Rube Goldberg Machine

Final Proposal Report

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1 BACKGROUND

1.1 Introduction

Rube Goldberg machine is a complicated machine which is designed using the simple steps of basic engineering to accomplish a given task in a most innovative and funny manner. The machine consists of several steps where each steps is triggered by the previous steps. In this design, the major focus will be on applying the theoretical lessons learned in various engineering courses into reality. The project will be of great significance to the sponsor and other stakeholders (fellow students) since it will be used to teach future students various engineering aspects and also be used as a form of brainstorming and leisure project. The major aim of this project is to create a cost effective, reliable, durable and unique Rube Goldberg machine that will be used to accomplish a given task. Since Rube Goldberg machine consists of many steps, it will help in better understanding of the physics basics and the student will be able to analyses the usefulness and importance of many machines which they come across in day today life. The team will conduct a lot of research and exchange ideas amongst themselves to make sure that the design will satisfy the customer need. The customer needs are the major points which must be considered to ensure success.

1.2 Project Description

According to Wonderopolis, a Rube Goldberg Machine is a device or apparatus that makes use of a chain of reactions to accomplish a very simple task in a manner which is indirect and complicated [1]. The team is required to create various steps of a Rube Goldberg machine such that in the end, it will accomplish the assigned task. In order to accomplish the goal, the steps involved should be complicated and must be presented in the professional manner. So to induce the gears, sensors, springs, fluid, aerodynamics, and magnets must be used.

1.3 Original System

Our Rube Gold Berg machine started from the scratch with stand-alone ideas with no original system. In this regard, the team will embark on building an original device which has never been built before.

2 REQUIREMENTS

The team's goal is to create efficient, reliable, and resettable rebuild berg steps. The team is required to liaise with the client so that they are able to know the actual requirements that will be incorporated. First, there are customer requirements and this will be obtained directly from the clients since they are the ones who are going to interact with the device for a long period of time. Customer requirements will be helpful in figuring out the Engineering requirements. Since the engineering requirements are specific and measurable, the future analysis of the various designs will be made easy. House of quality (HOQ) is a diagram and is a part of Quality Function Deployment (QFD) which relates the customer needs to how the team is going to achieve those by prioritizing the needs. All the requirements and HoQ are listed and explained in the following subsections.

2.1 Customer Requirements (CRs)

Customer requirements are the various kind of requests which are given by the clients and the users. The major requirements are as follows:

I. The steps should be efficient, reliable and durable so that it will not fail during demonstration.
II. The steps used should be resettable.
III. The setting time should not be very high.
IV. The steps involved needs to be complex, unexpected and entertaining to the audience.
V. The speed of the steps should be normal such that the human eyes are able to capture every action.
VI. All the steps should be safe so that it will not harm the audience as well as the audience.

2.2 Engineering Requirements (ERs)

The engineering requirements are regarded as specific and measurable and are very crucial in making work in later stages easier especially in analysis and discussion. From the customer requirements, the team formulated engineering requirements which were to be used in the steps of Rube Goldberg machine design and are presented in the **Table 1**.

Table 1: Engineering requirements

Engineering requirement	**Target values**
Number of steps	20 – 75
Process duration	Less than 2 minutes
Size	10 x 10 ft
Speed & Sound	Not loud or harmful to others/moderate speed to enjoy
Reset time	8 minutes

2.3 House of Quality (HoQ)

HoQ correlates the customer requirement and the engineering requirement and as a result gives the critical design characteristics. In this diagram, the engineering requirements are listed at the top and the customer requirements are listed on the left along with their weightage depending on their importance on a scale of 1 to 5. However, 1 is the least important whereas 5 is the most important. The HoQ is presented below in **Table 2.**

Table 2: HoQ Diagram

House of Quality								
Customer Requirement	**Weight**	**Engineering Requirement**	**Number of steps**	**Process duration (min)**	**Size (cubic feet)**	**Speed (m/s)**	**Sound (dc)**	**Reset time (min)**
Reliable	5		4	3	5	4	0	4
Durable	5		0	0	1	1	0	0
20 to 75 steps	5		5	4	1	3	1	1
Each process less than 2 minutes	4		5	5	0	5	0	4
Normal speed of the steps	3		4	4	0	5	0	2
Total size of 10ft by 10ft	3		1	0	5	0	0	0
Should be resettable	2							
Should be entertaining to the audience	2		0	0	0	2	0	0
Should not be loud	1		0	0	0	2	5	1
Absolute Technical Importance (ATI)			80	67	50	81	10	48
Relative Technical Importance (ATI)			27.8	15.6	13.1	3.2	18.6	4.5
Target ER values			<75	<2	<300	<10	< 0	<5
Tolerances of Ers			0	0	0	0	0	0
Testing Procedure (TP#)								

Strong relationship = 3; Weak relationship = 1; No relationship = 0

3 EXISTING DESIGNS

A variety of competitions have been carried out regarding the Rube Goldberg Machine and as a result, the team conducted a research on them. It was no doubt that the team was supposed to conduct thorough research from a variety of sources such as the internet and interviewing users. The major emphasis was on designs which met the proposed customer requirements. In addition, the focus was on designs that had components which could be incorporated into the design at hand so as to satisfy the user's needs. The existing designs are as follows.

