposite 3-way elbow joints, located on the back end of upper base, there are two, 3-way, T-shaped joints that extend their horizontal orifices, at a forty-five-degree angle away from an imaginary horizontal line extended out from the back of the PVC pipe their connected to. Connected to the two T-shaped joints are two elbow-joints with a PVC pipe creating a handle bar at a 45-degree angle with the top of the podium.

5.2.2 Podium Roller

Hoisted to the lower base is a 24” by 18” sheet of plywood. Hoisted to said sheet of plywood, towards the back end of the podium, are two 149mm Independent trucks with bone swiss bearings and 70mm wheels mounted on with quarter inch screws and quarter inch nuts.

5.2.3 Podium Platform

On top of the upper base, there is a right triangle prism with base dimensions of 24” by 18” and heights of 18” and 19” made out of plywood. The angle created by the base of the prism its highest point is 3 degrees. 1” up the short end of the prism’s hypotenuse is a 1/2” by 24” by 1/2” strip that prevents the teacher’s papers from sliding off of the platform.

5.2.4 Use of Podium

The outdoor podium has been designed to be lightweight and transportable so it can be used outside by Beth Baker during outside math activities and inside by a chosen child who needs to be distanced from the other students. The handle bar allows the podium to be tilted backwards onto the wheels at the bottom and pushed forward to a new destination. The inclined platform allows stationary to be laid across the elevated board and become stationary. The final design of the podium can be seen in Figure 5-1 below.



Figure 5-1: Final implementation of the Portable Podium (I. Duque, unpublished drawings, April 2018)

5.3 Number Line

Tape and cardboard were used as a preparation for the number line in order to get a straight line. There were two lines of taped cardboard parallel to each other and 3 inches apart. Surface preparation were critical before the spray paint went down. Those preparations were done by cleaning the concrete thoroughly. The spray paint was used to paint in between the tape while being 10 inches away from the ground. By following the tape, the line came out as straight as possible. The paint was water resistant, making it more durable. At the end, stencils were used to spray paint the numbers at their designated spots going from (-17 to 17), which may be seen in Figure 5-2.

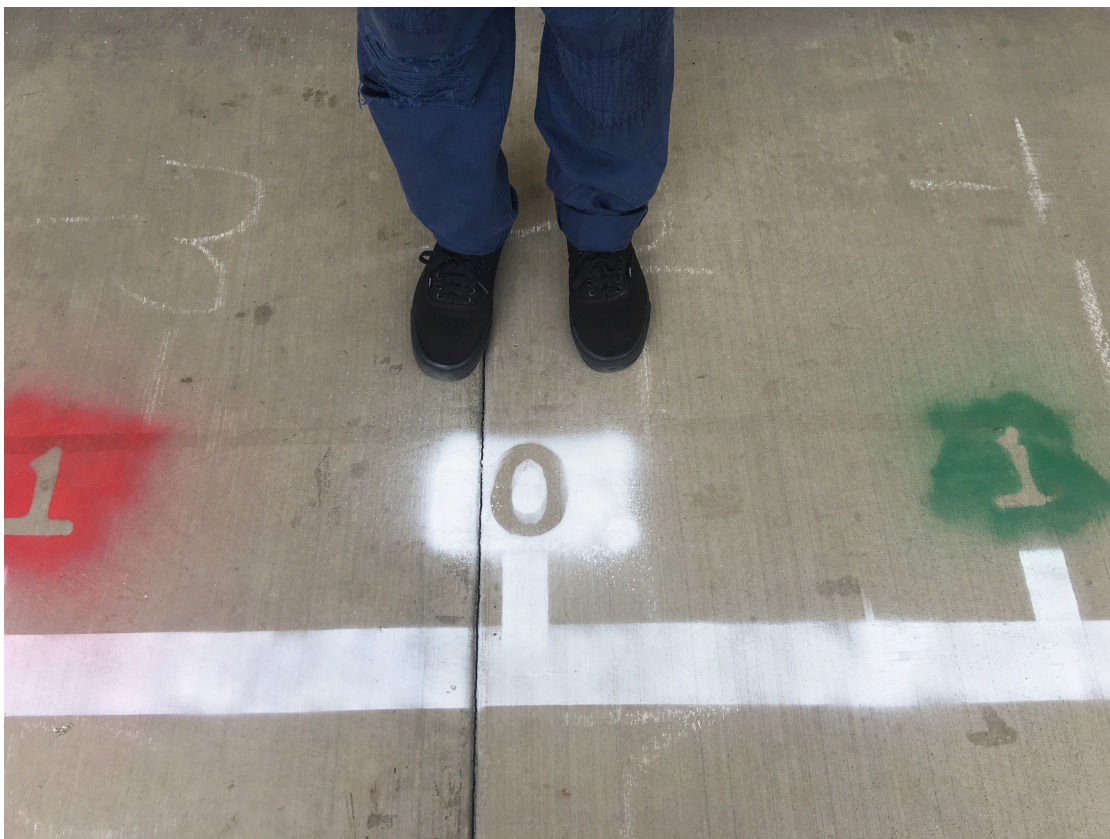


Figure 5-2: View of the final implementation of the number line with stenciled numbers (E. Baker, unpublished drawings, April 2018)

