Math Path

The Avengineers

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ENGR 215 – Professor Lonny Grafman – Spring 2021

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1 PROBLEM FORMULATION

1.1 INTRODUCTION

Listed below are the background and objective statement of the project formulation process.

1.2 BACKGROUND

The project team is made up of HSU Engineering 215 students during the spring semester of 2021. The client for this project is Zane Middle School, a STEAM based middle school located in Eureka, CA. The “HSU Avengineers”, will work directly with the 7th grade math program’s Instructor, Terra Pennsy. The finished project will end up outdoors and is aimed to be completed before the end of HSU’s spring term.

1.3 OBJECTIVE

The overall objective of the project is to design and build outdoor area that inspires and educates the 7th grade math students of Zane Middle School. The project needs to feature concepts specific to 7th grade common core standards for math as in an aesthetically pleasing manner. **Figure 1** depicts the current and expected state of the project before and after implementation.

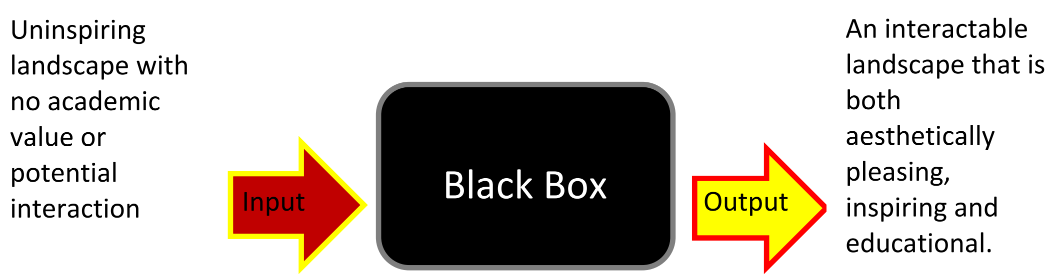


Figure 1: Black box model depicting the input and output values of our math walk project.

2 PROBLEM ANALYSIS AND LITERATURE REVIEW

2.1 INTRODUCTION

2.2 PROBLEM ANALYSIS

The following section discusses the problem analysis portion of the document regarding the Math-Path project at Zane Middle School. The problem analysis will cover the client's project specifications, considerations, constraints, and criteria. A project-specific examination of product usage and production volume will also be included.

2.2.1 SPECIFICATIONS

The project specifications guiding the design process and production of this product include the following:

- System content: contains varying layers of educational depth and mathematical value
- Location: near 7th grade math classroom
- Aesthetics: Uses Zane Middle School themes
- Product is low maintenance

2.2.2 CONSIDERATIONS

Listed below are the considerations that must be taken into account when designing the math path.

- Amount of foot traffic path is exposed to
- Implementation of modern technology
- Used by 6-8th graders at a STEAM school
- Product will be exposed to weather
- CA common core math/science

- Integration with course content

2.2.3 CRITERIA

Criteria and their constraints were developed in correspondence with the client. These criteria include the primary standards considered while designing the Math Path, and the specific constraints for each. These are listed below in Table 1 in descending order of importance.

Table 1: Criteria

Criteria	**Constraints**
Safety	No sharp edges or holes that could potentially injure a student
Accessibility/Usage	Must be physically and mentally accessible and inclusive to all ranges of students that use the path
Level of Inspiration	Promotes interesting applications of mathematical concepts
Educational Value	Includes math concepts appropriate for a middle school level
Aesthetics	Attractive and elegant design that fits the themes of Zane Middle School
Interactiveness	Design needs to include some levels of student and staff interaction with content
Production Vol.	Only one Math Path will be created
Durability	Won’t be destroyed with consistent foot traffic, use, and weather
Cost	The maximum cost cannot exceed $500

2.3 LITERATURE REVIEW

2.3.1 CLIENT CRITERIA

Following an overview meeting with Trevor Hammonds, the 7th grade math teacher of Zane Middle School, located in Eureka, CA, discussed a potential outdoor math project. The project would ideally highlight useful concepts found in K-12 math and science. The project would be long-lasting, interactable, and relevant to current math topics at Zane Middle School. During a client interview on February 18th, Pennsy emphasized various project criteria and goals which are listed below:

- Aesthetically pleasing
- Need to be walkable
- Near the math classroom
- Durable and weather resistant
- Low maintenance
- Includes useful math formulas/topics
- Implements game/activity
- Makes kids think differently about math (new concepts/perspectives)
- Preferably made out of reclaimed/ upcycled material

2.3.2 REFERENCE PROJECTS

The following section below covers two previous Engineering 215 projects similar to the Math Path project. Landscaping, construction, and building techniques are listed under each along with a small background and solution section.

2.3.2.1 Zane Middle School Sundial

Team members (Division by Zero): Alex Watson, Richard Thomas, Hannah Gidanian, Caitlin Gundert

Project Background/Problem**:** A group of ENGR 215 students were tasked with creating a sustainable project that uses empty space by teaching Zane Middle School students about time with respect to the sun.

Implemented Solution: Figure 1 shows an aesthetically pleasing interactive 90 square foot concrete pad that uses an imprinted sundial paired with human shadow to explore the concept of solar time.

Figure 2: 8th grader Keylei and School Psychologist Trevor Hammons with the final sundial (Watson 2017)

2.3.2.1.1 Construction/Installation

Plywood concrete stamps: Team cut out individual numerical characters out of ½" plywood, where they were then laid out and given a plywood backing to secure them in place.

Concrete:

1. Lined 10'x 9' rectangular hole with plywood around sides and fill base with 5'' of gravel to create concrete form.
2. Concrete is then poured in by means of truck, smoothed, and cured for 30-45min.
3. Using a series of stringlines across the concrete pad (fastened to plywood mold), the plywood stamps can be placed and pressed accurately
4. Concrete slab then cures for another 24-48hrs before completion (Watson 2017)

2.3.2.2 Zane Middle School permeable concrete 3

Team Members (Team^2): Ailynn Andersen, Jesse Bobrow, Catherine Carbajal and Julian Sicaud

Project Background/Problem: ENGR 215 students tasked with fixing a failed past engineering walkway in the Zane Middle School garden area. The project required investigation and understanding of a failed past attempt to successfully install the permeable concrete. The replacement walkway needed better ability to handle water and weather conditions while pleasing the aesthetic criteria set by the client.

Implemented Solution: A clean, permeable, and aesthetically pleasing walkway through the Zane Middle School garden area.

2.3.2.2.1 Construction/Installation

1. Area Preparation: Clear existing area of any previous concrete remnants, weeds, rocks, etc.
2. Level, dig, and compact dirt along cleared area to required depth for concrete type
3. Use a weed barrier/cloth paired with secured bender board and 1x4 dividers spaced horizontally along path to serve as stress relief points
4. Using a specific water to concrete ratio mix porous concrete (preferably in a large container that is easily movable i.e., wheelbarrow).
5. Pour concrete into divided sections evenly and cover with plastic when finished.
6. Allow 1 week under plastic to cure. (Sicaud 2018)

Figure 3: Area prep for permeable concrete, Zane Middle School (Sicaud 2018)

2.3.3 CATHERINE L. ZANE MIDDLE SCHOOL

2.3.3.1 Weather

Eureka city is exposed to a high amount of rainfall every month. The area also experiences frequent amounts of fog from Pacific Ocean. These conditions cause consistently high humidity levels in the area. Therefore, the product must be made from materials that are stable in cold and humid environments (Humboldt 2021).

2.3.3.2 STEAM

STEAM is the abbreviation for Science, Technology, Engineering, Art, and Math. It is a comprehensive approach for students to encourage them to think more broadly about real-world problems. Zane Middle School is committed to providing students with suitable skill sets for preparing for the modern world. The school implements practical policies in teaching through the combination of subjects in school as well as extracurricular activities. This combination is to let students gain knowledge through the activities that are interesting to them effectively (zane.eurekacityschools.org, 2021).