3.1 Design Research

Over the years there has been designing of Rube Goldberg Machines and there are changes which are incorporated every time due to technological innovations which are made in engineering aspects and also to meet the upcoming customer requirements. This has been made possible as a result of growth and development of technological advancement. In this regard, the team embarked on conducting an online research by use of the Google search engine and watching YouTube videos on the Rube Goldberg Machines (RGM) which have ever been developed. The RGM consists of a number of steps. The steps used for making a RGM a grand success are seen in the video to understand the physics behind it. A lot of emphasis is paid to learn about the triggering mechanism for the steps used in the machine. The team was lucky to find a number of already existing designs related to the project and they are as discussed below.

3.2 System Level

3.2.1 Existing Design #1: Northern Arizona University 2018: Pouring a bowl of cereal

This design was second in the 2018 USA competitions and it was comprised of 38 steps as follows. The gear mechanism, mouse trap, electrical circuit and DC motor is used to add the complexity. The best part of the machine is initiation with the alarm clock [2]. The vibration energy is used to initiate the movement of the ball. To add the fun element the team has made use of the mouse trap, curtains and the shoe. The mechanism of machine has helped us in enhancing our ideas for making a unique and quality RGM. The machine is further discussed in the subsections:

3.2.1.1 Subsection #1a Initiation

The mechanism starts by turning on the alarm clock. The arm of the clock sends the ball down the track and tube. The ball turns to switch "off". A metal ball is released from an electromagnet. The ball goes down the track, landing on a mouse trap. The mousetrap pulls the peg from under shoe. The shoe swings and kicks stopper. A fishing pole reels back.

3.2.1.2 Subsection #1b Middle steps

As the fishing pole reals back, a ball's gate is pulled from its slot. The ball tumbles down spine track. It lands in a cup, pulling out the blockade. The soup can roll through cup tower, releasing weight. The weight pulls stopper from ball column. Balls release from the column, dropping into a cup. The cup falls, pulling open curtains, and landing on a long lever. The long lever triggers driving gear. Driving gear turns pinion, in turn moving the rack to the right. The top piece of wind-up toy pulls up the bottom piece. The bottom-half of wind-up toy rotates lever clockwise. A lever rotates fishing pole counterclockwise. A "Gate" lifts, releasing the first golf ball down its track. The golf ball falls into a mini cereal box, tilting the top track clockwise. The second golf ball rolls down the track and tube. The golf ball knocks out the wheel's peg. The wheel spins, dumping cereal into a dispenser as it does so, and ultimately pulls up on the box door's latch. The collapsing door falls, releasing a ball inside. The ball rolls down the track, bounces out of the box, hits the target, and bounces back in. the whale teeters tips. Cadillac Ranch "dominoes" fall. A hinge/latch is released. Malt milkshake cup falls. A nail is pulled from spoon launcher. The spoon launches into a bowl.

3.2.1.3 Subsection #1c: Pouring of milk

As soon as the spoon falls on the bowl, it sense and send the signal to DC motor that is attached to the handle of the cereal dispenser. Cereal exits dispenser and slides down a chute. Once 30 grams of cereal reaches the bowl, the DC motor turns off, and the stepper motor and its attached arm spin 180 degrees. A peg under the milk lever is swiped away by the stepper motor arm, tipping lever. Finally, milk pours into the funnel, through tubes, and into the cereal bowl [2].

3.2.2 Existing Design #2: Purdue 2018: Pouring a bowl of cereal

This machine won the first place in the 2018 Rube Goldberg Machine Contest college division at Chicago's Museum of Science and Industry. Design consists of 75 steps. The design focused on the one which pours a bowl of cereal and is comprised of three separate vignettes which were each rotated into view when the previous steps were complete [3]. The best part of the machine is the use of wind mill and making it in the three separate vignettes since this adds the difficulty and error in movement of wheel and locking at the exact place may cause the fail in triggering the next step. The main attraction of the machine is the whirlpool sucking the ice cube, dropping the bowl and boxing gloves, card trick, door, and lifting the box containing cereals which can be incorporated in our machine after some improvement. The steps involved in machine is described in following sub-section:

3.2.2.1 Subsection #2a: Placement of Bowl

In the first vignette, a jug which is placed on a board triggered the operation of a blending machine which in turn triggered the plucking of wires of a guitar. Then the ball started rolling through a variety of steps which involved falling though hollows and being thrown to targets by use of springs and falls on the cup which releases Gane. The Gane pushes the ball to knockdown the knife. The knife releases the map and map throws a punch by releasing weight which in turn tips over the stool to escape through the door which triggered the broom to release the Bowl.

3.2.2.2 Subsection #2b: Pouring of cereal

In the second vignette, the fan rotates thus blowing the ball which flows through a variety of stages and at the same time dropping downwards. There are a variety of gears and hinges which facilitate opening and movement of some equipment. The ball eventually drops to a jar which turns and starts pouring water which in turn makes a turbine to rotate. In the third vignette, it is comprised the most innovative final step whereby a bowl of cereal was poured. In this case, there was a primitive hydraulic arm made of wood and syringes, which lifted and turned a Cheerios box for pouring the cereals.