5.4 Coordinate Grid

For the Coordinate Grid, a space was chosen next to a patch of grass where the asphalt is fairly flat. This space is large enough to accommodate a square grid with 13 gridlines x 11 gridlines. Each line is laid down 2ft away from the next line. The gridlines are all 4 inches wide. Two sides of the grid are painted in green marking paint, so that the grid can represent a first quadrant grid of a coordinate plane. The two center lines are painted in red marking paint to represent the x and y axis lines in a four-quadrant graph. The rest of the grid lines are painted in white marking paint. Tape and cardboard were used in the preparation of this grid, in order to achieve straight lines. The final implementation of the permanent coordinate grid is pictured below in Figure 5-3.

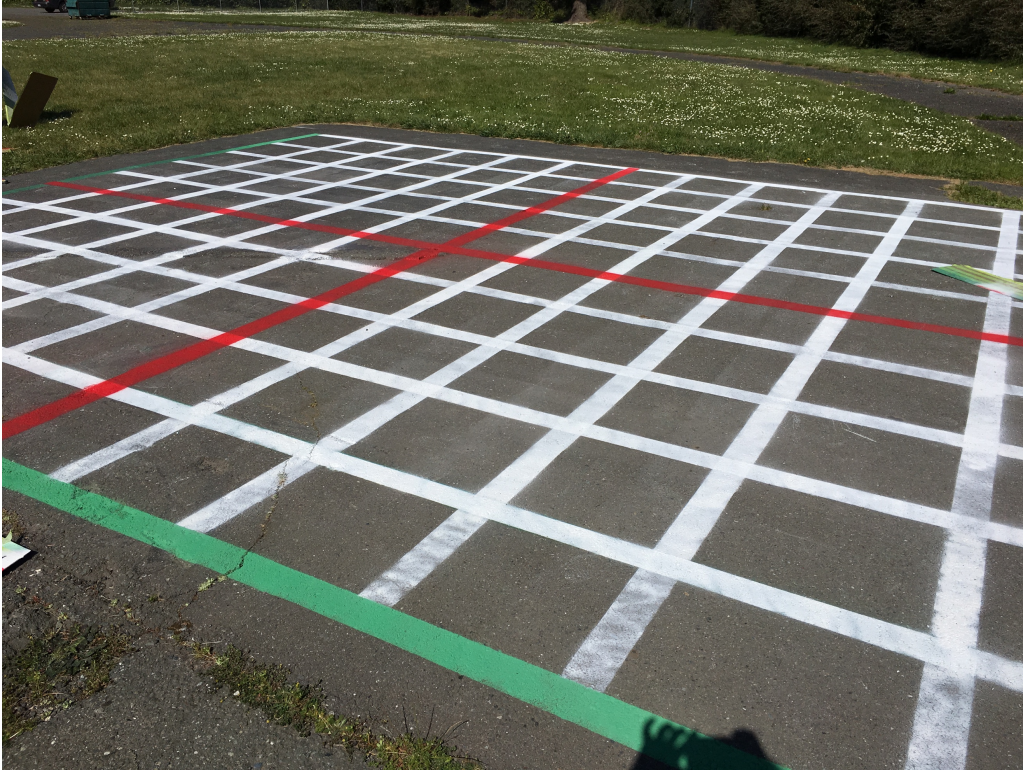


Figure 5-3: Implemented final design of Coordinate Grid (R. Turlington, unpublished drawings, April 2018)

5.5 Cost Analysis

This section contains an analysis of the cost of both the design work, as well as the direct monetary cost of the implementation of the design. This section will also contain an estimate of the maintenance costs of the design.

5.5.1 Design Cost

The design costs are determined by the time put into the project by the design team. Included is design time, as well as labor and implementation time put in by the group. The breakdown of the hours spent on the project is below in Figure 5-4. The most time was spent on the prototyping, building, and implementation phase of the project, Phase V. The next most amount of time was spent on the literature review, and after that the decision phase. Phase V made up for more than 50% of the time spent on this project.