2.3.3.3 7th grade math education

Current 7th grade mathematical education is structured around five key concepts: Ratios and Proportional Relationships, the Number System, Expressions and Educations, Geometry, and Statistics and Probability (CDE, 2013).

2.3.3.3.1 Ratios and Proportional Relationships

In the Ratios and Proportional Relationships subject, students use their understanding in proportional relationships and ratios of fractions between two quantities to solve one or multiple steps of ratio and percent problems (CDE, 2013). For examples:

- 1/3 divided by 1/6 = 2 (CDE, 2015).
- If an object has a constant speed v moving a distance d in a period of time t, we have the relationship between the speed and the distance that the object displaces is $v = d/t$ (CDE, 2015).
- A sale price is $12 which is on sale for 40% off. The original price is $12/0.6 = $20 (CDE, 2015).

2.3.3.3.2 The Number System

In this subject, students will apply and extend their understandings of operations with fractions to add, subtract, multiply, and divide rational numbers (CDE, 2013). For examples:

- Opposite numbers add up to make a zero (CDE, 2015).
- *a – b = a + (-b)* (CDE, 2015).
- (+17/2) + (-9/2) = (+8/2) + (+9/2) + (-9/2) = (+8/2) + (0) = +8/2 = +4 (CDE, 2015).
- *(-a)*b = ab; and (-a)*(-b) = ab* (CDE, 2015).
- *(-a)/(-b) = a/b* with b is not zero (CDE, 2015).

2.3.3.3.3 Expressions and Equations

For this subject, students will use their understanding in the properties of operations to generate equivalent expressions and to solve real-life and mathematical problems using numerical and algebraic expressions and equations (CDE, 2013). For examples:

- *a +* 0.03*a* = 1.03*a* represents that “increase by 3%) is the same as “multiply by 1.03” (CDE, 2015).
- *a(b+c) = ab + ac* **and** *ab + ac = a(b+c)* (CDE, 2015).
- *a/b* divided by *c/d* is equal to *a/b * d/c* (CDE, 2015).

2.3.3.3.4 Geometry

In the Geometry subject, students would draw, construct, and describe geometrical figures and describe the relationship between them, including computing actual lengths and areas from a drawing and reproducing a scale drawing at a different scale. They also would learn the methods to solve real-life and mathematical problems involving angle measure, area, surface area, and volume (CDE, 2013). For example:

- If 2 centimeters are equivalent to 5 feet on a scale given then we have 5.6 *cm* will be equivalent to (5.6)*(5/2) = 14 ft (CDE, 2015).

Explain why the two triangles shown are *not* scale drawings of one another.

Solution: Since the ratios of the heights to bases of the triangles are different, one drawing cannot be a scale drawing of the other: $\frac{2}{5} \neq \frac{4}{8}$.

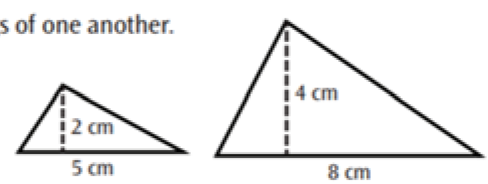
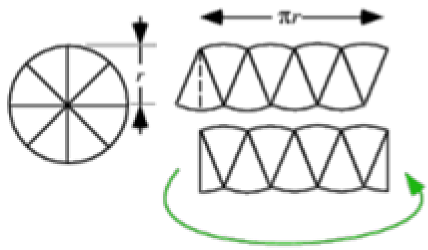


Figure 4: Triangle Ratios (Adapted from CDE 2015, Math Framework, Grade 7)

To have a deeper understanding in the circle area formula, students can divide a circle into equal pie pieces, and range them into an approximate parallelogram. So that, we have the approximated parallelogram has the same area with the area of the given circle. We also have the area of a parallelogram is calculated by taking multiplication of its height and one of its bases. In this case, the calculation of the parallelogram's area is r times pi(r). This result is expressed to pi*(r^2). In other words, pi*(r^2) is the area formula of a circle, where pi is equal to 3.14 (CDE, 2015).



$$Area\ of\ Parallelogram = Base \times Height$$
$$Area = \frac{1}{2}(2\pi r) \times r$$
$$Area = \pi r^2$$

Figure 5: Area of a parallelogram (Adapted from KSDE 2018, 7th Grade Flipbook)

- The area of a triangle with a base b and a height h is (1/2)*b*h
- The area of a rectangular with a with w and a length l is w*l
- The area of a square with an edge a is a^2
- The area of a trapezoid with two bases b1, b2, and a height h is (1/2)*(b1 + b2)*h
- The area of parallelogram with a base b and a height h is b*h
- The surface area of a sphere with radius r is 4*pi*r^2
- The volume of a sphere is (4/3)*pi*r^3
- The surface area of a cube with an edge a is 6*a^2
- The volume of a cube with an edge a is a^3

2.3.3.3.5 Static and Probability

In this subject, students will learn how to use statistics in giving valid inferences about a population based on examining a random sample of that population. Student can use these inferences to make estimates or predictions in different simulated random samples. Student also will learn how to defy and compare two data samples of two populations by using measures of center and variability for numerical data. In probability matters, students will learn methods of investigating and evaluating to find probabilities of events and compound events from using probability models, organized lists, tables, tree diagrams, and simulation (CDE, 2015). For examples:

- Used data from a random sample to determine inferences about a population with an unknown characteristic (CDE, 2015).
- A random sample can be representative of a total population and will generate valid predictions (CDE, 2015).

- Compare two data sets to build on the understanding of graphs, mean, median, mean absolute deviation, and interquartile range (CDE, 2015).
- Approach the concept of probability. Develop and use probability models to find theoretical probabilities (CDE, 2015).
- Examine compound events and use basic counting ideas for finding the total number of equally likely outcomes for such an event (CDE, 2015).
- Use simulation to determine probabilities (frequencies) for compound events (CDE, 2015).

2.3.3.4 Math Path in Helping to Learn Mathematics

In the article "Visual Learning in Elementary Mathematics", Murphy states learning visually is one of the most effective ways for children as they observe the world. He shows that many researchers have agreed children learn and remember subjects most effectively through images, and this includes math concepts, a natural science of human learning. Murphy argues that children tend to understand abstract math concepts easily by trying to see how the concepts work visibly. This says children usually hand on the materials around them to get the math concept more tangible or image the information in models or pictures in their head so that they can solve the problem. This is understandable because by "seeing" something (either in reality or in mind), children can easily get attention to understand and remember the materials, as well as focus on solving the subjects (Murphy, 2009).

Murphy also expresses that from visual learning, students can gain or develop observation, recognition, experience, clarification, self-expression, and communication skills. That means to solve a specific problem, students will observe different aspects of the problem. They question themselves what kind of problem is, which methods they should use, what type of data needs to be collected. From this, they practice how to approach the problem with those materials, and get the experiences on how to observe and choose the right images for solving the problem. Knowing or not-knowing the aspects of the problem motivate students to communicate to each other (Murphy 2009).

2.3.4 MATERIALS

This section details the potential materials that could be used in the construction of a math path.

2.3.4.1 Concrete

There are many types and compositions of concrete on the market that vary in durability, cost, permeability, etc. The use of concrete in our project could potentially resemble the conditions required by a standard sidewalk or patio. In Humboldt county, the regulation for sidewalk thickness is 4”, and the minimum strength after 28 days is 3,000 lbs. per sq. inch (humboldt.county.codes 2021). Basing construction requirements from this standard, there are a few basic types of concrete that can be considered including standard all-purpose concrete, fast-setting concrete, and pervious concrete (cemexusa 2021).

2.3.4.2 Standard All-Purpose Concrete

Standard All-Purpose concreteis very pliable when freshly mixed, and very strong and permanent once it hardens. It generally contains 10-15% Portland cement, 60-75% aggregate, and 10-15% water (cemexusa 2021). Standard concretes are usually gray in color, impervious to water (making them prone to runoff), and have very long lifespans.