3.2.2.3 Subsection #2c: Pouring of milk

After pouring the cereals, a pin attached to the cereal box hits the ring at the board which triggers the movement of the ball which results in the rotation of the wheel to get the final vignette. After rotation a pin attached to the structure which holds a tube for pouring the milk is removed which triggers the pouring of milk to the funnel. Milk travels through the plastic tube poured into the bowl.

3.2.3 Existing Design #3: Purdue 2018: Apply a Band aid

The machine is setup in 57 step with the task of applying a band aid. The team had the theme of a "Dinner Date Disaster". The machine was based in a kitchen and many of the steps used objects like a frying pan, cheese slicer, wooden spoon, ketchup bottle, candle, microwave and a rolling pin. The best part of the design was taking advantage of the height (potential energy) with the help of the two walls. The major attraction of the design were the steps like falling of the painting from the wall, Use of the magnets. The idea of moving the steel ball with the help of magnet can be effectively modelled during the development of our unique design. The steps involved in this Rube Goldberg machine is as follows [4].

3.2.3.1 Subsection #3a: Initiation

The machine starts when the user hits the frying pan that hits the flour box. The floor box closes the door of the microwave which hits the card board flame. As a result white marble rolls down to trigger the mouse trap which releases the cheese slicer.

3.2.3.2 Subsection #3b: Magnet and the blender step

When the weighted lever pulls up candle, the magnet on the bottom of the candle lets go of weighted magnet which triggers the mouse trap to release the kettle by the slipping action of the string. In other step the motion of the magnetic ball causes the motion of steel ball which hits the catch to open the lid of a pizza box.

A wooden dowel is to the blender. One end of a string is connected to that wooden dowel while the other end is attached to a curtain. When the previous step triggers the blender to turn on, the string is wound up which results in opening the curtain. The idea of using the magnetic energy and the rotational energy to wind/ open something can be effectively incorporated in the team design.

3.2.3.3 Subsection #3c: Step of band aid completion

The task was to apply the band aid which is applied by laying over a rolling pin that rolls on the table top. The steps include knocking off the train stopper by the silver marble. Removing the stopper results in rolling down the train against the ramp, Train pulls spatula to push the corkscrew arm which turns spreader. The spreader pushes the rolling pin to apply the band – aid. This is the best example how the simple and smaller steps can be effectively used to complete the task.

3.3 Functional Decomposition

In this project, the major aim is to create a reliable and durable Rube Goldberg machine that will accomplish an assigned task. The functional decomposition of the team is to design a device that meets all the requirements given by the client. However, this section contains a black box model and functional model of the device, to be achieved in the project. When both models are analyzed and utilized, there is the identification of the focus of the device for further emphasis in the design process.

3.3.1 Black Box Model

In the black box model, the major focus is on the various mechanisms and operations of the device that eventually leads to the completion of task assigned. In order to represent all these processes, a box will be used as a simulation of the entire machine whereby inputs on the machine will be presented on one side whereas outputs are presented on the other side. In the black box model, the inputs which are being considered include the various forces which are incorporated for energy production, the types of materials and gadgets which have been used and the way they are linked to each other to ensure that there is a smooth flow of the entire process. However, it should be noted that there is a combination of mechanical and electronic elements which lead to the production of various forms of energy including mechanical and electrical energy. There is also the potential energy which is presented by the water which is stored ready for releasing or some other sort of material like the sand which is stored so that once it is released, it will trigger another action. For instance, at the start of the steps, there is the input of human energy whereby the ball must be set rolling by the hitting action. In other parts, the rotating gears and wheels lead to the production of kinetic energy which triggers some actions. For instance, the rotating wheel with a hook leads to knocking down of a bucket full of water. The magnet can also be used for removing the pin or movement of the metallic ball. However, the major form of outputs which are manifested in this design includes the production of a various form of sounds as result of rolling and dropping of the ball on various paths, lighting and the pouring to accomplish the goal of machine. The black box model of a step is shown in **Figure 1.**

