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1 Problem Formulation

1.1 Introduction

In Section 1 of the design process, the formulation of the objective statement will be presented. A black box model of the design process is shown in Figure1-1.

The client is Zane Middle School. Zane is a 6th-8th grade Magnet school with STEAM (Science, Technology, Engineering, Art, and Math) being the focus for the future. Zane formed a partnership with Humboldt State University (HSU) around STEAM principles. The HSU course Intro to Design includes a group project which tasks engineering students with building a structure or apparatus relating to STEAM. For the Spring 2015 semester at HSU, Team GID (Get it Done) has been tasked to build a probability machine for Ken Pinkerton, a teacher at Zane Middle School. The probability machine fits into Zane Middle School's STEAM curriculum, because the probability machine will be designed to provide middle-school students with a hands-on demonstration of the mathematical concept of probability.

1.2 Objective

The objective of this project is to design a probability machine that demonstrates probability using hands-on physical methods for Zane Middle School engineering students. The probability machine must educate middle-school students on the mathematical concept of probability, must be safe for children to operate, and must cost no more than \$400.00 to build.



Figure 1-1 By the end of this project, Zane Middle School will have a probability machine that shows students how probability works.

2 Literature Review

2.1 What is Probability?

2.1.1 Definition

Probability is a likelihood or chance of something. People use the concept of probability to estimate the chances of an occurrence. Many of these methods of estimation involve the use of past experiences to predict what will happen in the future. Probability can be described as the mathematical theory of uncertainty (Isaac, 1995).

2.1.2 Significance

What makes the theory of probability stand out in mathematics is the inconsistency of final results. Probability can be measured by using mathematical formulas, but that does not mean the final results will reflect that number. The probability of a flipped coin landing on heads is 50%, but there is still a possibility that a trial of four coin flips will result in three heads and one tails. Even if the coins were flipped with the same amount of force and at the same angle, the results would still remain unpredictable due to the “uncertainty principle,” which dictates that it is impossible to predict the exact position and direction of very small particles (Isaac, 1995).

Despite these limitations, probability can still be a useful tool to help make unpredictable phenomena more predictable. Even if results do not perfectly reflect the calculated probability, they are still consistent enough to merit the use of the concept. As long as there are many trials or possible outcomes, the results should remain consistent with the calculated probability (Isaac, 1995).

2.2 Mathematical Description

2.2.1 Mathematical Definition

The mathematical definition of probability can be represented by the formula

$$\text{Probability of Favorable Results} = \frac{\text{Number of Favorable Results}}{\text{Total Number of Trials}}$$

By this mathematical definition, probability must be a number between zero and one, where a probability of zero is an impossible result, and a probability of one is a sure thing (McGervey, 1986).

2.2.2 Pascal's Triangle

Named after the French mathematician Blaise Pascal, the Pascal's Triangle has a wide variety of uses in mathematics. The Pascal's Triangle is oftentimes used for the expansion of binomial series'. Pascal's Triangle also has a place in the calculations of probabilities. By using the mathematical definition, it's easy to determine that a flipped coin landing on heads has a probability of 50%. However, in order to calculate the probability of a coin landing on heads three times in a row, Pascal's Triangle can be used.

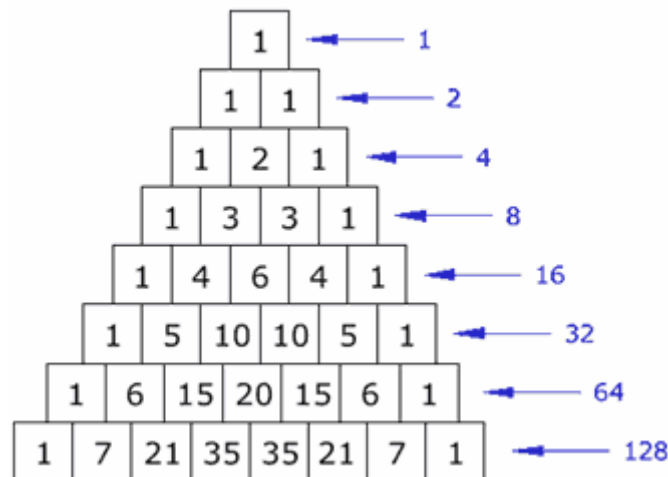


Figure 2-1 Pascal's Triangle can be used to determine the probability of something happening more than once (Math is Fun, 2014) <<http://www.mathisfun.com/images/pascals-triangle-4.gif>>

Each number of Pascal's Triangle can be calculated by taking the sum of the two numbers above the number intended to be calculated. The numbers on the right of the triangle in Figure 2-1 are the sums of each row, which we will call "S". The variable "k" will represent a number in Pascal's Triangle, and "n" is the row number that contains "k." The sums of each row form a pattern, one which can be represented by $S=2^n$. To calculate each probability P in this new binomial triangle, take the quotient of k and S (Killian, 1976).

$$P = k/S \text{ or } P = k/2^n$$

In Figure 2-2, if the result is heads, shift down to the left, and, if the result is tails, shift down to the right. To determine the probability of three coin flips all landing on heads, go to row three and shift to the far left. The probability of such an outcome is 0.125.

Table 1 The Binomial Probability Triangle shows the probability of each possible outcome of many coin flips (Killian, 1976).

Probability Triangle					
Row #					
0	1.000				
1	0.500	0.500			
2	0.250	0.500	0.250		
3	0.125	0.375	0.375	0.125	
4	0.0625	0.250	0.375	0.250	0.0625

2.3 Applications of Probability

2.3.1 Gambling

In gambling, probability can be used to determine whether or not a bet is in one's favor. For example, by using the formula in the Mathematical Description section, one can determine that the probability of rolling a seven on two six-sided dice is $1/6$, while the probability of rolling a six is only $5/36$ (McGervey, 1986).

Another example of probability in gambling is the probability of drawing an ace in a game of poker. Assume that two players are playing with a deck of 52 cards, and each player has 5 cards. One player wishes to exchange two of his/her cards for potentially getting two aces. Assume that there are four aces in the deck and that neither player currently has an ace. This formula can be used to help calculate the probability of two events occurring back-to-back:

$$P = A * B$$

Where P is the total probability, A is the probability of event one happening and B is the probability of event two happening (McGervey, 1986). Since both players have five cards, there are 42 cards in the deck now, so the probability of drawing one ace (probability A) is $4/42$, or $2/21$. Next, we will determine probability B. Keep in mind that there are 41 cards in the deck now that the first ace was drawn, so probability B is $3/41$. The total probability is the product of A and B, which is $2/21 * 3/41 = 6/861$, or about 0.7%. Therefore, although this exchange may have positive results, this player should not get his/her hopes up for two aces!

2.3.2 Statistics

We already somewhat delved into statistics in the Pascal Triangle section, but we can delve even further by plotting a bell-shaped curve. Something worth noting about the binomial triangle

in Figure 2-2 is that, for each row, the probability is at its greatest in the center. This result reflects the probability of a flipped coin landing on heads, which is 50%. Therefore, a bell-shaped curve of number of heads vs number of possible results will peak at the mid-point of the x-axis.

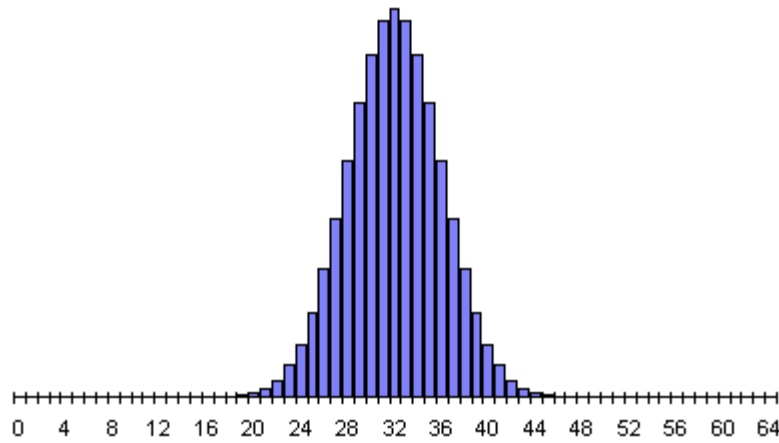


Figure 2-2 The bell-shaped curve peaks at the midpoint, because the probability of a coin landing on heads is 50% 0.5 (Walker) <<https://www.fourmilab.ch/rpkp/experiments/figures/bd64.png>>

2.4 Children Learning Styles

2.4.1 Grade 6-8 Teaching Methods

Have kids work in small or big groups and ensure all the kids are included in all work; do not allow the kids to be grouped with friends often, have the kids sit with other peers in the classroom. It is good to make every student feel important in his or her efforts to contribute and to never embarrass a student in front of their peers. Make questions for the kids challenging enough to have them think for extended periods of time, also have the children work for the answer rather than giving the answer out. Teach the kids how to make decisions from planning and to break down the tasks they are assigned because not all of the kids will understand complex language (Methods For Teaching Middle Schoolers, Unknown).