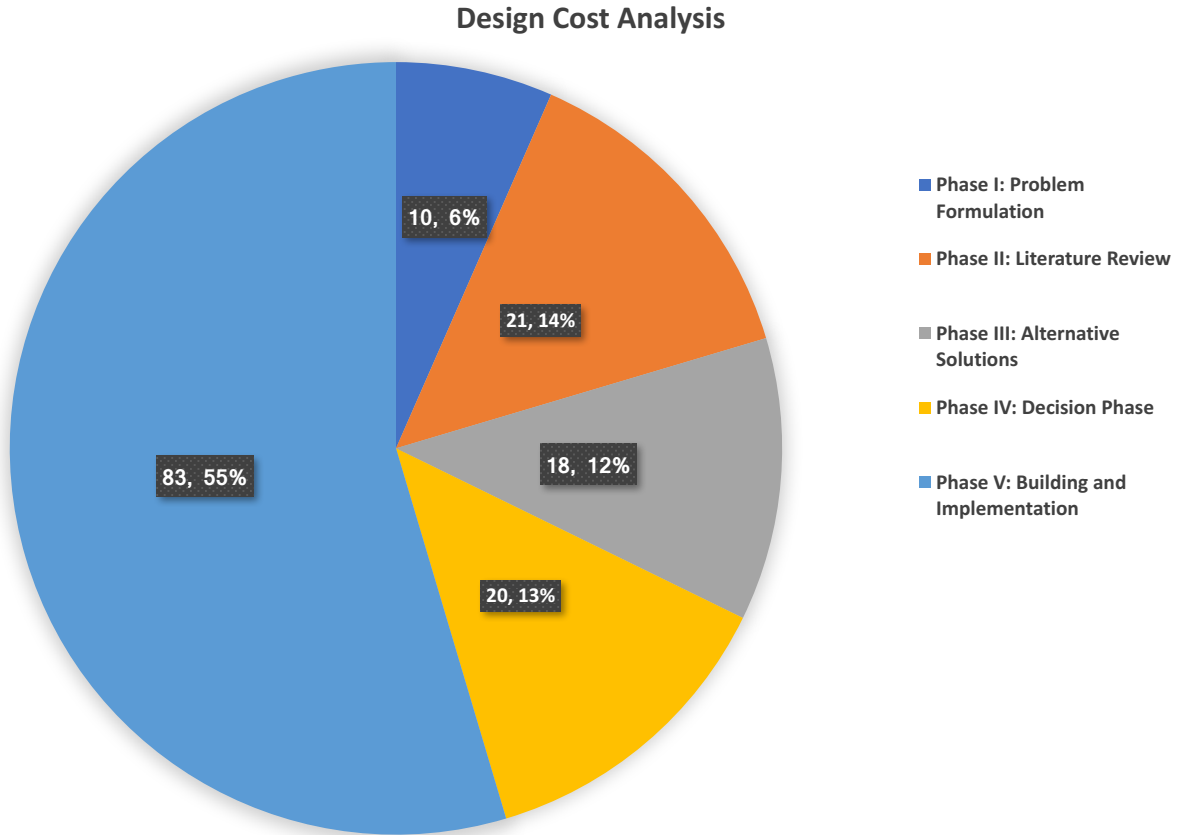


Figure 5-4: Cost of labor for the Blue Notes for the Outdoor Math Learning Space project

5.5.2 Implementation Cost

The implementation costs include all of the direct monetary costs incurred during the building and implementation of the project. A list of all of these costs is below in Table 5-1. The most money was spent on the marking paint, which ended up costing \$122.69 for 16 cans. The next most expensive were the skateboard wheels used on the podium. The total cost was determined to be \$338.99. This cost was offset by a \$100 reimbursement from Zane Middle School, as well as a personal donation of \$100 from Beth Baker.

Table 5-1: An analysis of Implementation Costs associated with the project

Quantity	Material	Source	Cost (\$)	Total (\$)
4	1"x10'PVC Pipe	Ace Hardware	5.41	21.64
12	Tee 1"PVC	Amazon	1.59	19.09
2	3-way elbow 1"PVC	Amazon	13.76	27.52
1	1" PVC connectors - Straight	Ace Hardware	0.69	0.69
40	10x3/4 dry wall screws	Almquist Lumber	0.02	0.8
24	pipe straps	Ace Hardware	0.49	12.32
1	foam Tape	Ace Hardware	3.99	3.99