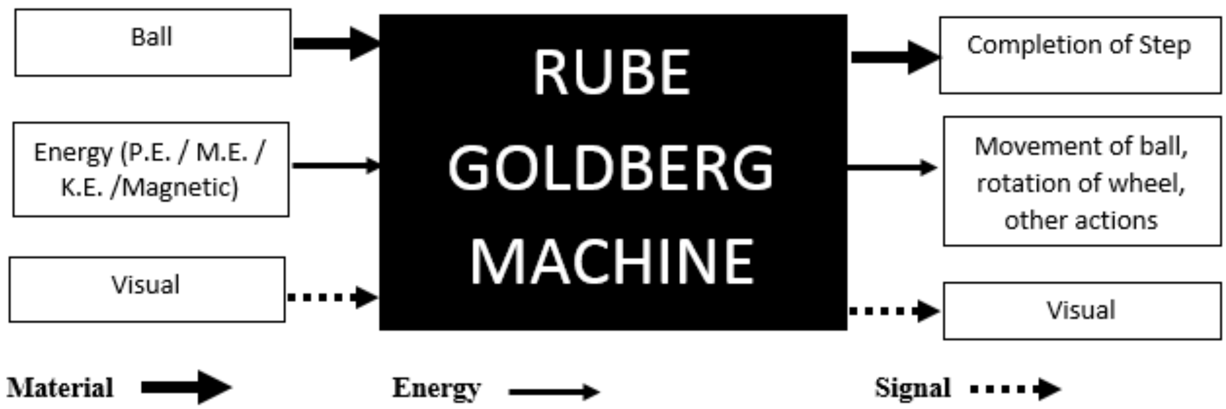

Figure 1: Black Box Model

3.3.2 Functional Model

The functional model gives an explanation of the process which has already been described in the black box model in a stepwise manner. As evidenced by the functional model, the Rube Goldberg machine is comprised of numerous operations which made use of human energy, electrical, potential, magnetic and even mechanical energy. A number of mechanisms which have been well organized have been integrated into a unique and amazing set up so as to push, hit, drop and even throw the ball to the required target. For instance, in areas where there is mechanical energy, it is converted into kinetic energy once the ball starts rolling so as to hit a target or to move to a particular destination. The diagram of the functional model used is placed in **Appendix A.**

3.4 Subsystem Level

The subsystem levels of the already existing designs addressing the requirements relevant to our project are as discussed below.

3.4.1 Subsystem #1: Springs

Springs are very crucial in this project as they will be used to make launcher, pop things out from a box, or even make things turn in a circle direction.

3.4.1.1 Existing Design #1: Compression Springs

Compression springs are made from coils. It works by putting load on the spring and it will compress and store energy, and after that it will go back to its original place releasing the stored energy. Which can be used as a launcher. [5]

Figure 2: Compression Spring

3.4.1.2 Existing Design #2: Torsional Spring

The torsional spring does not compress or extend but instead it works by twisting it to store the potential energy. They follow Hooke's law in an angular form. They can be seen in a lot of application examples like mouse trap or having a car move by itself. [5]

Figure 3: Torsional Spring

3.4.1.3 Existing Design #3: Tension/Extension Springs

This kind of spring works by extending the spring therefore it will have a lot of potential energy and by releasing the spring it will transform the potential energy into kinetic energy. Some of the application examples are building launchers, trampolines, and car manufacture. [5]

Figure 4: Tension/Extension Spring

3.4.2 Subsystem #2: Hinges

Some of the hinges which have been used are made up of steel, aluminum and plastic. Hinges are of great significance to this project since they are used at every joint to facilitate movement.

3.4.2.1 Existing Design #1: Steel Hinges

In our project steel hinges are crucial since they are light in weight and strong. In addition, they are long lasting. Schematic diagram of the steel hinge is shown in **Figure 5**.

Figure 5: Steel Hinges

3.4.2.2 Existing Design #2: Aluminum Hinges

Aluminum hinges are crucial in our project since they are strong and light in weight. They are also rust resistant. Schematic diagram of the aluminum hinge is shown in **Figure 6.**

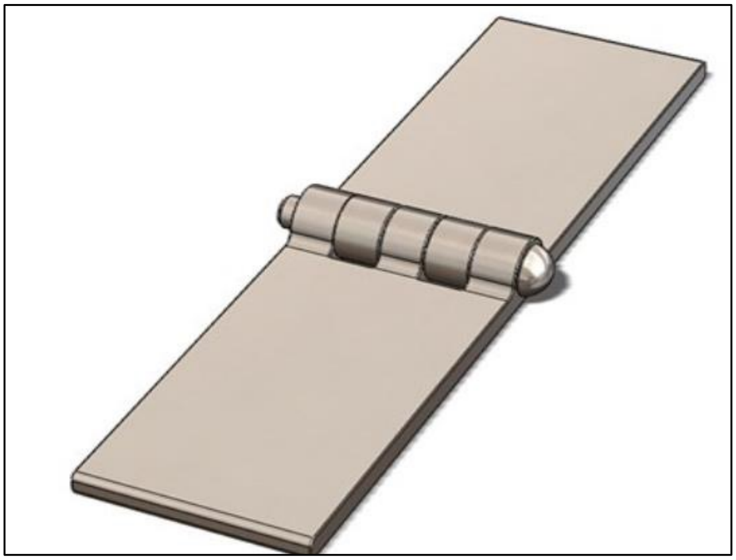

Figure 6: Aluminum Hinges

3.4.2.3 Existing Design #3: Plastic Hinges

Plastic hinges are also crucial in our project since they are light in weight and easy to clean. However, they can be modified with ease through heat application and drilling holes. An example of the plastic hinge is shown in **Figure 7.**

Figure 7: Plastic Hinges [6]

3.4.3 Subsystem #3: Gears

Gears are used to transmit forces and rotations from the shaft which is driving to the one being driven. They are crucial in our project as they will help in efficient movement of some components.

3.4.3.1 Existing Design #1: Spur Gears

As sheen from **Figure 8**, spur gears are cylindrical gears with a tooth line which is parallel and straight to the shaft. These gears are crucial in our project since they are able to achieve high accuracy with easy production processes. This will also help in maintain the angular speed by selecting the number of teeth in both the gears.