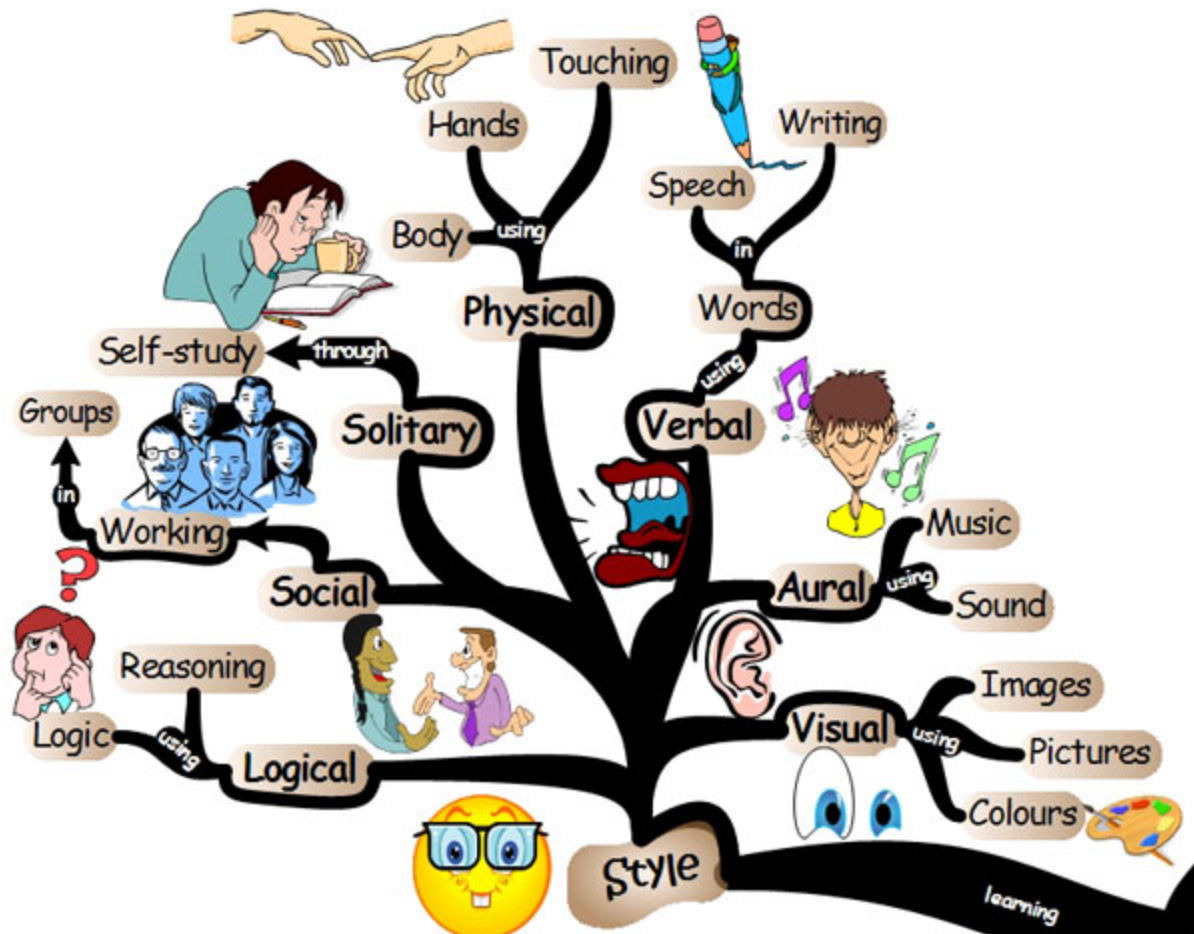


Figure 2-3 Learning Methods <http://www.ccsf.edu/content/ccsf/en/about-city-college/slo/professional_development/learning_styles/_jcr_content/contentparsys/imagebanner/image.img.jpg/1360704177544.jpg>

2.4.2 Core Curriculum

The kids will have to be able to cite the text and be able to prove their stance. The kids will have to be able to write a summary of the text only due to their prior knowledge of it. The kids will have to be able to follow distinct steps to a process. The kids will have to be able to understand and read independently at a satisfactory level (English Language Arts Standards>> Science & Technical Subjects>> Grade 6-8, 2014). For grade 6 the California State Board of Education says that the 6th graders should cover four major points in mathematics. Two of these four points apply to our project which are making connections from ratios and whole numbers using multiplication and to develop an understanding of statistical learning (California State Board of Education, 2014). For Grade 7 the students will need to develop an understanding of and applying proportional relationships (California State Board of Education, 2014). For Grade 8 the standards say that they must capture the concept of a function and using functions to describe quantitative relationships (California State Board of Education, 2014).

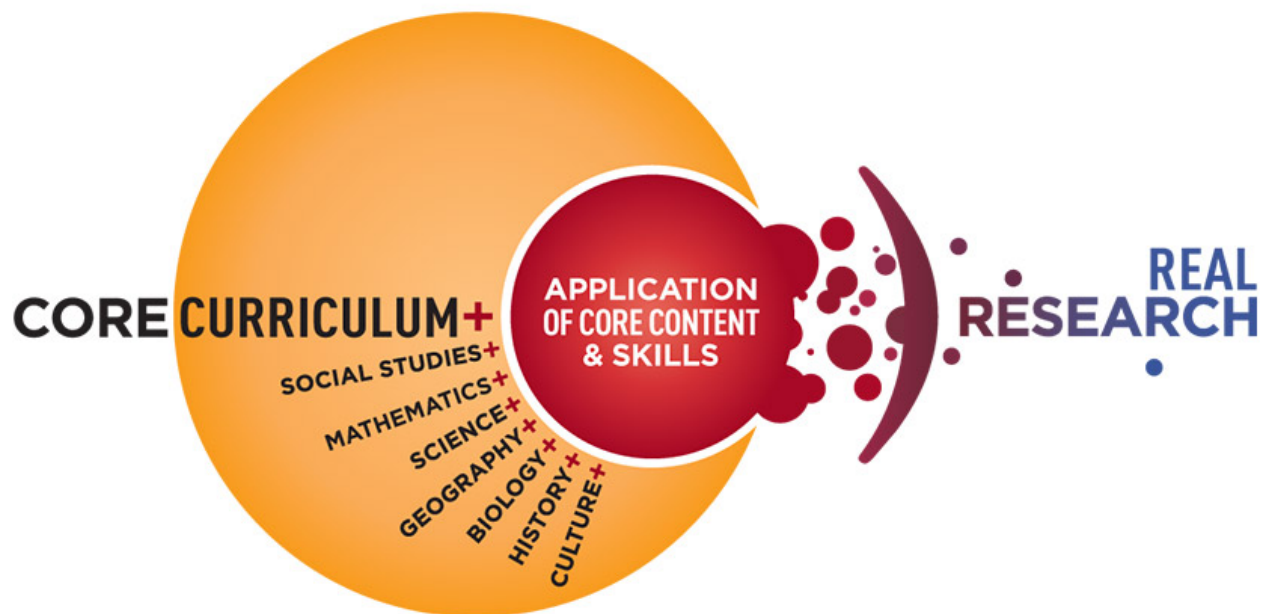


Figure 2-4 Core Curriculum <http://thinkglobalschool.org/wp-content/themes/tgs-theme/images/core_curriculum.jpg>

2.4.3 Pedagogy

Pedagogy is the method and practice of teaching. Engaged pedagogy supports student activities when the instructor takes on the role of being the facilitator rather than being the dominant figure in the classroom. Usually this method has a high student learning statistic (Library, 2014).

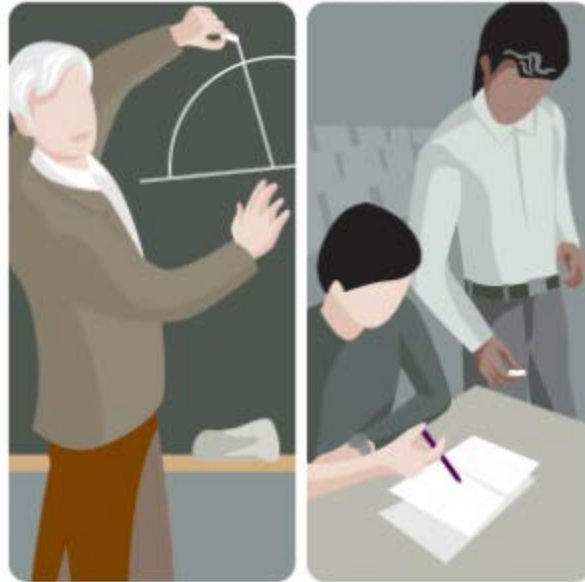


Figure 2-5 Pedagogy

http://learndat.tech.msu.edu/sites/default/files/styles/in_content/public/Characters01.jpg?itok=jlmMyUU4http://learndat.tech.msu.edu/sites/default/files/styles/in_content/public/Characters01.jpg?itok=jlmMyUU4

2.5 School Curriculum

Zane imposes the program of STEAM: Science, Technology, Engineering, Art and Math. STEAM is used for preparing students for the skills needed in the 21st century's workforce. The main goal is to teach the needs of today's society while satisfying the student's interests (Eureka City Schools, 2015).