Popular and widely available types of standard all-purpose concretes are pre-blended mixtures where water is added on site, usually with a drum mixer. A typical brand for this type of standard concrete is Quickrete Concrete Mix No. 1101. This particular mix is recommended for thickness of 2 inches or more and the yield for an 80lb bag is 0.60 cubic feet. The recommended curing conditions for this concrete are 50 – 70 degrees Fahrenheit over 7 – 5 days, respectively (quickrete.com 2020). The cost of an 80lb bag of Quickrete 1101 is $7.99 at Shafer’s Ace Hardware in Eureka, CA (Ace Hardware 2021).

Figure 6: Quickrete Concrete Mix No. 1101 (homedepot 2021) and drum mixer (theconstructor 2020)

Ready-mix standard concretes are widely available and come pre-mixed with water directly from local concrete manufacturers.

2.3.4.3 Fast-Setting/High Early Strength Concrete

This mixture of concrete sets very quickly compared to standard concrete, and has high early strength, which makes it preferable in colder temperatures. The difference between fast-setting concrete and Portland cement-based standard concrete is the use of rapid-hardening hydraulic cement composites.of hydraulic tetracalcium trialuminate sulphate (CSA) and dicalcium silicate (C2S) (concreteconstruction 2010). Disregarding the setting time, fast-setting concrete differs little in durability, impermeability, and color from standard concrete.

Much like standard concretes, fast-setting concretes can also be bought as pre-blended mixtures that are combined with water on site using a drum mixer. One of the products for this pre-blended mixture is Quickrete 5000 Concrete Mix No. 1007. This is also designed for thicknesses of 2 inches or more with the same 80lb bag yield of 0.60 cubic feet. While the recommended curing conditions are the same for fast-setting concrete as they are for standard, there is a walk-on time of 10-12 hours due to the rapid setting. This also makes curing in cold conditions much more viable (quickrete 2020). The cost of an 80lb bag of Quickrete 1007 is also $7.99 at Shafer’s Ace Hardware in Eureka, CA, making it the same price as regular concrete (acehardware 2021).

Figure 7: Quickrete High Early Strength Concrete Mix 5000 No. 1007 (homedepot 2021)

Similarly to Standard Concrete, fast-setting/high early strength concretes are also usually available from local concrete manufacturers which provide more expensive, and less labor-intensive alternatives.

2.3.4.4 Pervious Concrete

Pervious concrete is designed to maintain interconnected void space to promote permeability of water and avoid runoff (B. Eisenberg et al. 2015). The concrete is created using an aggregate and a cementitious mix. Notably, an acute amount of fine additive creates a rough rigid surface that has between 15% to 25% void space.

Pervious concretes are generally implemented in areas where stormwater runoff is a concern to help control groundwater recharge, pollutant removal and the peak flow rate. Some important requirements for the location of the pervious concrete include separation from wells, septic systems and subsurface structures, and an aggregate storage base of 36% to 42% void space (B. Eisenberg et al. 2015).

Generally, initial costs of pervious concrete are more expensive than traditional concrete and are only more cost-effective when there is effective stormwater runoff control.

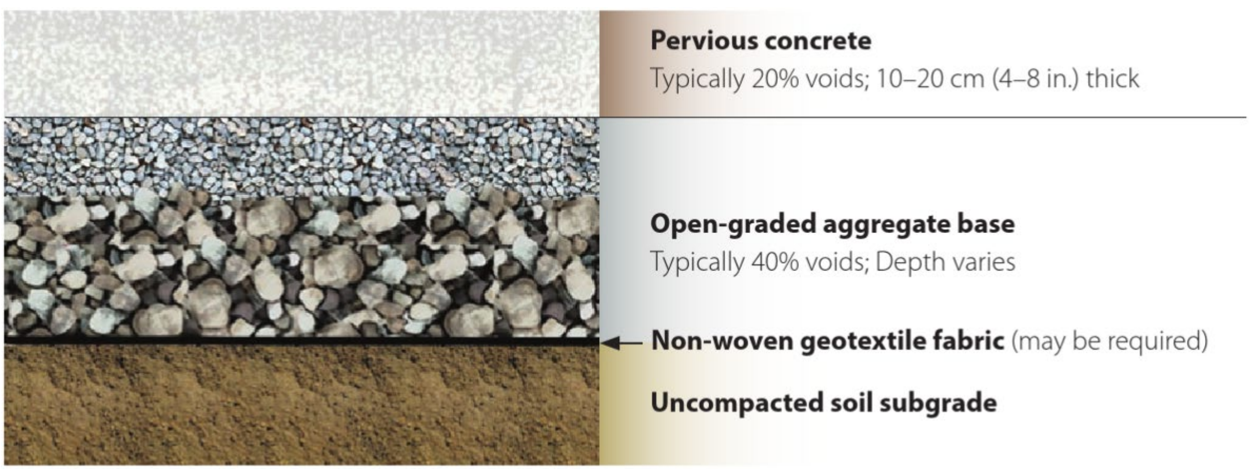


Figure 8: Typical pervious concrete pavement system section (B. Eisenberg et al. 2015).

2.3.4.6 General Concrete Finish Techniques and Types

This section will cover general concrete finish work, and the fundamentals of each technique. Advantages and disadvantages will also accompany each form of finish work for future reference.

2.3.4.6.1 Broom Finish

Tools needed

- Darby- Handheld wooden tool with flat edge used to shape wet concrete
- Edging tools- Handheld steel tool with round shape used to edge and corner concrete
- A broom with hardy bristles and long handle for final concrete texture

Technique Procedure

1. Allow poured concrete to dry for roughly 4 hours, letting surface water bleed off
2. After the pad is semi cured and moderately malleable, a chosen broom with hardy bristles is pulled across the pad surface until the desired area is covered in texture (Concrete Network 2020)
3. After brooming is complete and satisfactory, a curing agent with chosen color is sprayed thoroughly over the pad and left to cure, speeding up both the drying time and locking in necessary moisture and air (Fattuhi 1986)

Table 2: Advantages and Disadvantages of Broom Finish

Pros	Cons
Great traction	**Very Rough texture**
Very Feasable	**Color can vary over time**
Time efficient	**More difficult to maintain (traps debris)**
Cost effective	**Less aesthetic**

2.3.4.6.2 Smooth Finish (Float and Trowel)

Tools needed

- Darby- Handheld wooden tool with flat edge used to shape wet concrete
- Edging tools- Handheld steel tool with round shape used to edge and corner concrete
- Groover- a tool used to create joints/lines in the concrete to minimise cracking
- Magnesiums hand float- a metal tool with a flat face and edge used to smooth concrete surface. (Family Handyman 2019)

Technique procedure

1. Darby the poured concrete by passing over every area at least twice while applying pressure to smooth the surface clearing voids and chunks/lumps
2. Let the surface water drain and evaporate before running the edge tool around the edges of the pad.
3. Paired with measured lines on concrete forms, use a straight piece of wood as a guide to evenly run the groover across the pad horizontally (smaller slabs recommend joints every 4ft)
4. Lastly, brush the magnesium hand float back and forth in consistent motions over the pad surface. After each successful pass, lift the trowel to increase the angle of the edge and continue to pass over until desired surface texture is met. (Family Handyman 2019)

Table 3: Advantages and Disadvantages of Smooth Finish

Pros	Cons
Very Durable	**Takes time (tedious)**
Easiest to clean	**Can look unsatisfactory unless perfect**
Weather resistant	**Industrial look**
Looks very smooth	**Slippery**

2.3.4.7 Imprinting Concrete

When considering design prospects for a "math path", there is a high likelihood that we will need a way to incorporate graphics into our medium of choice. In the medium of concrete, a very popular method of incorporating designs, textures or patterns into concrete is the use of stamping or imprinting. This is when a premade stamp is pressed into freshly poured, partially set concrete, which when dry makes the concrete permanently take on the shape of the applied stamp (Concrete Network 2019). This allows limitless customization options if planned properly.