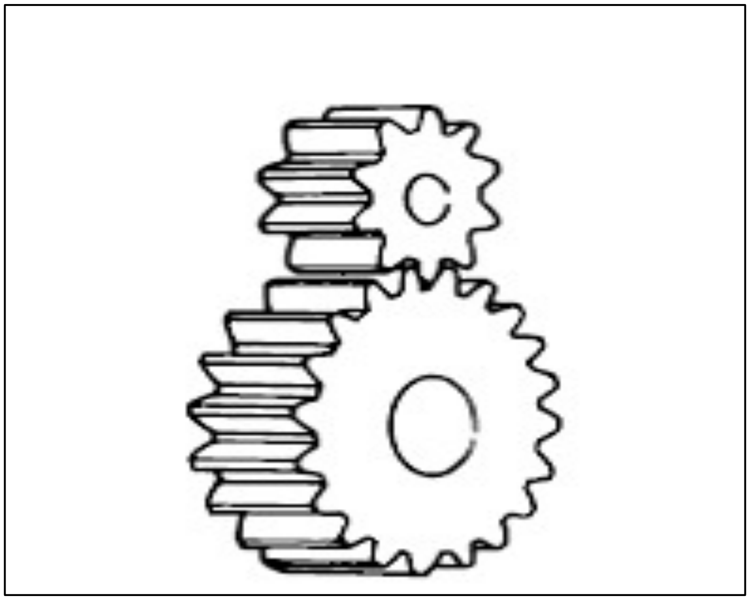

Figure 8: Spur gears [7]

3.4.3.2 Existing Design #2: Helical Gears

The teeth in the helical gears are inclined with the shaft. These gears facilitate the gradual engagement and disengagement which will reduce the impact load coming onto the teeth of the gear. They are suitable in our project since they are able to transmit higher loads at high speed and with superior quietness. A diagram of helical gears is shown in **Figure 9**.

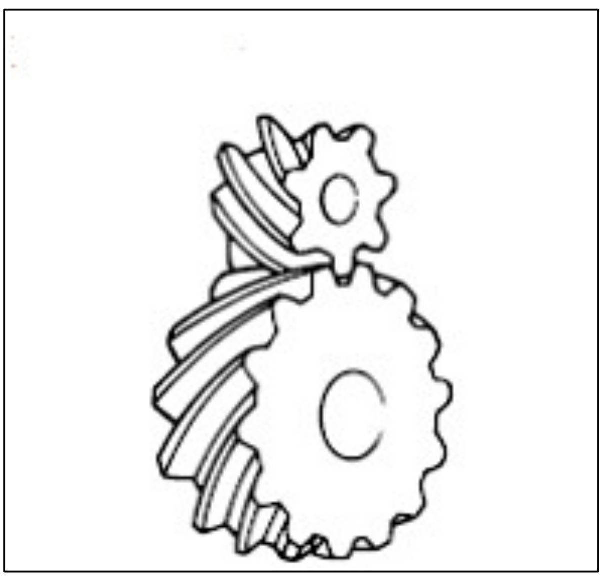

Figure 9: Helical gears [7]

3.4.3.3 Existing Design #3: Gear Rack

Teeth of same size and shape are cut at equal distances along a flat surface. A gear is meshed having the same shape and size of teeth. This gear is crucial in our project as it will facilitate the conversion of rotational motion into linear motion. These are also simple and easy to fabricate as well. A isometric view of gear rack is presented in **Figure 10**.

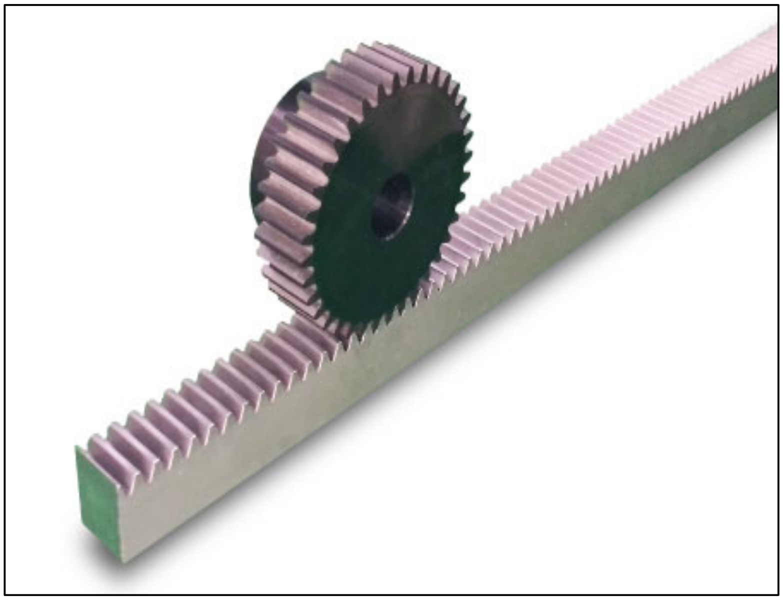

Figure 10: Gear rack [7]

4 DESIGNS CONSIDERED

For designing the Rube Goldberg machine a lot of emphasis is paid for selecting the individual steps. Further that will be combined with some transitional steps to make a unique and effective Rube Goldberg machine. The design is comprised of the laser lights, magnets, aerodynamics and water wheels etc. to attract the audience. The 6 design considered are discussed in the flowing subsections and some extra 9 number of designs are discussed in the **Appendix B**.