2.6 Examples

2.6.1 Galton board

A Galton board also known as a quincunx or a bean machine, is a vertical board with pins or wedges placed in offset rows. The top of the Galton board has a funnel that directs balls that are dropped into the machine onto the first pin or wedge. The balls then bounce off of each pin or wedge; with each bounce the ball will either fall to the left or right of the pin, with equal probability (Hilsenrath and Field 1983). Once a ball falls all the way through the pins it falls into it's a column. The purpose of a quincunx is to demonstrate deviation, the more layers of pins used and the more balls used the closer the end result will be to a standard deviation curve (Chernov and Dolgopyat 2009). The curve can be skewed by moving pins or slanting the entire bean machine (Hilsenrath and Field 1983).

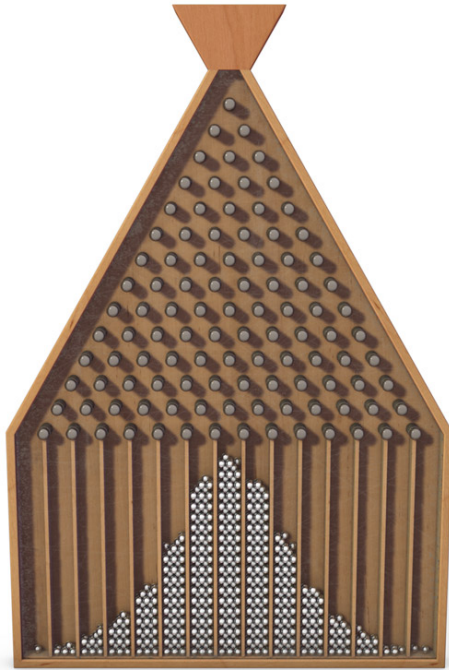


Figure 2-6 One example of a quincunx machine
<http://www.etereaestudios.com/docs_html/inspirations_htm/maths_index.htm>

2.6.2 Roulette wheel

Roulette wheel is a casino game that involves a large wheel with the numbers 00,0, and 1-36. Half of the numbers are black and the other half are red with the exception of 0 and 00 they are green. The numbers are ordered on the wheel such that large numbers alternate with smaller numbers and even numbers alternate with odd numbers. During game play the player places a bet predicting where a ball will land on the wheel then a ball is rolled along a groove and the wheel is spun in the opposite direction as the ball slows it falls out of the groove and lands into the wheel. Players can bet on: a single number, two numbers, three number, four numbers, six numbers, twelve numbers or eighteen numbers. A single number bet pays 35 to 1 but the chances of winning, assuming even probability of landing on any given tile, are 1 to 38 ("Roulette", <http://www.math.uah.edu/stat/games/Roulette.html>). An off balance wheel can have skewed probability for landing on a given number (Ethier 1982).



Figure 2-7 An example of a roulette wheel <<http://fineartamerica.com/featured/the-roulette-wheel-tom-conway.html>>

2.6.3 Lottery machines

2.6.3.1 Air powered lottery machines

Air powered lottery machines blow air into a clear enclosure filled with light plastic balls, usually numbered one through fifty. There is one hole in the top of the machine that the air or balls can escape through. The air rushing through the enclosure causes the balls to bounce around and randomly hit the hole in the top and get blown out. In order for the machine to be completely random all of the balls must be weighted equally, lighter balls are more likely to be selected (Karim nice).

2.6.3.2 Gravity powered lottery machines

In Gravity powered lottery machines numbered balls are dropped in to an enclosure that has two paddles spinning in opposite directions that mix the balls. Once the balls are sufficiently mixed they are let out through a door that is controlled by an optical sensor, at the bottom one at a time (Karim nice).

2.6.4 Pachinko Machine

A Pachinko machine is an arcade game from Japan that is frequently used as a gambling device. A Pachinko machine consists of a vertical board with pins placed in a design and pockets that reward the player with extra game pieces if a ball makes it in them. The player uses a spring and plunger to shoot the balls in to the game board at varying velocities. If the ball

makes it in to a winning pocket 10-15 more balls are rewarded. If the ball does not make it in to a winning pocket it is collected by the Pachinko machine (Dan Reed.).



Figure 2-8 One example of a pachinko machine <<http://pachinkoparlour.blogspot.com/2012/03/more-pachinko-machine-pictures.html>>

2.7 Teacher Criteria

Ken Pinkerton has requested a model that would demonstrate probability. The goals of this project are to create a machine that can clearly demonstrate probability mathematically and visually while being interactive with the students. The machine should be durable, moveable, and easily storable in a small space.

2.8 Building Materials

2.8.1 Acrylic

Acrylic is a plastic that is similar to glass but created from polymers of acrylic acid or acrylates. Acrylic is a light weight material, one square foot that is 1/8" thick weighs in at less than 3/4 of a pound. In comparison to glass acrylic is soft, which allows it to break into large pieces with softer edges. Because of the softness characteristic acrylic has, cleaning and handling should be done carefully. Acrylic is also strong but if continuous force is applied then only a maximum force of 1500 psi should be exerted. The softness allows the acrylic to be easily cut and glued to other surfaces making the loss of strength from gluing negligible. If caught on fire, acrylic will decompose into water and carbon dioxide. If there is not enough air to react then carbon monoxide may form. (Evonik Industries, 2008)



Figure 2-9 Sheets of acrylic

http://www.tapplastics.com/product/plastics/cut_to_size_plastic/acrylic_sheets_clear/508

2.8.2 Glass

Glass is a hard, brittle surface, created from sand, soda, lime, and other chemicals. The weight of glass can vary depending on the type of glass but typically a 1/8" thick square foot sheet of glass weighs 3.5 pounds. Glass is stiff and brittle causing sharp rigid edges when broken. Glass has a hard surface making it easy to clean. The smooth texture of the glass makes gluing difficult and requires a special type of glue. Glass also requires special tools to cut. Glass Melts at extreme temperatures.



Figure 2-10 Sheets of glass

<<http://www.starfireglassandmirror.com/glass.php>><http://www.starfireglassandmirror.com/glass.php>

2.9 Problem Analysis

2.9.1 Introduction

The probability machine must be designed with a list of criteria in mind. The problem analysis contains constraints, specifications and criteria that have been selected with the client in order to insure that the final design can be easily and effectively implemented by the client.

2.9.2 Specifications

Specifications are constraints that must be met in order for the project to be successful. The specifications for the probability machine are that it is:

- Interactive with the students
- Storable in a crowded class room
- Completed before the math fair (April 26, 2015)

2.9.3 Criteria

Criteria presented in a table with constraints ordered by weight. The higher the number for the weight, the more important the criteria is. The educational value and safety are the more important.

Table 2 Criteria ordered by descending importance.

Criteria	Weight	Constraints
Educational Value	10	Demonstrates probability to 6-8 th graders.
Safety	10	Meets district standards.
Ease of Interaction	8	Students must take some part in using the machine.
Durability	8	Remains operational and scratch resistant.
Aesthetics	6	Attracts and keeps the attention of 6-8 th graders.
Portability	4	Easily moved by one adult.
Ease of Implementation	4	Less than 10 minute set up time.
Cost	3	Does not exceed \$400.

3 Alternative Solutions

3.1 Introduction

The Alternative solutions section includes descriptions of six different solutions that meet the client's criteria. During the brainstorming session, Team GID came up with 12 alternative solutions, and then narrowed them down to six alternative solutions. These six solutions are the Centrifugal Machine, Air Mix Lottery Machine, Distributer Machine, Lottery Launcher, Quincunx, and Skee Drop.

3.2 Centrifugal Machine

The Centrifugal Machine consists of four major parts. The first part contains two clear 2' long tubes. One tube is fitted inside of the other and both are just wide enough for a ping pong ball to fit through. The outer tube has a nob attached to allow sliding up and down around the inner tube. The inner tube has a four equal way divider at the bottom. Each divide has its own small opening. Next is a 1'6" wide, 9" tall cylindrical clear tube with a black base. There are four holes equally spread out around the side-base of the cylinder. The first set of tubes sit inside the larger tube on the base. The smaller cylinders are vertical to the larger cylinder with the flat sides of the 1' 6" cylinder facing up and down. There are four spinning arms at the base in the middle of the larger cylinder. The spinning arms are attached to a small cylinder that fits around the two tubes that are in the center of the large cylinder to allow the arms to rotate freely. This cylinder also protrudes out the bottom of the larger cylinder where a spring loaded pull cord is attached to spin the cylinder and arms when the machine is in use. The machine has four tubes that are 3' long and wide enough for a ping pong balls to fit through. Each tube has an opening at one end. These tubes are attached to the side-base of the largest cylinder facing down to catch the ping pong balls as they come out of the four openings on the cylinder base. These tubes act as legs for the machine and hold the larger cylinder off the ground. The openings at the bottom have movable latches to remove the ping pong balls.