1	PVC cutter	Ace Hardware	13.99	13.99
2	3M PRO Grade 9x10 180GR	Ace Hardware	1.79	3.58
2	SANDPAPR 9x11 GR80	ACE Hardware	1.79	3.58
4	Longboard Wheels clear/green core 70mm	Tactics Skateshop	33.95	33.95
1	12MM Baltic Birch BB/BB 5X5	Almquist Lumber	29.95	29.95
1	Cutting Board Piece	Almquist Lumber	1.25	1.25
16	Marking Paint	Ace Hardware	7.59	122.69
2	Podium Legs	Thrift Store	2.49	4.99
1	Sidewalk Chalk	CVS	3.99	3.99
1	Masking Tape	Ace Hardware	1.99	1.99
2	Painters Tape	PPG Paints	5.99	12.58
1	Box Cutter	Ace Hardware	1.59	1.59
1	Stencil Material	PPG Paints	14.24	14.24
2	Box of Wood Screws	Ace Hardware	4.29	9.05
Total Cost				338.99

5.5.3 Maintenance Cost

This section contains an estimate of the projected costs required to maintain this project. A breakdown of each of these projected costs, as well as the estimated total maintenance cost is show below in Table 5-2. This estimate heavily depends on the durability of the marking paint. The life span estimate is based on the small amount of information on the durability of similar paints that was available. There is no durability information for the particular brand of marking paint used for the project. The marking paint is durable, and should hold up to the weather in Eureka, CA fairly well. The number line is located under an awning, so it should last longer being protected from the elements. The podium wheels are large skateboard wheels, and should last at least 3 years.

Table 5-2: Breakdown of the cost estimate of maintaining the Outdoor Learning Space project

Item	Expected Life Span	Cost (\$)	Cost (\$/year)
Marking Paint	4 years	122.69	30.67
Podium Wheels	3 years	33.95	11.32
Total (\$/year)			41.99

5.6 Implementation of Design

The Implementation of Design contains instructions detailing the process by which the project was built and implemented. The painted elements of the design are permanent, and had to be built and implemented on site at Zane Middle School. The podium was designed for portability, and so was assembled first and then brought to Zane.

5.6.1 Coordinate Grid and Number Line

The Coordinate Grid and Number Line were both painted on the ground at Zane Middle School using Ace Hardware durable marking paint. In order to get straight lines, cardboard edges were taped to the ground, which can be observed in Figure 5-5. The outer bounding lines are laid down first, and then the inner gridlines are painted.



Figure 5-5: Using cardboard and tape to create a straight line (R. Turlington, unpublished photos, April 2018)

5.6.2 Portable Podium

The Portable Podium was built with a PVC skeleton, with wood panels attached on the outside with pipe straps and screws. The first step is to build the PVC skeleton out of PVC joints, and straight PVC pipes that are cut to the appropriate size. Cutting the PVC pipe is shown in Figure 5-6.



Figure 5-6: Cutting the PVC pipe to size (I. Duque, unpublished photos, April 2018)

The next step taken was to assemble the PVC joints and cut PVC into the podium skeleton to make sure it fits before applying glue. The PVC skeleton is shown in Figure 5-7.



Figure 5-7: Assembled PVC frame (I. Duque, unpublished photos, April 2018)

Once the skeleton is assembled, and an appropriate size. The next step is to apply the glue to the ends of the PVC and then reassemble the frame. The application of the PVC glue is shown in Figure 5-8.



Figure 5-8: PVC glue applied to the end of a piece of PVC pipe (I. Duque, unpublished photos, April 2018)

Once the skeleton is reassembled and secured with glue. The next step is to affix the wood panels to the outside of the frame. Each wood panel is secured by drilling wood screws through pipe straps that sit around the PVC. Figure 5-9 shows the wood panels being drilled into place.



Figure 5-9: Securing the wood panels to the outside of the PVC frame (R. Turlington, unpublished photos, April 2018)

After the wood is secured, holes are drilled into the bottom panel of the podium. Four holes are drilled towards each side of the podium, and skateboard trucks and wheels are attached with nuts and bolts. After the wheels are attached, the finishing touch is added, the Zane Middle School Falcon is painted on each of the wooden side panels. Figure 5-10 shows the final painted logo.



Figure 5-10: Painted Zane logo on wooden side panel (I. Duque, unpublished photos, April 2018)

5.7 Results

The final implementation of Team Blue Notes' Outdoor Math Learning Space includes two permanent features at Zane Middle School, and a portable teaching podium. The coordinate grid and number line are durable and permanent features in a space in the school that was not being used for any class activities before. The grid and number line are both visually engaging and easy for the students to understand. Feedback from the client has been very positive, and the students are able to enjoy the grid and number line outside of math class activities. Figure 5-11 shows the students participating in a math activity using the number line. For this activity, the instructor called out an inequality equation, in this case $x < 1$. All students standing on numbers that are a part of x kneeled, and others stayed standing.



Figure 5-11: Students using the number line to visually represent the inequality $x < 1$ (E. Baker, unpublished photos, April 2018)

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