4.1 Design #1: Spring 1

As shown in the **Figure 11** a ball is placed on top of the spring which is preloaded and locked. When an external force is applied at the stick by some previous step this will unlock the spring and the ball or any object placed on top of the spring will be launched. In this step potential energy of the compressed spring is converted into the kinetic energy of the ball. Amount of compression of the spring can be determined during the development of the prototype.

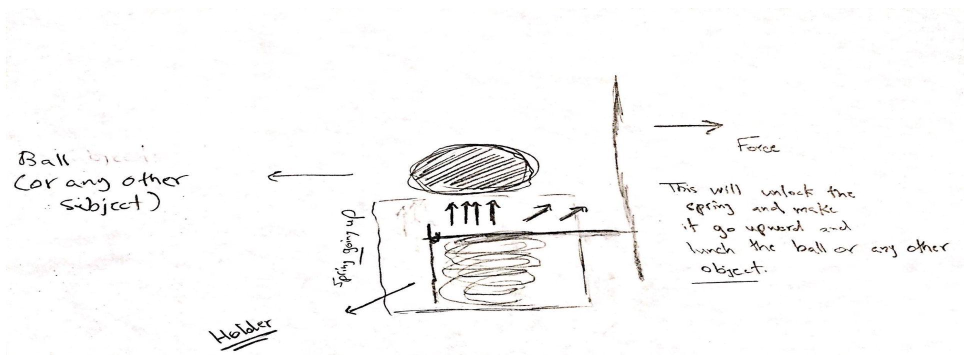

Figure 11: Spring #1

4.2 Design #2: Spring 3

The **Figure 12** shows a setup containing two springs and the part of a cooking syringe fixed to the wooden plank. When an object falls on the top of the cooking syringe, it will transfer its kinetic energy to the spring. As a result, spring will be stretched and energy will be stored which will assist in launching of the object to the upward. Spring will launch the object only when all the kinetic energy of the object is transferred to the spring.

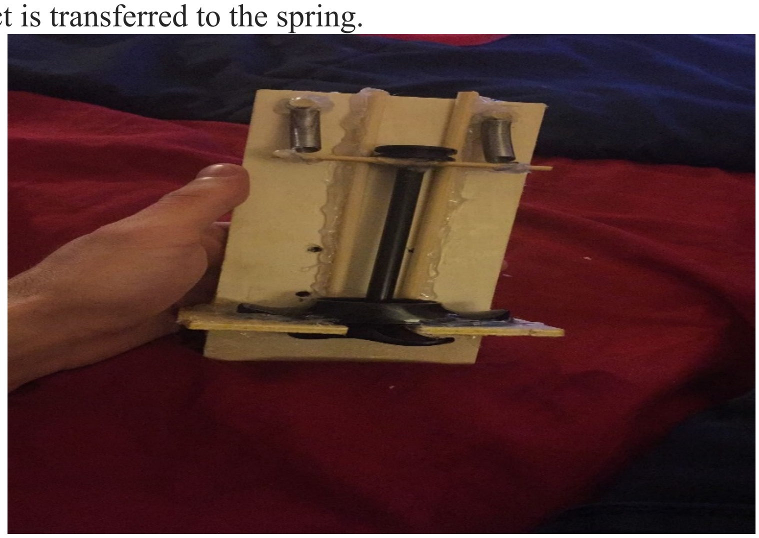

Figure 12: Spring#3

4.3 Design #3: Fluid 1

A homemade water pump is presented in **Figure 13**. Upward and downward motion of the lever will suck the water up from the water reservoir. During the downward motion, the ball will close the opening so that water will not drain out of the pump. Upward and downward motion of the lever continued till the water reaches to opening at the top. From the opening water will come out and flows through a pipe where a ball is kept. The water will hit the ball and the ball will start to move forward to trigger the next step and the water is recollected to the reservoir from the opening at the pipe.