The operation of the Centrifugal Machine involves a number of steps. First, ping-pong balls are added to the set of tubes that sit on the larger cylinder with the four-way divider shut. The pull cord causes the arms to rotate around the center tubes. The four-way divider is opened by lifting the outer tube by its knob, allowing the balls to fall into the largest cylinder. In the largest cylinder, the balls are forced to the outside by centrifugal force created from the rotating arms. The balls are then sent through the openings at the base of the larger cylinder. The balls land in the legs of the device and are collected by sliding up the latch at the bottom of the tubes.

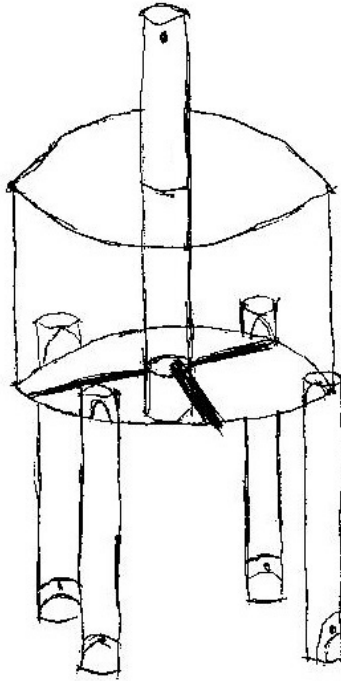


Figure 3-1 The Centrifugal Machine uses spinning arms and four chambers to demonstrate probability.

3.3 Air Mix Lottery Machine

A number of components make up the Air Mix Lottery Machine. The Air Mix Lottery Machine is composed of a container, ping pong balls inside the container, tubes, vents at the top of the container, and an air jet power source. Figure 3-3 illustrates how an air mix lottery machine is designed.

The selection process of The Air Lottery Machine will be discussed. As shown in Figure 3-3, The Air Mix Lottery Machine is powered by an air jet at the bottom of the container. The air jet mixes the balls, and the vents at the top of the machine manually open to allow air to escape the machine. The air jet and the vents create an upward force of air that carries randomly-selected ping pong balls through the tube. Gravity then carries the selected ping pong balls to a storage tube. The storage tube is for record-keeping and for showing which balls were selected (Nice, 2001).

The Air Mix Lottery Machine meets the client's criteria in a number of ways. In regards to aesthetics, the air mix lottery machine is composed of colored balls, because colors are attractive to middle-school students. The Air Mix Lottery Machine is also durable, because middle-school students are generally less careful than adults. Furthermore, the Air Mix Lottery

Machine is easily operated by middle-school students, because all that the users need to do is press a button.

The biggest challenge in building an air mix lottery machine is finding a safe and reliable source of air power. The client cannot provide such a source, and some sources, such as blow-dryers, can get dangerously hot. In order for the Air Mix Lottery Machine to be safe, a blow-dryer without the heating element is a better option for the air power source.

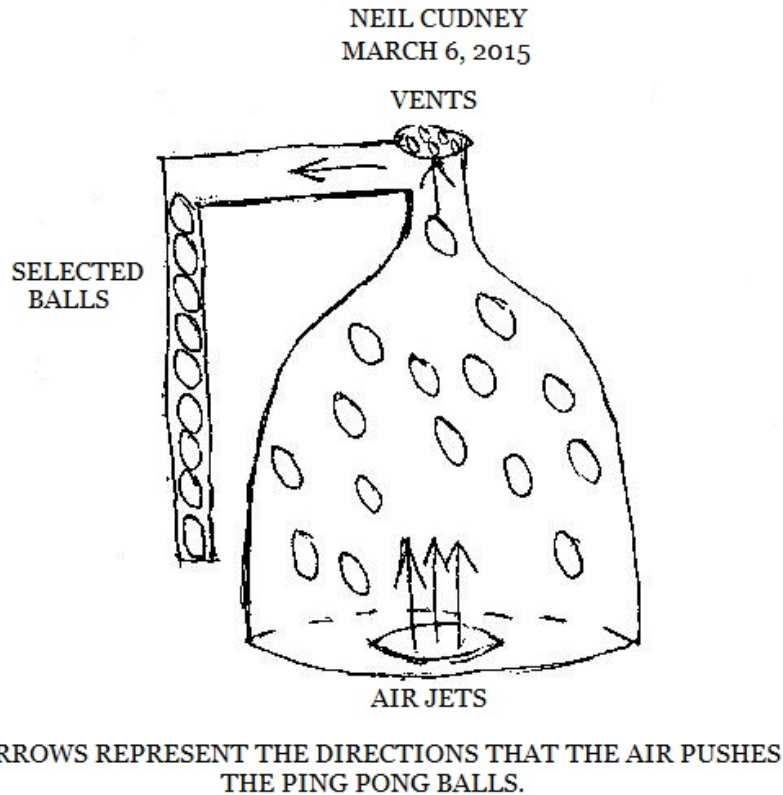


Figure 3-2: An air-mix lottery machine uses air pressure to randomly select a ping pong ball (Nice, 2001).

3.4 Distributer Machine

The Distributer Machine randomly distributes balls to one of the four chutes on the side. The chutes on the sides are clear so that the color and order of the balls can be observed by the students. The body of the machine is a cylinder to allow the ramp to rotate. The ramp is held in place by a drive shaft and rotated by the students using a recoil starter. A recoil starter is used in order to prevent students from rotating the ramp at a predictable speed. While the ramp is rotating, a ball is placed in the tube. Once a ball is placed in the tube, it falls down to the rotating ramp. The ramp then rotates until it is aligned with one of the collection chutes. The balls fall in

the collection chute to be displayed. The machine demonstrates a one in four probability of a ball falling into any given chute.

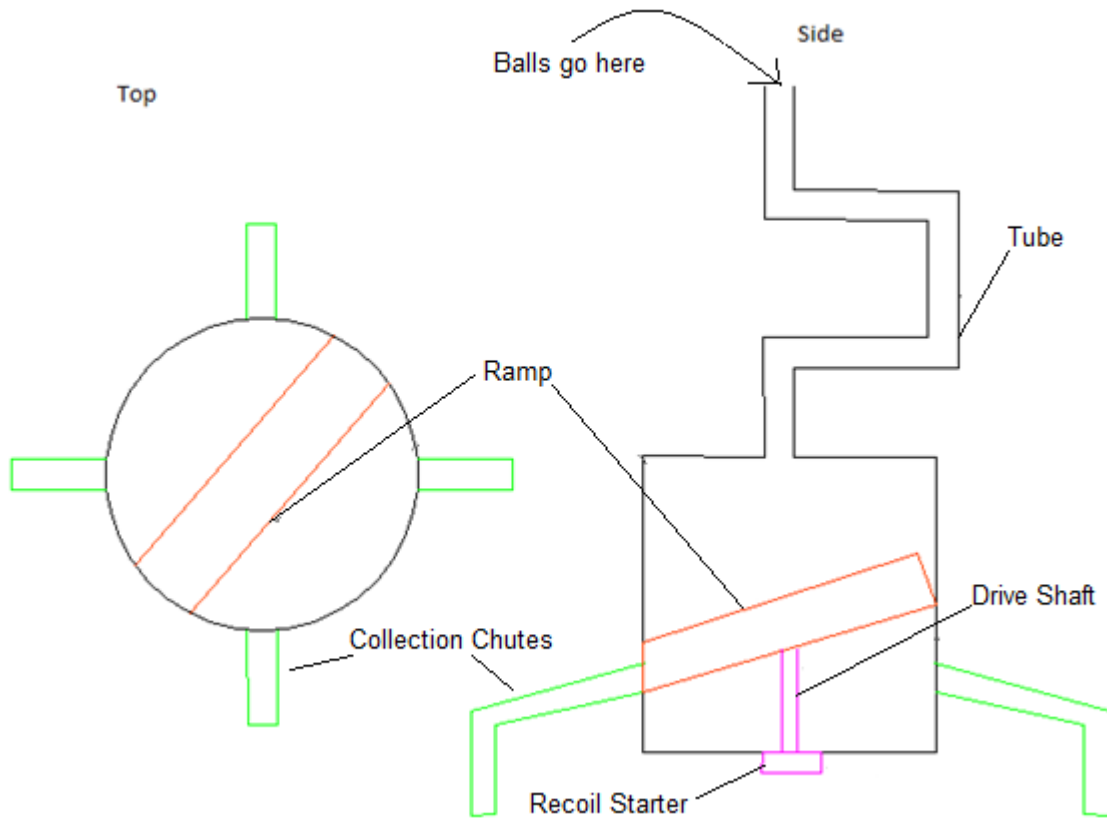


Figure 3-3 The distributor machine randomly sorts balls into one of the four collection chutes.