2.3.4.7.1 Process of Imprinting

The process of stamping the concrete is complex and done in a short amount of time. After pouring concrete and there is no bleedwater left on the surface, color hardener should be applied in two layers. Following this, a powdered or liquid release agent should be layered on the concrete right before stamping happens. Usually stamping is done as a texture or pattern that covers the whole surface of the concrete. If this is the case, then the stamping must be done all at once using several identical mats that tesselate in straight rows. Various tools and stepping are used to press the stamps into the concrete. Usually touch up work is necessary to be done with a hand roller to fix any imperfections from the stamps. One to three days after stamping, the release agent should be washed off with water, and curing compounds should be applied. This is when joints should be cut to avoid cracking later. Once cured sufficiently, sealer should be applied to the concrete (usually several weeks after stamping) (Concrete Network 2019).

Figure 9: Stamps being used to imprint fresh concrete, and sealer being applied in the final stage (Concrete Network 2019)

2.3.4.7.2 Costs of Imprinting

Prices of imprinting will vary dramatically depending on labor costs, stamp costs, and the costs of color hardeners, release agents, curing compounds, and sealers. Some estimates for basic stamped concrete projects range from $8-12 per square foot (Concrete Network 2019). Most of this cost however is in the expert labor and premade stamps. Costs and means to create stamps from scratch should be further explored.

Table 4: Costs of Imprinting Materials

Product	**Cost**
Brickform Color Hardener 5 Gallon Bucket	$50.00 (stampedconcretesupplies 2021)
Kleen Kote 32 oz. Concrete Release Spray Bottle	$14.59 (homedepot 2021)
Quickrete 5lb. Acrylic Concrete Cure and Sealer	$28.80 (homedepot 2021)
Quickrete 1 Gal. High Gloss Concrete Sealer	$21.28 (homedepot 2021)

Table 5: Pros and Cons of Imprinting

(Concretenetwork 2019)

Pros	**Cons**
More affordable than alternatives like natural stone or bricks	Difficult and involved process that may need professional involvement
Highly customizable	Cracking is common
Slip resistant with additives	Needs to be maintained
Very durable and long-lasting	can be damaged by freezing and salts
	Potentially too expensive

2.3.4.8 Outdoor Paint

2.3.4.8.1 Traffic Paint

Water reducible acrylic paints such as *PPG Aexcel Traffic Paint* are used for outdoor marking and are ideally applied to surfaces such as concrete and asphalt. The traffic paint can come in a variety of colors, and after fully applied and cured, is reflective due to small glass spheres in the paint (Aexcelcorp 2021).

2.3.4.8.2 Application

Traffic paint must be mixed well before applied, where a roller or spray machine can then be used. The paint requires that the surface of application be clean, dry, and that paved concrete is allowed 30 days to cure prior to. At 25 degrees Celsius, the applied paint has an estimated dry time of 30-45min (Aexcelcorp 2021).

3 SEARCH FOR ALTERNATIVE SOLUTIONS

3.1 INTRODUCTION

This section covers the brainstorming process and alternative solutions regarding the Zane Middle School math path project. The solutions covered below are the product of extensive brainstorming sessions based primarily on client satisfaction and criteria.

3.2 BRAINSTORMING

The alternative solution brainstorming process was used to generate a multitude of ideas and to conceptualize feasible solutions. Approximately 10 hours of Brainstorming accumulated during meetings held virtually over Zoom between March 11th and March 14th, 2021. Using effective communication and collaboration techniques, the team was able to produce a wide variety of feasible and complex solutions. Following the massive ideation sessions, the team was then able to narrow down the solutions to the select few that met the criteria.

Listed below is the list of all alternative solutions that were generated following team brainstorming:

- Computation Conflict
- Walk the Sin
- Math Land
- The Arithmetic Arc
- Cheat Sheet
- Fibonacci Path

3.3 ALTERNATIVE SOLUTIONS

3.3.1 COMPUTATION CONFLICT

Computation conflict is a competitive math game played with four teams or players. The premise of the game is to do progressively harder math problems on four different ends of the game area until meeting in the center for a final problem. The winner is the person or team to finish all the problems first. Some other variation of this sort of game could be considered, and the problems at each step would not be set in stone (literally) to be usable with different levels of math. The game would be set on a large square plot of concrete, with the battle area being a large “+” shape that features 4 problem squares for each team or player. Each problem square would also have a different physical texture as you progress towards the center of the area. In each of the four quadrants outside of the “+” is a different geometric shape with the relationships and formulas for calculating parameters within the shapes like area, circumference, and length. These shapes include circles, trapezoids, parallelograms, and triangles. An interesting feature would be to add actual units and a graph paper design onto all the shapes. The means of creating all the different patterns and shapes would likely be imprinting on the concrete using premade molds and other tools. Shown below in ***figure 9*** is the diagram of Computation Conflict.

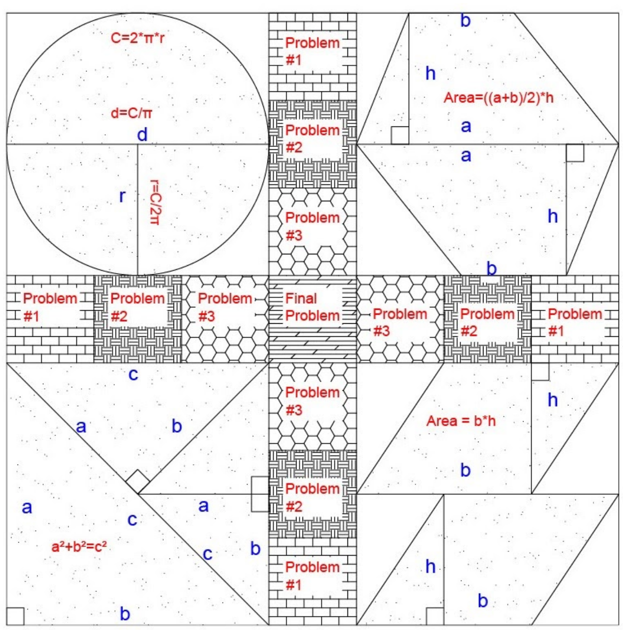


Figure 10: Computation Conflict, Steven Camara

3.3.2 WALK THE SINE

The alternative solution Walk the Sine is a design that functions primarily as a walkable path between buildings at Zane Middle School Middle School shown in Figure 10 below. This solution contains math concepts, formulas, and examples specific to 7th grade and specifically target the aesthetic, educational value, and inspiring criterion. Point 1 in the figure displays the concrete walkway connecting to the math classroom. Point 2 shows a connected circular concrete pad which demonstrates how to solve for circumference and area of a circle. A stained red concrete dot will mark the center point of the circle, where one student could stand connected to other students' arm-length apart to interact with radius, diameter, and circumference. Point 3 marks the second concrete pad within the path that contains fundamental math information such as slope formulas, finding the angles of triangles (SOHCAHTOA), a negative-to-positive integer list, etc. Point 4 on the figure represents the final circle in the path which would demonstrate a basic mnemonic solid knowledge through angle-finding examples while allowing students to calculate the area of a multitude of geometric shapes.