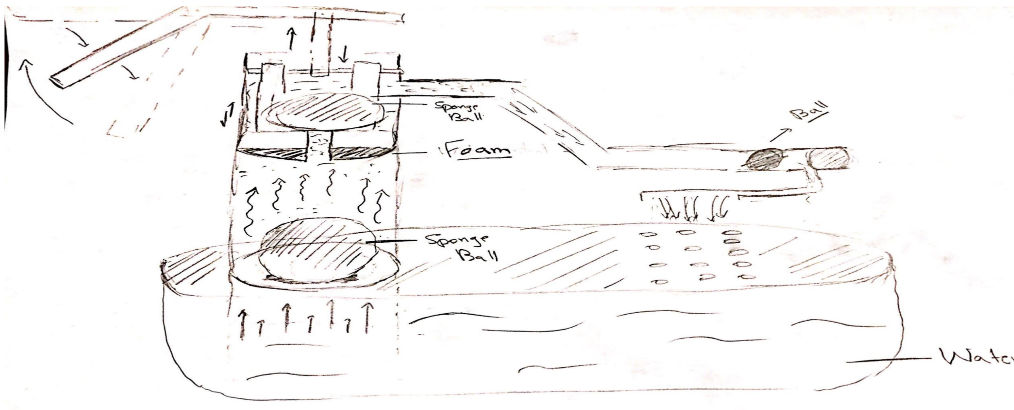

Figure 13: Fluid#1

4.4 Design #4: Fluid 2

The schematic view of the setup is presented in **Figure 14**. As the switch of the motor is turned on, it will pump the water at the surface of the wheel. As a result, the wheel starts rotating. A human doll is attached to the shaft of the wheel. Human starts rotating in the direction of rotation of wheel.

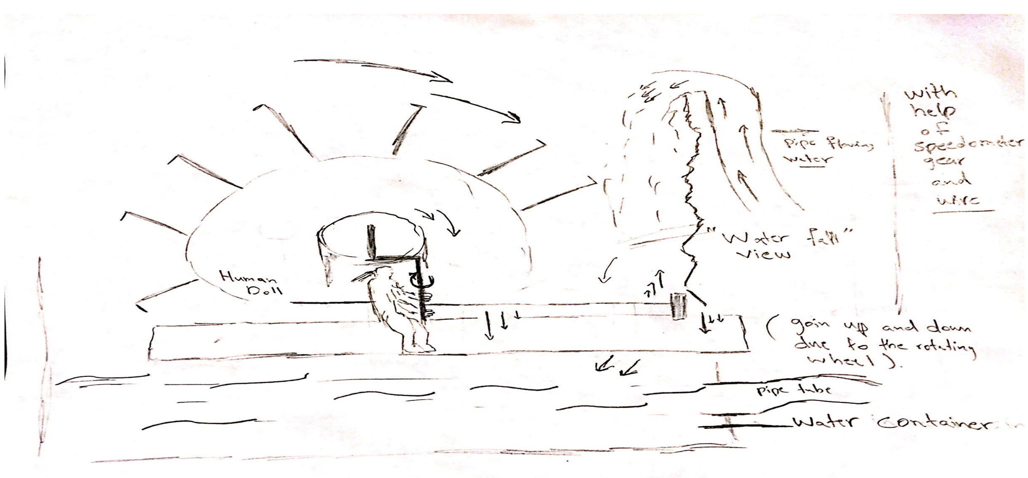

Figure 14: Fluid#2

4.5 Design #4: Fluid 3

Figure 15 shows the schematic view of the entire setup. As the switch of the engine is turned on, it starts generating the power. The power is supplied to the pump which pump out the water in the upward direction. The water starts splashing when its kinetic energy diminished and falls on the seesaw. Due to the impact and weight of the water, one ends starts moving downward whether another end of the seesaw pushes some object to triggers the next setup.

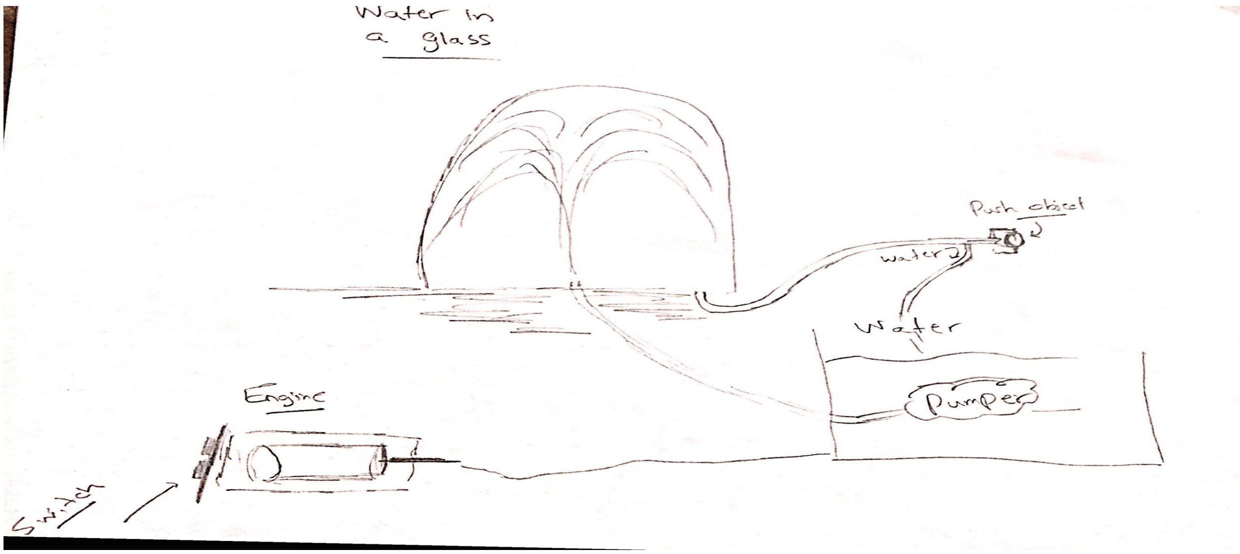

Figure 15: Fluid#3

4.6 Design #6: Sensor 1

The sketched **Figure 16** shows a schematic diagram of a step using sensors. First, on this design the ball is triggered by some previous step and falls into the route where it will hit the ultrasonic sensor. The ultrasonic will measure the distance between from the ball falling until the red light therefore, the red light will turn on. After that, it will measure the short distances between the red light and the green light which indicate the "GO" order. The sensor will only work with the Arduino by coding. This design will be put at the beginning of the project, so it can attract the people to our project.