3.5 Lottery Launcher

The lottery launcher is similar to the air mix lottery machine but tosses the balls out rather than collecting them in a tube for viewing. The lottery launcher uses a fish tank for the body of the machine (C). The balls (E) bounce around the inside of the enclosure because the inside is slightly higher pressure than the outside. A large volume of air is moved across the enclosure by the fan (A) attached to the fan is ducting (B) that ensures the air moves across the enclosure and out the tube (D). The lottery launcher randomly ejects, every so often, one colored and/or

numbered ball (E) through the tube (D).

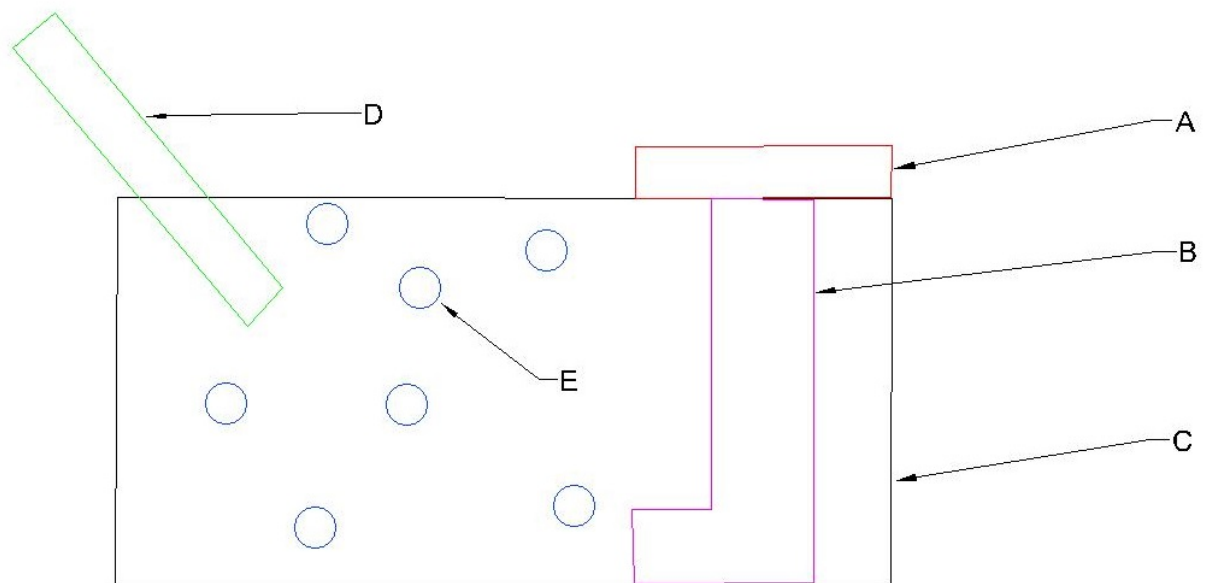


Figure 3-4 The lottery launcher tosses balls that are randomly selected by an air mix process.

3.6 Quincunx

A quincunx probability machine demonstrates probability using bb's and pegs within a 2-dimensional plane to show the likelihood of a bb falling in a certain chamber (Pierce, 2014). The pegs are attached to a rectangular surface, such as a board, in the shape of a triangle. Boards are placed parallel to the triangle's sides to ensure that all bb's remain in the triangular portion of the quincunx. To keep the bb's strictly in a 2-dimensional plane, a see-through surface, such as glass, vertically covers the surface of the quincunx. A specific number of chambers, equal to the number of peg rows plus one, are arranged in an equal manner at the bottom of the quincunx. The majority of the bb's fall into the center chambers and form a bell-shaped curve at the bottom of the quincunx. Figure 3-5 shows the arrangement of a quincunx with twelve rows of pegs and thirteen chambers.

The bb's enter at the funnel-shaped top of the quincunx and bounce either left or right on one peg in each row. The probability of a bb landing in a middle chamber is high, because that are plenty of pathways leading to the middle chambers. The probability of a bb bouncing in the same direction in all twelve rows is small, which is why the end chambers have the least amount of bb's.

The quincunx fits the client's criteria, because it is safe to use and very durable. A wide variety of probability lessons can be taught with the quincunx, including applications with Pascal's Triangle. The Quincunx has a picture of the Zane middle school falcon to draw the attention of the students.

The downside of the quincunx is the lack of student interactivity. The only interaction required for the quincunx is pouring bb's into the top funnel. Unloading and reloading the bb's at the bottom chambers can also prove to be inconvenient for continued usage. The bb's can be

unloaded by installing a removable compartment at the bottom to allow the bb's to be gathered in a bucket.

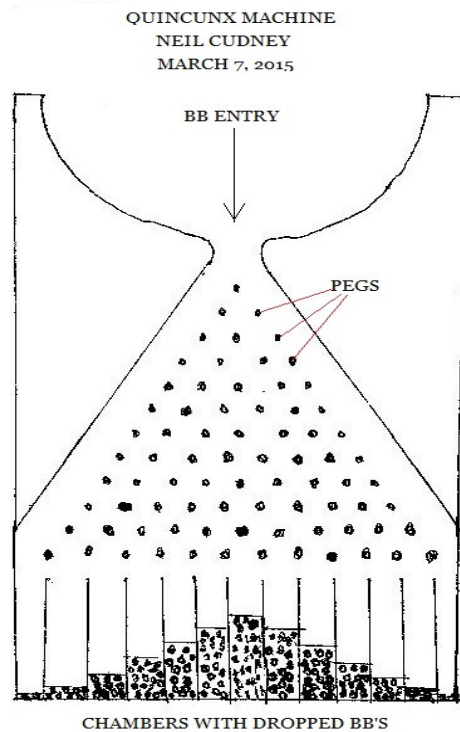


Figure 3-5: The quincunx machine shows that dropped bb's are more likely to land in center chambers than in side chambers (Pierce, 2014).

3.7 Skee Drop

The Skee Drop, shown in Figure 3-6, is a modified version of an arcade game. The bottom part of the machine has holes for the balls to drop into. Like the quincunx, the theoretical shape of the balls resembles Pascal's Triangle as well as the bell curve.

The process of the Skee Drop will now be described. The machine works by first dropping the balls into the top container that pivots in a full rotational motion. Once the ball falls out of the first container it then falls into the larger container that is filled with pegs to alter the drop path of the ball several times to prevent the same drop path of any two balls or more happening often. Once the balls drop through the larger container filled with pegs, they will fall onto the skee ball platform. In the figure, it shows an example of what the platform looks like. Unlike in the figure, the platform will be laid/set at a slight angle. Therefore, when the balls hit the platform, they will roll down into one of the skee ball holes, creating a trend in the middle which is similar to the bell curve.

This alternative solution meets the client's criteria in a number of ways. First off, the Skee Drop demonstrates probability to the students because of the formation of the bell curve once the balls reach a destined hole. The students will be able to drop the balls into the container and

control which direction the balls will shoot out from the pivot head into the container. The construction materials will be clear acrylic, which is more durable than glass.