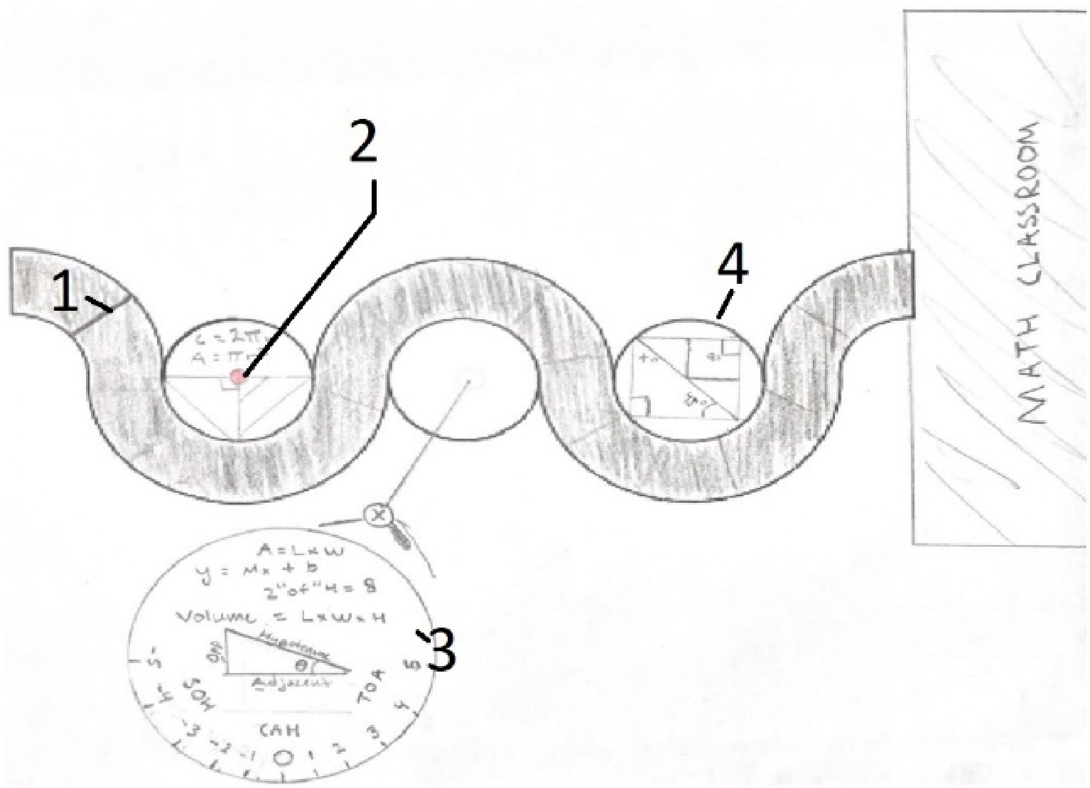


Figure 11: Walk the Sin, Avery Tunnicliff

3.3.3 MATH LAND

Math Land is another competitive math game that is based on the award-winning board game “Candyland”. The idea of the game is to progress on a path that has different math problems at each tile or square. Each tile or square would consist of a different texture. While progressing on the path there are shortcuts that consist of more advanced or difficult math problems. Something that could potentially be implemented is a system that sends you backwards if incorrect answers are given. As the game progresses, math problems would likely become more difficult. The shape of the path would be designed to fit inside of a rectangular area. The medium of construction would likely be imprinted concrete. Shown below in ***figure 11*** is a diagram of Math Land.

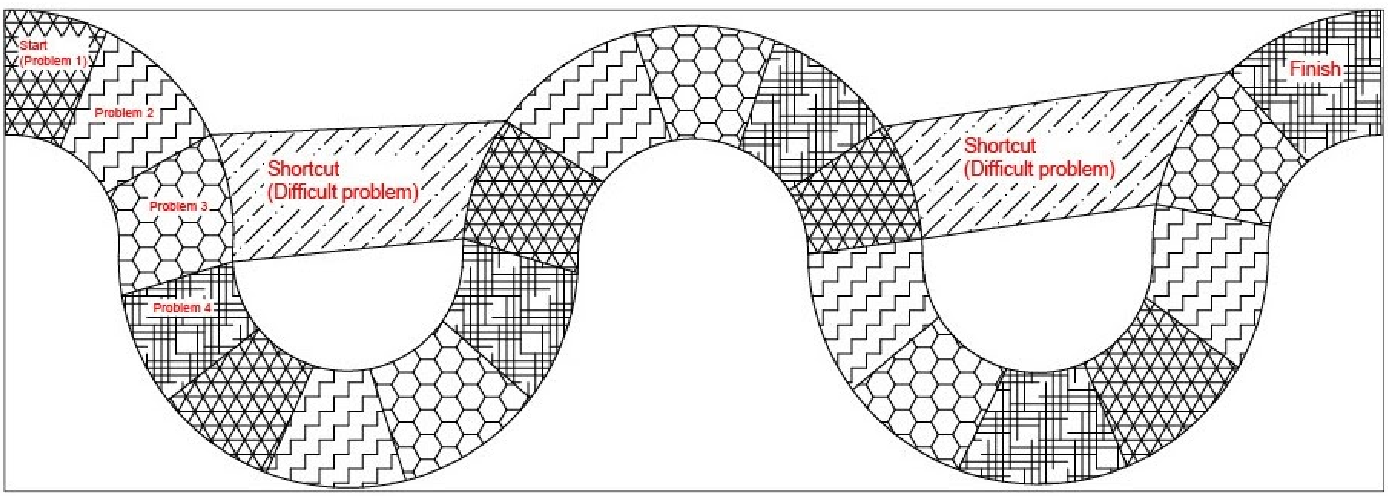


Figure 12: Math Land, Steven Camara

3.3.4 THE ARITHMETIC ARC

In the Arithmetic Arc solution, mnemonic solids are the emphasis of the walkway, which forms a horseshoe shape linking the 7th-grade classroom to the rest of the school (shown in figure 12 below). Point 1 in ***figure 12*** depicts the concrete sidewalk that starts from the math building and borders the imprinted content within. Point 2 displays a circular concrete pad containing a wide variety of mnemonic solids, general shapes, and how to solve for each of them. Trapezoids, circles, rectangles, and various triangles can be found within the path. Chalk can be implemented between shapes and lines to create a larger variety of polygons and angles to parallel concepts and topics covered in 7th-grade mathematics.

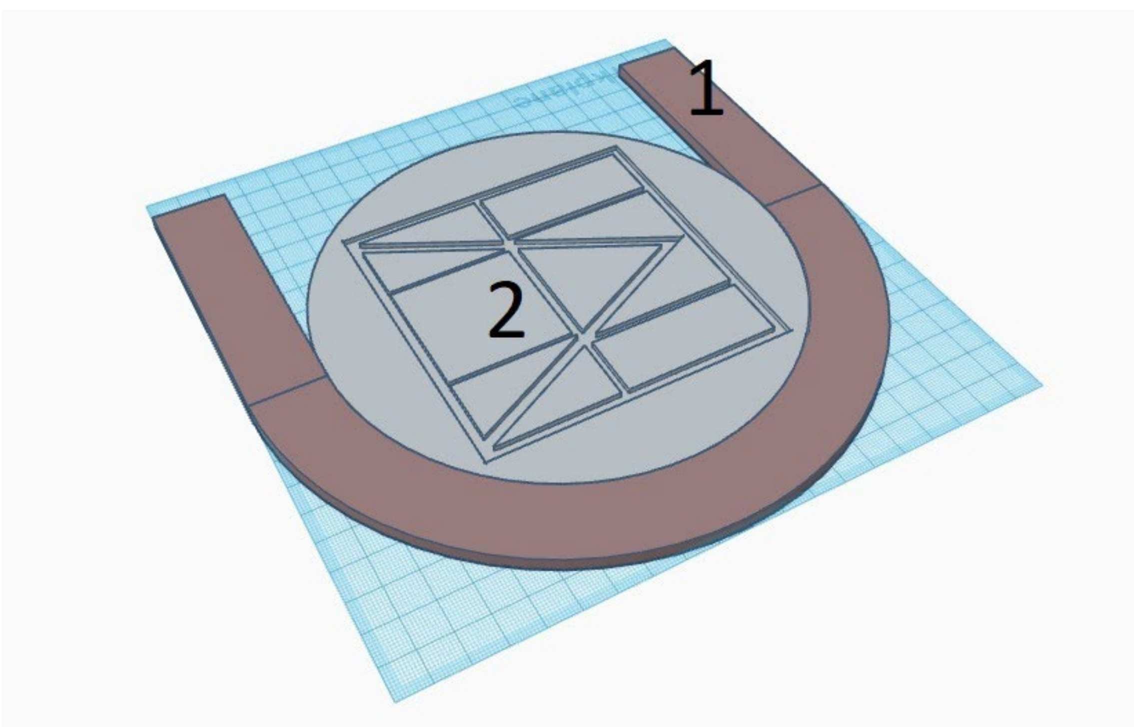


Figure 13: The Arithmetic Arc Alt. Solution, Avery Tunnicliff

3.3.5 CHEAT SHEET

A rectangle cheat sheet made from concrete which is walkable for students at Zane. It has a flat surface which at the same level of the ground so that there will be no water remaining after every time it rains. Most of the content is about geometry which includes area formulas of the 2-D shapes, volume and surface area formulas of 3-D shapes. There are formulas for ratios, proportional relationships, the number system, expressions, equations. There is one example of statistic and probability compound. Figures 13 – 16 show the cheat sheet.

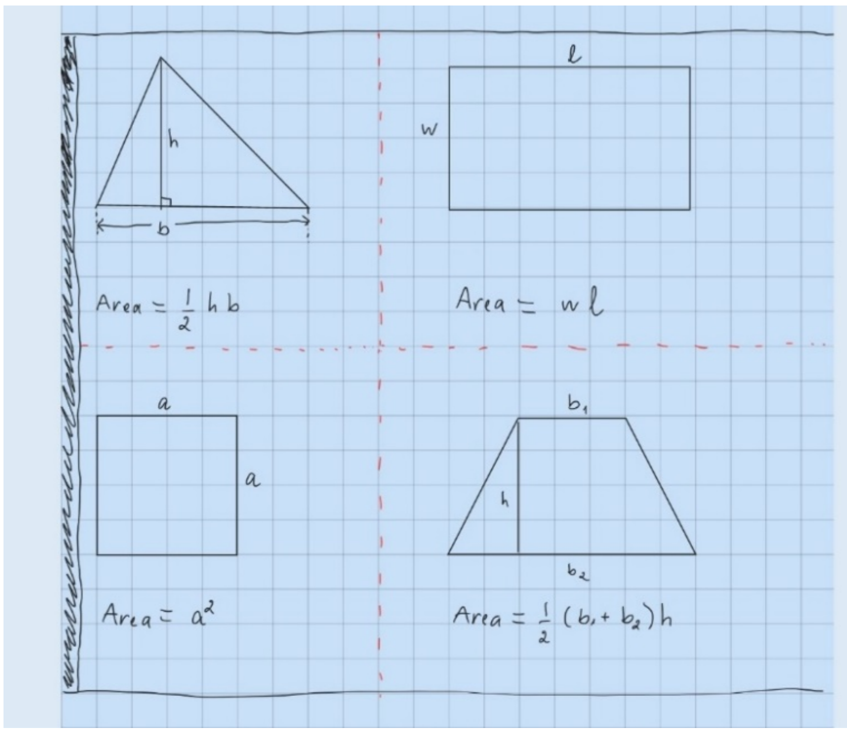


Figure 14: Cheat Sheet pt. 1, Minh Truong

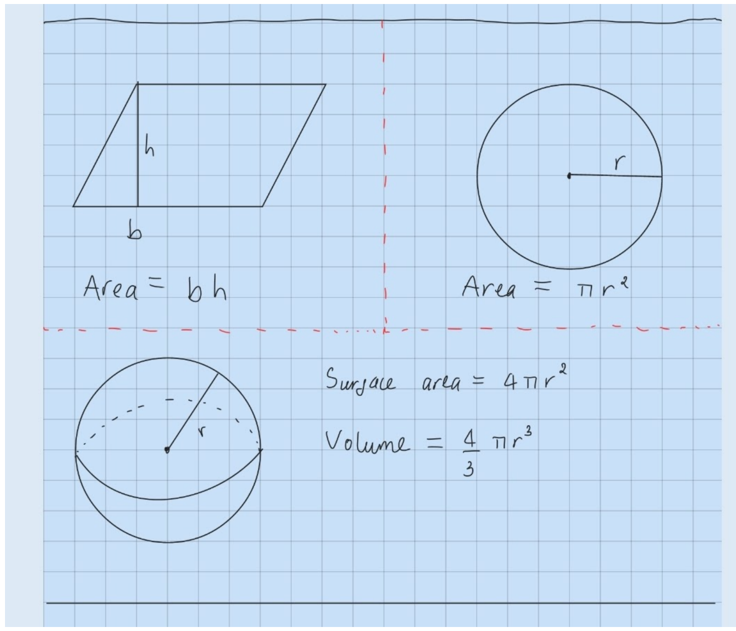


Figure 15: Cheat Sheet pt. 2, Minh Truong

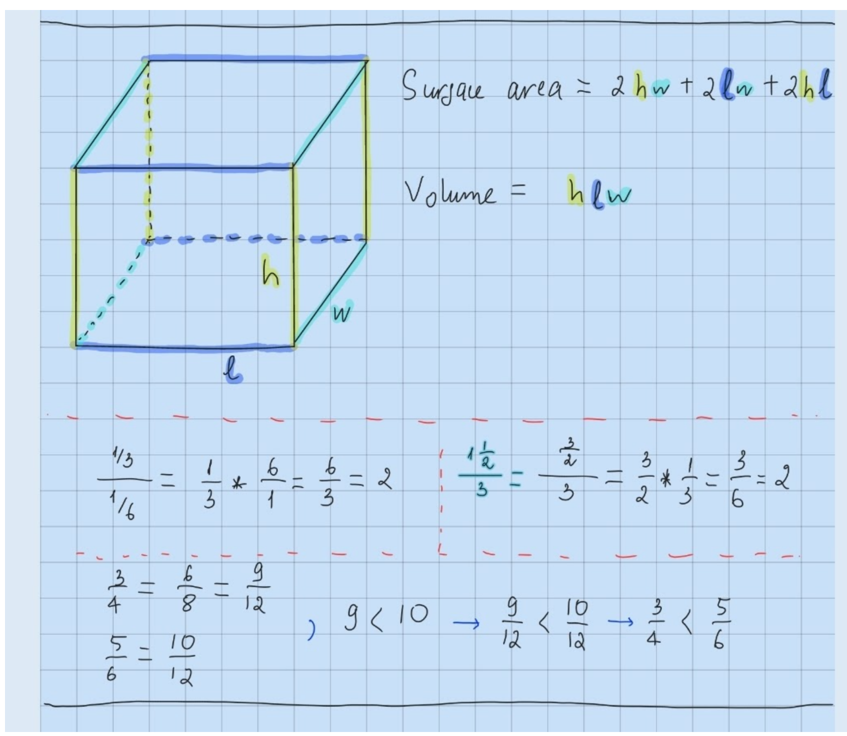


Figure 16: Cheat Sheet pt. 3, Minh Truong

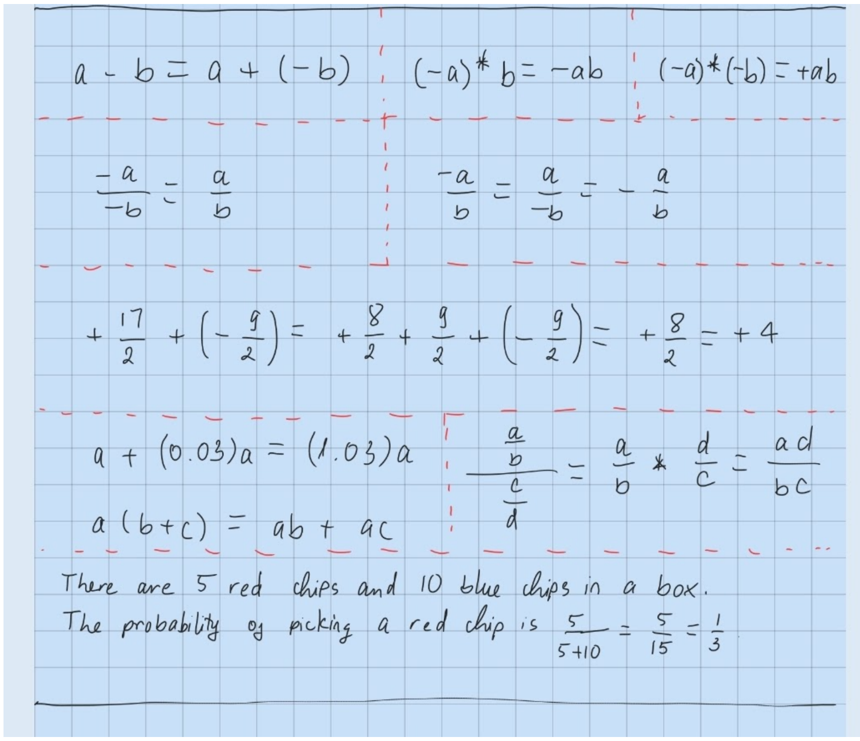


Figure 17: Cheat Sheet pt. 4, Minh Truong

3.3.6 FIBONACCI/GEOMETRY

A symmetrical figure of two Fibonacci sequences made from concrete in a rectangular shape. It's a walkable concrete surface. The largest length starts from 13 (unit) and the smallest length ends at 1 (unit).

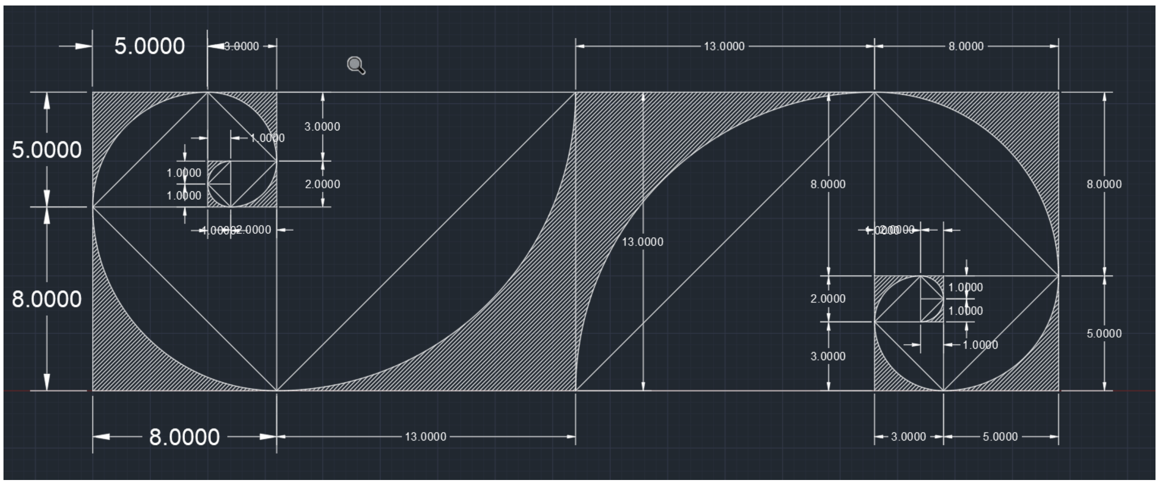


Figure 18: Fibonacci/Geometry, Minh Truong

4 DECISION PHASE

4.1 INTRODUCTION

The goal of the decision phase is to determine the final solution for the project. This section analyzes through the alternative solutions in section 3 by using a Delphi table. The Delphi table evaluates the alternative solutions in different weight that is established based on the criteria in section 2.

4.2 CRITERIA DEFINITION

The criteria in section 2 are listed and defined below to declare how each alternative solution in section 3 is evaluated:

Educational Value: The educational benefit from that the students can gain when they interact with the project.

Durability: The ability of the project that is long lasting after multiple uses and under varying weather conditions.

Level of Inspiration: The function of the project that promotes the interest of students in learning and applying mathematical concepts.

Aesthetics: The suitability of the project to the landscape and the theme of organization.

Safety: The ability of the project that meets the required standard of health and safety from related administrations with the material and structures used.

Interactiveness: The function of the project that has students joining as a group activity.

Accessibility: The function of the project that is physically and mentally accessible and inclusive to all ranges of students that could use the path.

Cost: The project follows the limitation of total cost that is arranged in section 2.

4.3 DECISION PROCESS

To narrow down and determine solutions in our design process, the team chose to use the Delphi method technique. The Delphi method functions by rating each solution out of a set value with respect to weighted criterion. For the purpose of the project, individual solutions were rated out of 100 while each criterion was weighted on a scale of 1-10, with 10 representing highest importance. Following the creation and formatting of the Delphi chart, the team held a virtual meeting to determine where how solutions meet each of the criterion. One member of the team was responsible for entering in values that had been determined, discussed, and agreed upon for each individual solution until the matrix was complete. The totals were gathered separately at the bottom of the chart representing how each solution satisfies the criterion overall. The three highest totals were chosen, and selected solutions were then presented to our client for further feedback in the decision process.

Table 6: Delphi Chart of Alternative Solutions