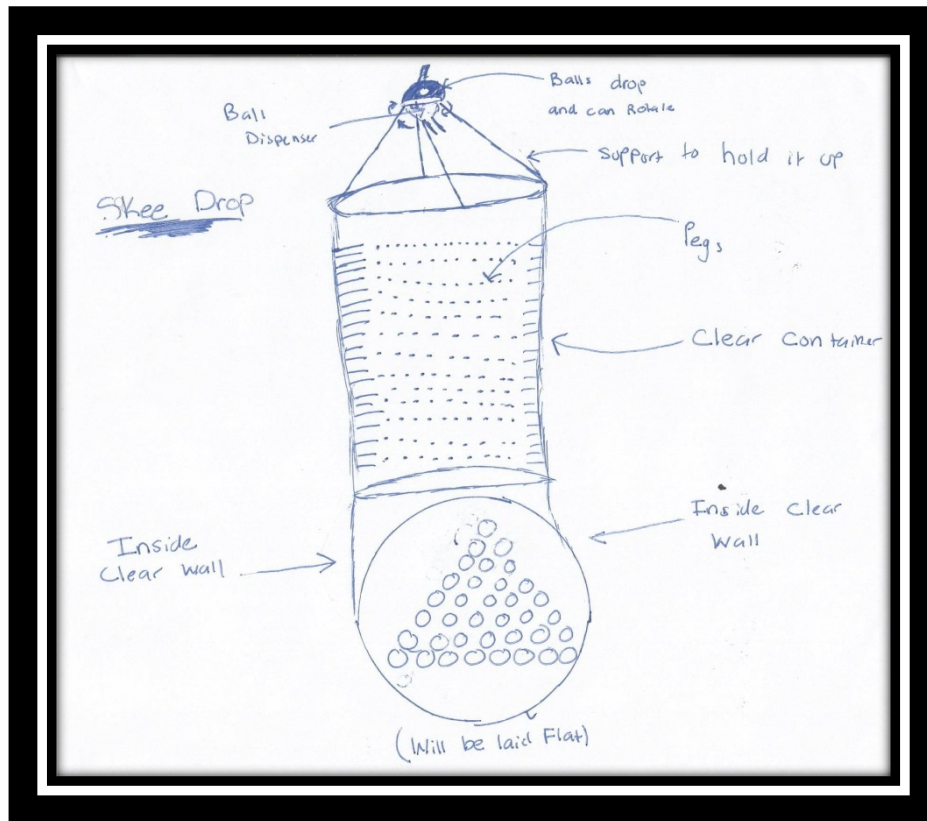


Figure 3-6 The Skee Drop machine shows how balls will be dropped from the pivotal head onto the slanted ramp, hitting the pegs, and rolling into the Skee ball holes creating The Bell Curve on the other side.

4 Decision Process

The alternative solution that GID has decided to use for the project is determined by the Delphi matrix. The Delphi Matrix is used to select the solution from our client criteria. We took into account the criteria as well as other things that could possibly be utilized in our alternative solutions. The alternative solution selected reflects the client's criteria the best.

4.1 Criteria Definitions

The criteria definitions help to determine the decision of which solution will best meet our client's needs. The definitions give more detail and direction to what the intent of the criteria is. More information about the criteria can be found in section 3.2.11 of the document.

Safety- Must meet district safety codes. The machine is able to be used improperly and still be safe.

Educational Value- The ability to visually teach students how probability works to 6th-8th graders.

Ease of Interaction- The machine should be simple so children can interact with it. No specialty tools should be needed when using the machine.

Durability- Withstands wear and tear from children for an extended period of time as well as functionality. Should be resistant to scratches in order to preserve the visual integrity.

Aesthetic- The ability to attract and keep the attention of 6th-8th graders. Supports school spirit by including school colors.

Portability- The ability to be easily moved by a single adult and easily fits through doorways.

Ease of Implantation- This can be described as the ability to fit through a doorway and to be moved by one or two people.

Cost- Defined as being able to keep the price of the machine affordable.

4.2 Solutions

This section posts the different possible alternative solutions from section 3. More specific information about the machine can be found in section 3 of the document.

Centrifugal Machine

Air Mix Lottery Machine

Distributer Machine

Lottery Launcher

Quincunx

Skee Drop

4.3 Decision process

In order to select which alternative solution would be implemented, all of the alternative solutions from section 3 were entered into a Delphi matrix. Each of the alternatives were rated on a scale of 1 to 10, 10 being the most important and 1 the least important, for each of the criteria. This score was then multiplied by the weight of the criteria. Criteria and weights can be found in detail in section 2.3. All of the scores from each criteria were added up for each of the alternative solutions and the solution with the most total points was selected.

Table 3 Delphi matrix outlining the merits of each of the alternative solutions.

Criteria	Weight	Centrifugal Machine	Air mix Lottery Machine	Distributer Machine	Lottery Launcher	Quincunx	Ski-drop
Educational Value	10	80	30	80	30	90	40
Safety	10	80	100	80	70	100	70
Ease of Implementation	8	72	48	72	36	48	72
Durability	8	40	64	40	64	72	40
Aesthetics	6	34	34	42	60	34	34
Portability	4	20	36	24	32	40	12
Cost	3	9	24	9	24	18	9
Totals		355	376	347	356	422	297

4.4 Final solution

The final solution that was chosen by the Delphi matrix was the quincunx as seen in table 1 with the highest overall score. It had the highest score in the Delphi matrix because it is simple, durable and, most importantly, it can be used to teach multiple different probability lessons using various equations and principles of probability. And with safety being a top priority, the quincunx has the smallest risk of injuring children.

5 Design Specification

5.1 Introduction

The specifications for a product are essential for its final design. The most common listed specifications include: the description of a solution, design costs, implementation costs, maintenance costs, instructions for implementation, how the model is used, and how the model will be maintained. These specifications can describe the final design. Testing the final design of the quincunx probability machine demonstrates how Pascal’s Triangle creates a bell curve.

5.2 Design description

The quincunx machine is a rectangular box that is five feet tall, three feet wide and one and a half inches in depth as seen in figure 37. There is a hopper at the top of the machine which feeds the balls into the center. The bottom foot of the machine is a drop chute that collects the balls by running them down a ramp to the side of the machine. The quincunx machine is made primarily from 1/8 inch aluminum sheet and 1/2 inch diameter aluminum round stock. The back board, chute and legs are all constructed from 1/8 aluminum sheet while the pins that are used to redirect the balls are made of 1/2 inch diameter aluminum round stock. The viewing area of the machine will have a face plate constructed from 1/4 inch Plexiglas that wraps around the side of the machine.

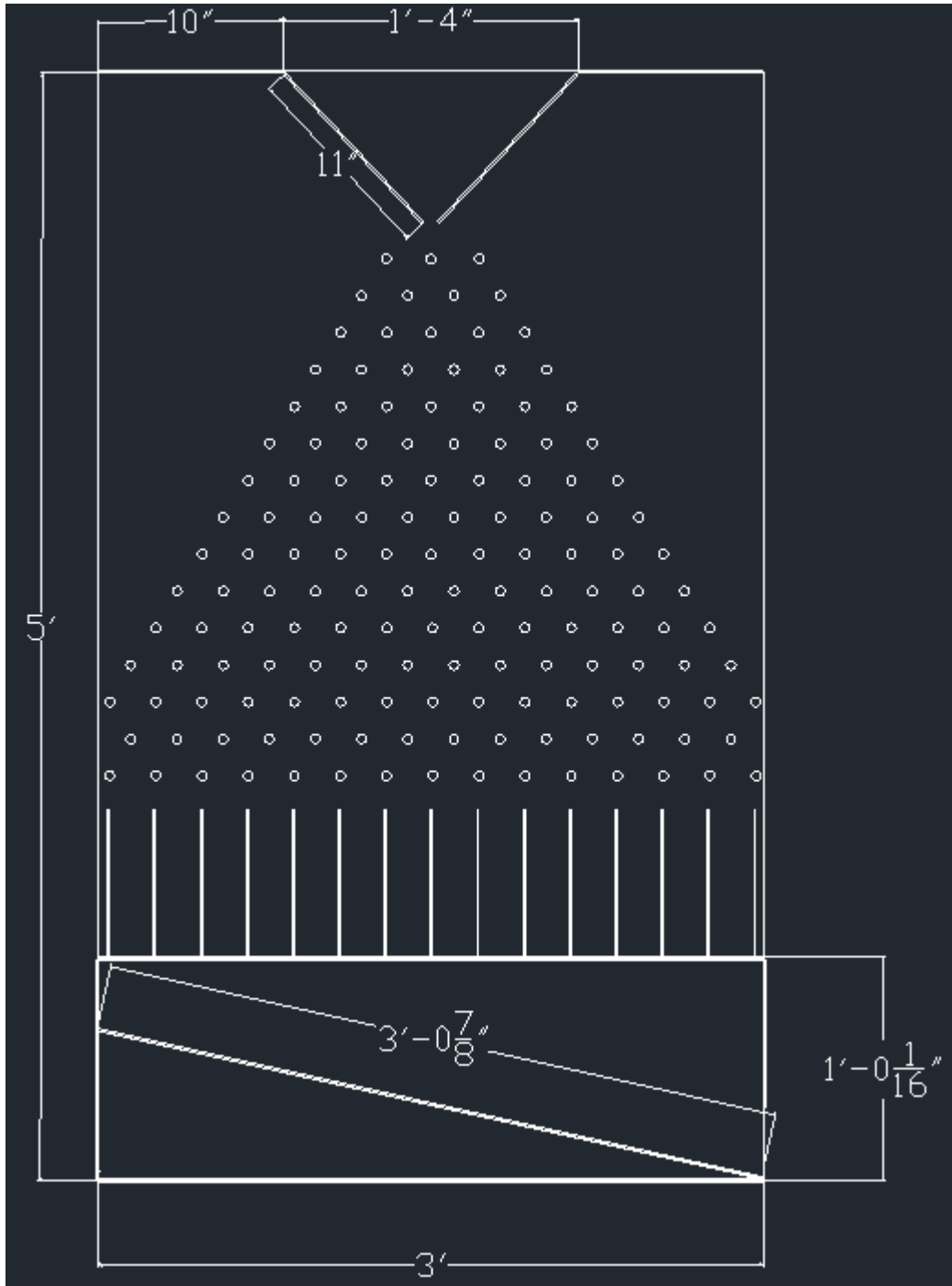


Figure 5-1 Front view of AutoCad drawing of the quincunx machine with dimensions. By Eli Wallach.