Criteria	Weight	Alt Solutions (0-100high)					
	(0-10high)	Comp. Conflict	Mathland	Arithmetic Arc	Walk the Sine	Cheat Sheet	Fibonacci/Geo
Educational Value	9	80 / **720**	75 / **675**	70 / **630**	80 / **720**	90 / **810**	65 / **585**
Durability	9	100 / **900**	100 / **900**	100 / **900**	100 / **900**	100 / **900**	100 / **900**
Level of Inspiration	7	60 / **420**	60 / **420**	60 / **420**	60 / **420**	60 / **420**	95 / **665**
Aesthetics	6	90 / **540**	80 / **480**	85 / **510**	90 / **540**	60 / **360**	96 / **576**
Safety	10	95 / **950**	90 / **900**	90 / **900**	90 / **900**	100 / **1000**	100 / **1000**
Interactiveness	6	95 / **570**	95 / **570**	70 / **420**	85 / **510**	90 / **540**	70 / **420**
Accessibility	10	95 / **950**	95 / **950**	95 / **950**	95 / **950**	95 / **950**	95 / **950**
Usage	8	80 / **640**	75 / **600**	78 / **624**	80 / **640**	95 / **760**	72 / **576**
Production Volume	5	100 / **500**	80 / **400**	90 / **450**	80 / **400**	80 / **400**	80 / **400**
Cost	8	65 / **520**	75 / **600**	85 / **680**	65 / **520**	65 / **520**	80 / **640**
		6710	**6495**	**6484**	**6500**	**6660**	**6712**

4.4 FINAL DECISION JUSTIFICATION

Using the Delphi method, we narrowed down our top three alternative solutions to Computation Conflict, Cheat Sheet, and Fibonacci. All three of these solutions are very similar in terms of construction process, expense, feasibility, and Delphi score. The main differences between them are in the specific content included in the designs which led to a prototyping process of each. After prototyping of each solution and consultation with our client, it was determined that we should combine ideas from each solution into one final design that incorporates themes and content from each solution. The final design will be a pad of concrete with imprinted mathematical designs including various 7th and 8th grade mathematical concepts, a Fibonacci spiral, and a template for a competitive math game.

5 SPECIFICATION OF SOLUTION

5.1 INTRODUCTION

In this section, the final solution of the math path chosen in the previous section will be described. Specifically, estimates on costs of materials, implementation, and maintenance are analyzed as well as the design cost. Alternatively, it also includes detailed descriptions of the final solution, prototype performance, implementation instructions, use, maintenance, and the results.

5.2 SOLUTION DESCRIPTION

The final solution of the math path is a combination of the Fibonacci spiral and 7th-grade geometric contents, we call it “Fibogeometry”. The final design has three main Fibonacci spirals bordered by rectangles that all have a width of 8.5 ft and a length of 13ft and 11 in. The middle rectangle is filled with the geometric math contents including a circle, triangle, parallelogram, trapezoid, and the Pythagorean theorem. The two rectangles on the sides are left blank. The gaps between the rectangles are 2.5 ft. The consequence series of each spiral are -blank-. An estimated vision of the design on the field can be seen in Figure 18 that has the three rectangles in a row inside the big rectangle of Doom.

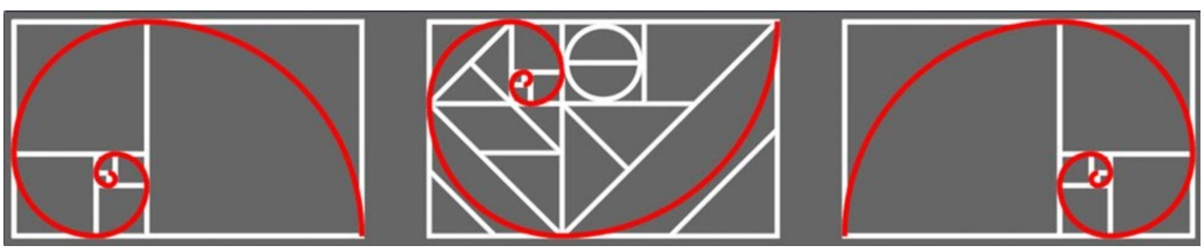


Figure 19: Final Fibogeometry Solution; 9 ft 3 in wide and 47 ft 4 in length.

Multiples of straight lines are painted by using white traffic paint with a thickness of 2 in. The straight lines create multiple squares that contribute the Fibonacci series and shapes within.

Fibonacci Spirals

The Fibonacci spiral is painted that fits the dimension of each small rectangle. The Fibonacci spirals have a thickness of 2 in and are painted with red traffic paint. Each

Fibonacci spiral is contributed by 9 segments of arcs that fit the Fibonacci series of the straight lines above.

Geometric Contents

In the middle small rectangle, the geometric figures can be recognized as being seen in the Figure 19.

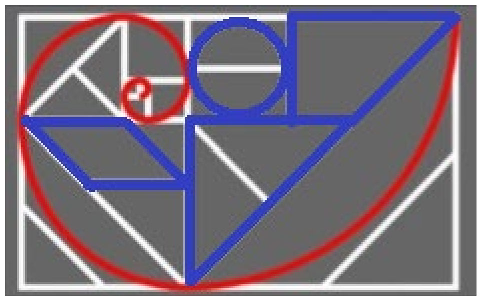


Figure 20: Geometric Contents

Equations

In the middle small rectangle, there are 5 geometric equations that are used to calculate the areas of the geometric figures above. The equation A=b*h is used to calculate the area of the parallelogram. The equation a2=b2+c2 is the Pythagorean theorem. The equation A=12*b*h is used to calculate the area of the triangle. The equation A=2r is used to calculate the Area of the circle. The equation A = 12*(a+b)*h is used to calculate the area of the trapezoid.

5.3 COST ANALYSIS

The contribution of estimates on costs of materials, implementation, maintenance, and design cost will be described in this section.

5.3.1 DESIGN COSTS

The design cost represents the amount of total group time (hours) spent on this project. The total group time consists of design hours, general course hours, and implementation hours. They can be seen as breakdowns in the Project Time Chart as the Figure -blank- shows below. The most time our team spent on this project is the design component. A total of 141/225 hours was spent in the design time which includes brainstorming, meeting clients, doing research, finding resources, prototyping, and testing. The next most time that was spent is the general course hours, 72.2 hours. This consists of writing project documentation, learning methods such as Auto CAD.

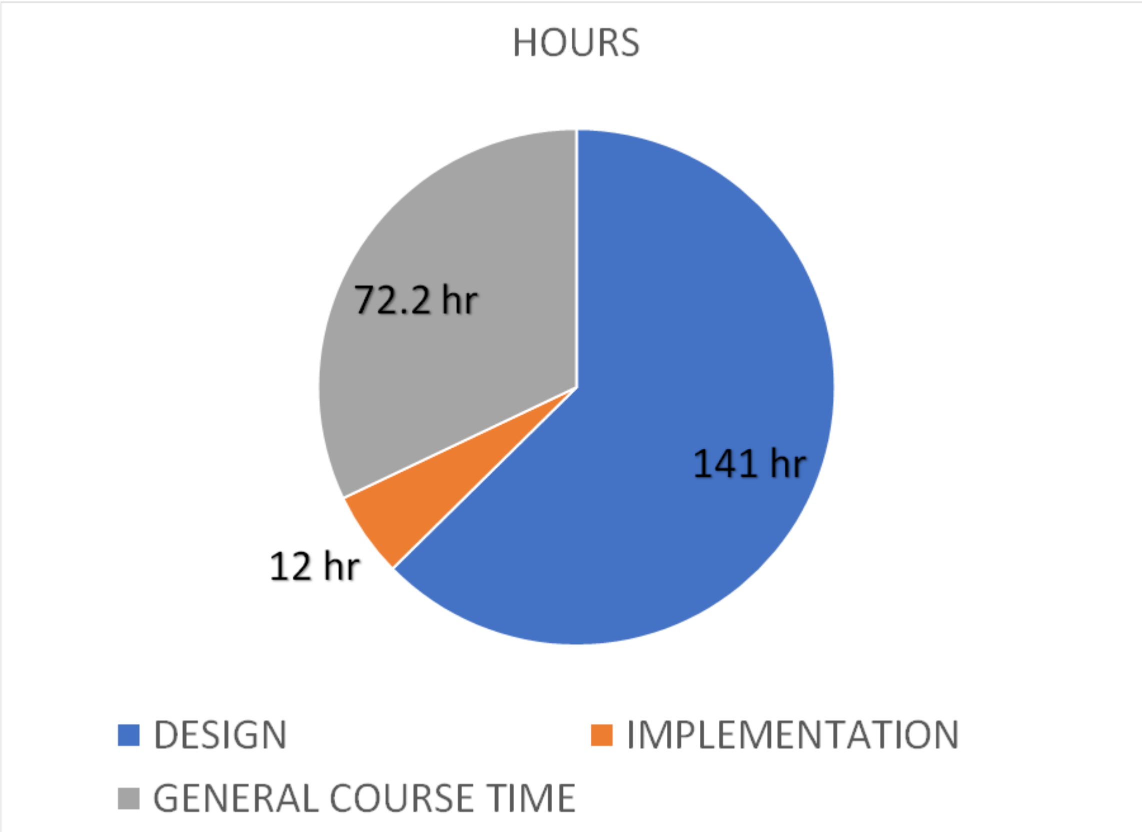


Figure 21: Project Time

5.3.2 COST OF MATERIALS

Table 7: Cost of Materials

Cost of materials	Number of Item	Price per item ($)	Price ($)
4'x5' Aluminum Sheets (0.063" Thick)	1	66.50	72.15
1 Gallon White Traffic Paint	1	19.99	21.69
1 Gallon Red Traffic Paint	1	19.99	21.69
Estimated O&M Labor costs (Stencil Cutout)	1	50.00	50.00
Duct tape	3	6.31	20.54
1 Sqft Concrete paver	4	2.49	9.96
Total			**196.03**

5.3.3 IMPLEMENTATION COSTS

Since the implementation is done by our group members so there is no cost of implementation contributed in this project.

5.3.4 MAINTENACE COSTS

The Fibogeometry project will need maintenance every 5 years. In Table X below, necessary materials for reparations are listed opposite costs.

Table 8: Cost of Maintenance

5-year Maintenance Cost	Number of Item	Price Per Item ($)	Price ($)
1 Gallon White Traffic Paint	1	19.99	21.69
1 Gallon Red Traffic Paint	1	19.99	21.69
Duct tape	3	6.31	20.54
Total			**63.92**

5.4 CONSTRUCTION

5.5 MAINTENANCE

5.6 IMPLEMENTATION INSTRUCTIONS

5.7 PROTOTYPE PERFORMANCE

6 APPENDICES:

6.1 A. REFERENCES

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6.2 B. ...

6.3 C. ...(AS NEEDED)