Figure 5-2 Picture of quincunx after painting

5.3 Costs

5.3.1 Design Cost

The design costs specify the amount of hours GID spent on each section of the probability machine. A total of 59.7 hours were spent on planning and building the probability machine. Figure 5.13.21 illustrates the distribution of hours spent throughout each section.

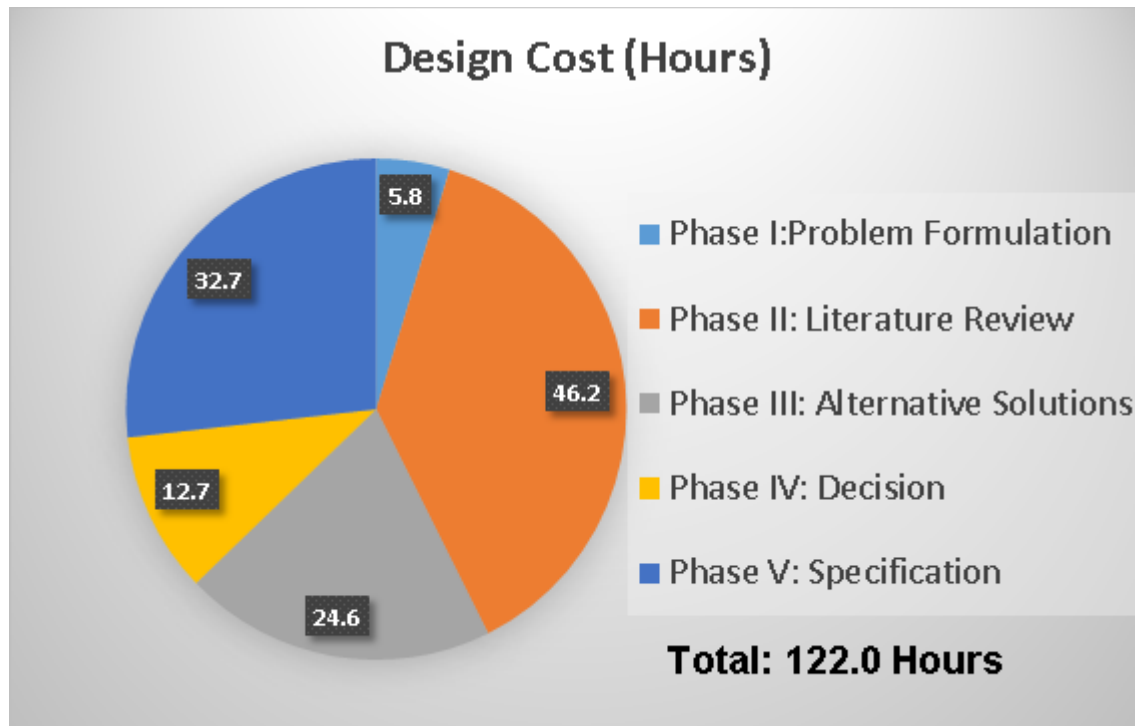


Figure 5-3: The design cost in hours.

5.3.2 Implementation Cost

Figure 5.2 shows the costs of the materials that were needed to build the quincunx machine. The total amount of money spent on these materials is \$150.99. Some of these materials were donated but the most expensive material was the acrylic sheet. The aluminum rods were purchased as a 12' round instead of individual 3/2" rounds to save money.

Table 4 Cost of materials for the quincunx machine.

Implementation Cost		
Item	Quantity	Price
Aluminum Sheet 15' X 5' X 1/8"	1	Donated
Bouncy Balls	150	Donated
Acrylic Sheet 4' X 3' X 1/4"	1	\$81.00
Aluminum Round 1/2" X 12'	2	\$30.00
Acrylic Glue	1	\$9.99
Paint	3	\$30.00
	Total:	\$150.99

5.3.3 Maintenance Cost

Maintenance of Since the quincunx machine should be minimal since it is made mostly made from using durable aluminum which is a light weight and durable metal,, the cost of maintenance should be very small. The maintenance required only costs about 20 minutes of man power per month. Maintenance also requires a damp cloth and Philips screw driver.

5.4 Instructions for Implementation

5.4.1 Location

The Quincunx machine will be located at Zane Elementary School, specifically in Mr. Pinkerton's class room. The device will be placed on the ground standing upright. When not in use, with two twenty-two inch feet running perpendicular to the machine will be leaned upright against a wall for balance.

5.4.2 Instructions

There will be between 250 and 500 plastic balls located in the bottom portion of the machine called the collection chute. To use the quincunx machine, lift a small latch, located on the side panel of the machine which allows the balls to roll out of the machine and into a collection container. Once all the balls are collected then the door is shut and the plastic balls can now be fed slowly feed marbles into the hopper at the top of the machine labeled 1 on Figure 5-4. This machine sorts the balls out using the aluminum pins, labeled 2 on figure 46, creating a bell shape. Once all the balls have been fed into the hopper and have stopped moving, the process is complete and can the bell curve can be observed in the collection chambers labeled 3 on Figure 5-4.

If desired, the balls can be left in the machine with the shape of the curve. If not, or one would want to use the machine, locate the handle. There is a drawer on the front that can be pulled out of the machine at the bottom of the bell curve. This drawer is located at the bottom of the acrylic where the balls are resting which is labeled 3 on Figure 5-4. Make sure when the drawer is pulled out that something on the side latch is ready to catch the balls as they roll out of the collection chute which is labeled 4 on Figure 5-4. After the balls are collected, collect the balls again and repeat. The process can be repeated or leave the balls in the bottom of the machine.

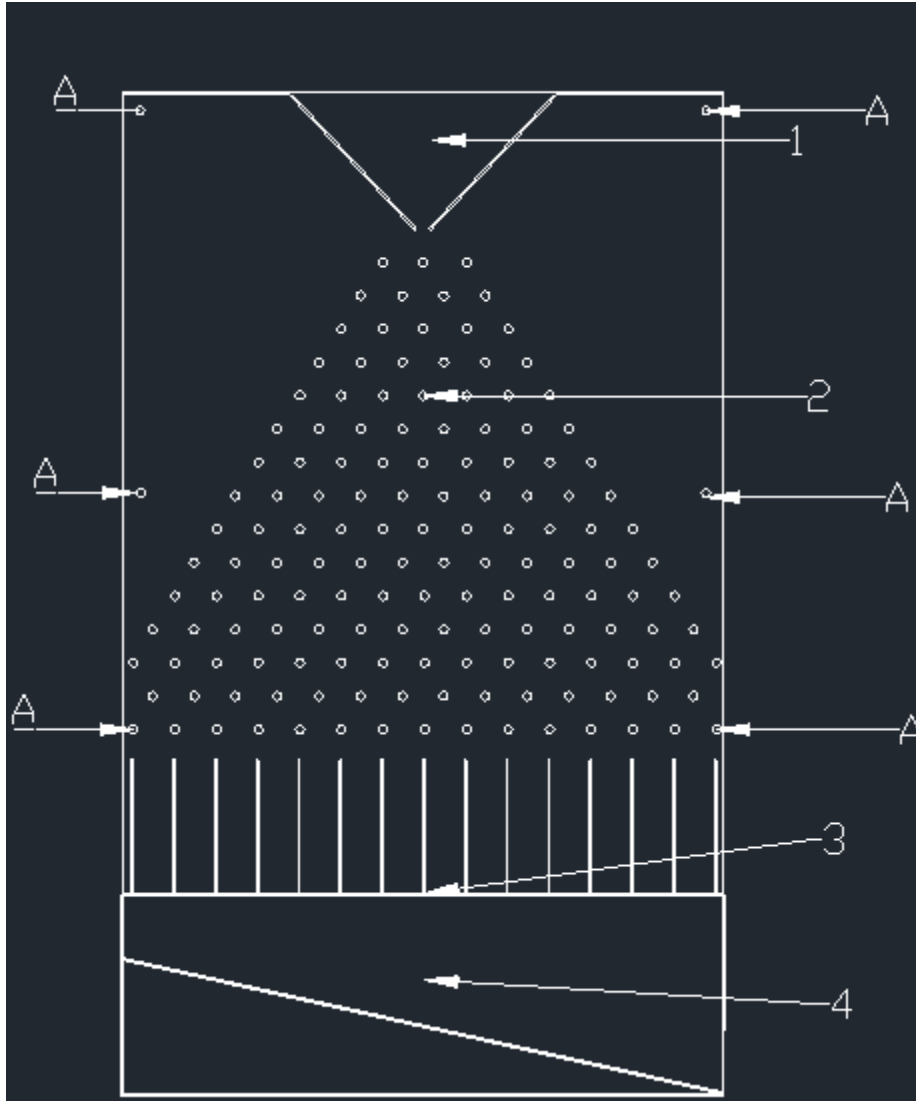


Figure 5-4 1: Loading hopper, 2: Aluminum pins, 3: Balls fall into chambers to form bell curve, 4: Collection chute, A: location of bolts to remove acrylic.

5.4.3 Maintenance

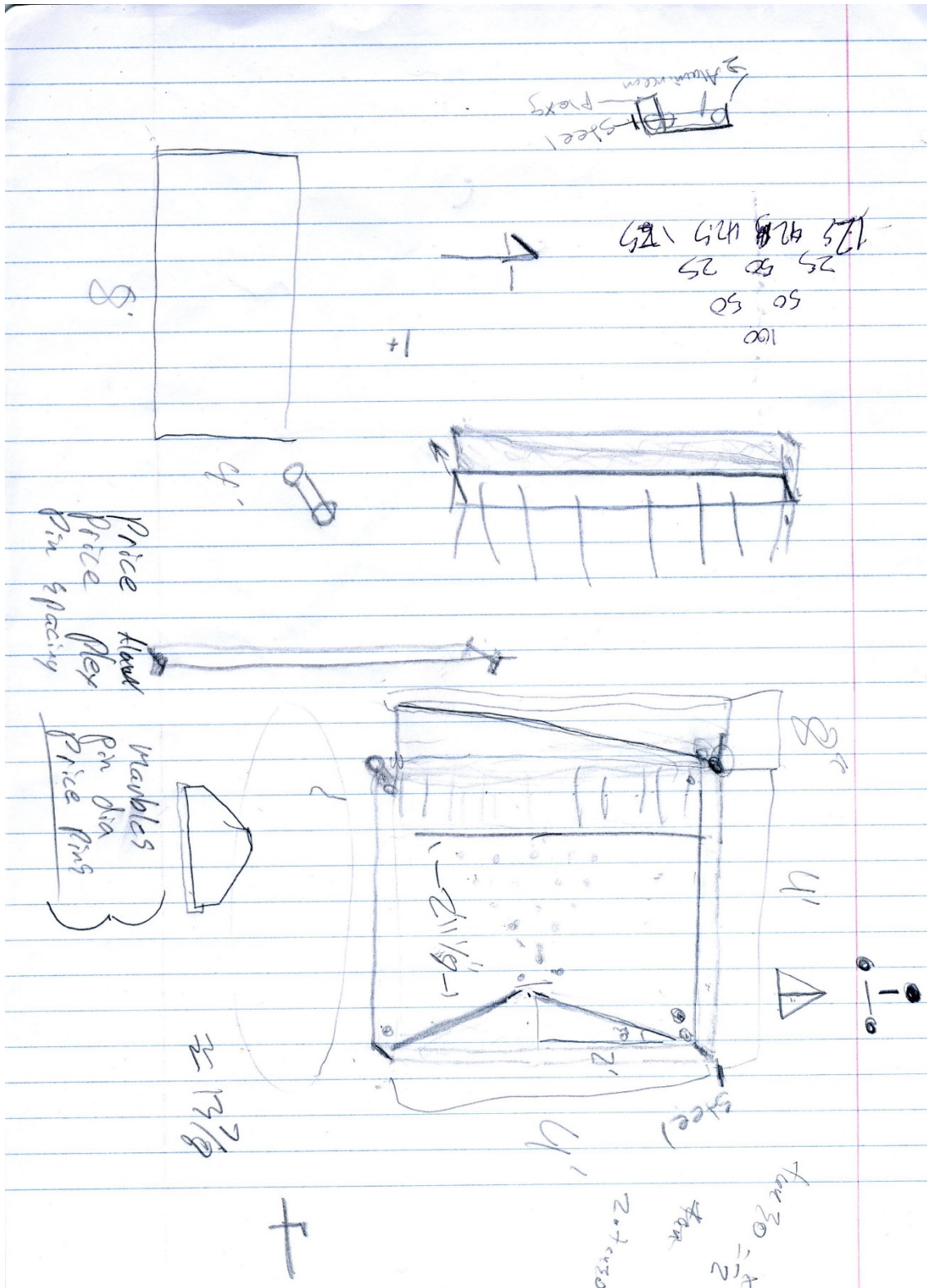
Cleaning the machine requires a Philips screw driver. There are six bolts that must be removed in order to take the acrylic panel off of the aluminum. Which are labeled A in Figure 5-4. The bolts are located on the outer edges of the acrylic, as seen in figure. When taking the bolts off make sure enough pressure is kept on the acrylic so it does not fall. Once the bolts are off, carefully remove the acrylic and gently place it upright lying against a wall or another flat surface. Take a damp cloth and wipe down the inside of the machine to remove any dirt, dust or any other unwanted substance. Once the machine is clean the acrylic can be placed back onto the frame and carefully bolted back into position. Any residue that accumulates on the outside of the machine should be wiped down with a damp cloth whenever desirable.

5.5 Results

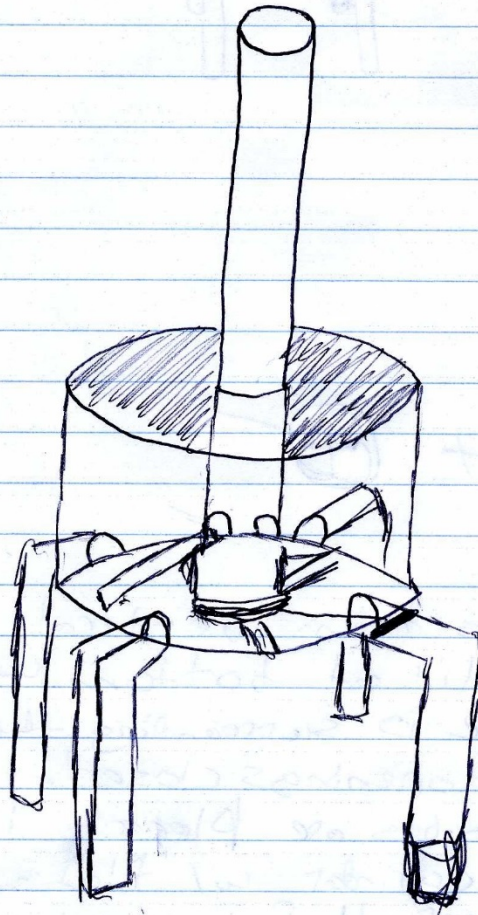
The quincunx probability machine creates the bell curve using bouncy balls that students place in the hopper. To simulate this, balls were tested and used from a downsized prototype of the probability machine. Given examination, the bouncy balls have a fifty percent chance of bouncing in either direction (left or right) after hitting a pin. The continuous fifty percent chance of the balls falling from one side of a pin to the other side pin keeps the probability curve from getting skewed and keeps the predictions held to its assumed outcome. Having more balls also keeps the curve from being skewed which is why we chose to use 250 bouncy balls.

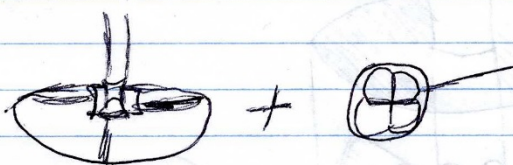
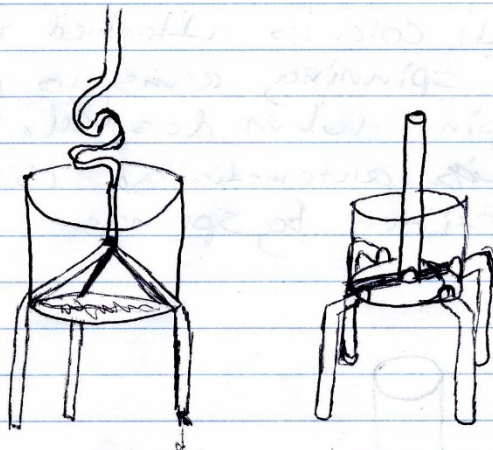
6 Appendices

6.1 Appendix A: Brainstorming Session



done. A pull cord is attached to the free spinning arms to allow them to spin when desired. The pull cord ~~is~~ automatically is rolled back into position by springs.





Balls are set in vertical tube w/ 4-way split at bottom, w/ 4 openings. A second tube is surrounding the 1st tube which keeps openings closed. These vert. tubes are placed in the center of a cylinder w/ flat sides on top & bottom, clear 4 free spinning arms are positioned on the center tubes to hit the balls towards the outside wall of cylinder. There is 4 holes in the outer bottom sides of the cylinder to allow the balls to exit the cylinder. 4 tube legs catch the balls and are equip. w/ small openings at bottom to remove balls.

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