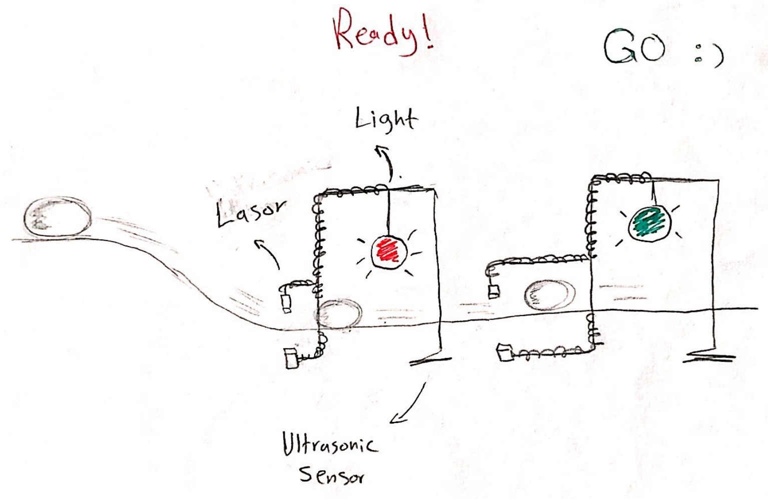

Figure 16: Sensors#1

5 DESIGN SELECTED – First Semester

In this section, the best design which meets the client's requirements is selected. Before settling on the final design the team must ensure that the design selected meets all the requirements by looking into all the components. The major requirements to be met include the customer needs and also come up with a design which is unique, efficient and reliable. Since the Rube Goldberg machines is consist of multiple steps, so a number of steps is considered for designing the machine and evaluated the each individual step to reach to the best design. The best design is comes out to be the design 13. Schematic view of the design is presented below in **Figure 17**.

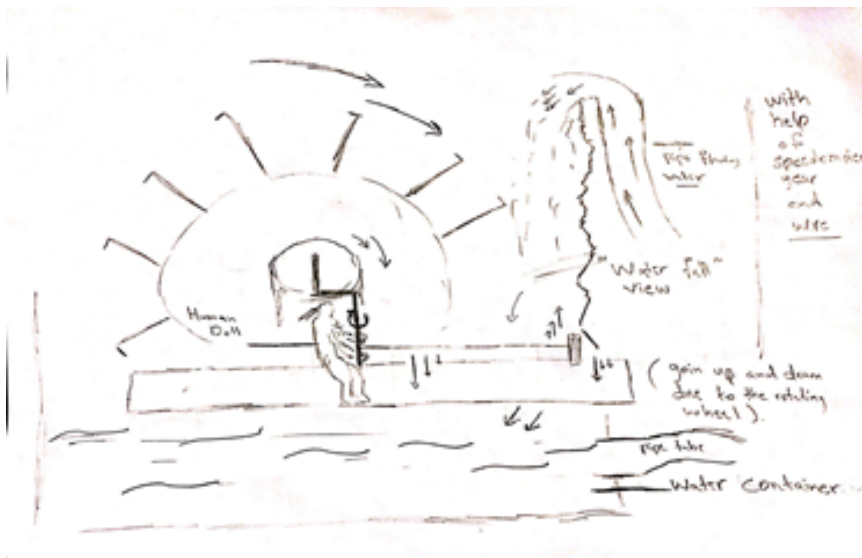

Figure 17: Schematic diagram of the best design (Design 14)

To evaluate the steps, the team made use of a Pugh chart and decision matrix to select the most appropriate design which are discussed in detail in the following sub sections:

5.1 Rationale for Design Selection

Pugh chart is used to evaluate the 15 listed designs and to reach to the some selected design which performs well in the analysis. In the Pugh chart design criteria is listed at the left and all the designs are evaluated with respect to some datum. The detailed Pugh chart is placed at the **Appendix C.** All the design are evaluated and given the '+', '-' and 'S'. The design which have got more number of '+' is highlighted and considered for further analysis. Out of 15 design, the team end up getting 6 best design from the Pugh chart analysis which are highlighted in the **Table C.1** placed at **Appendix C.**

To evaluate these 6 possible design, decision matrix is used. In the decision matrix the design criteria is listed at the left and all the possible design is evaluated to reach out the best possible design. The decision matrix is placed at the **Appendix D.** In the matrix a weightage is given to each selection criteria and based on those the score is given to each design. From the decision matrix analysis design 4 turn out to be the best design with highest score of 135.

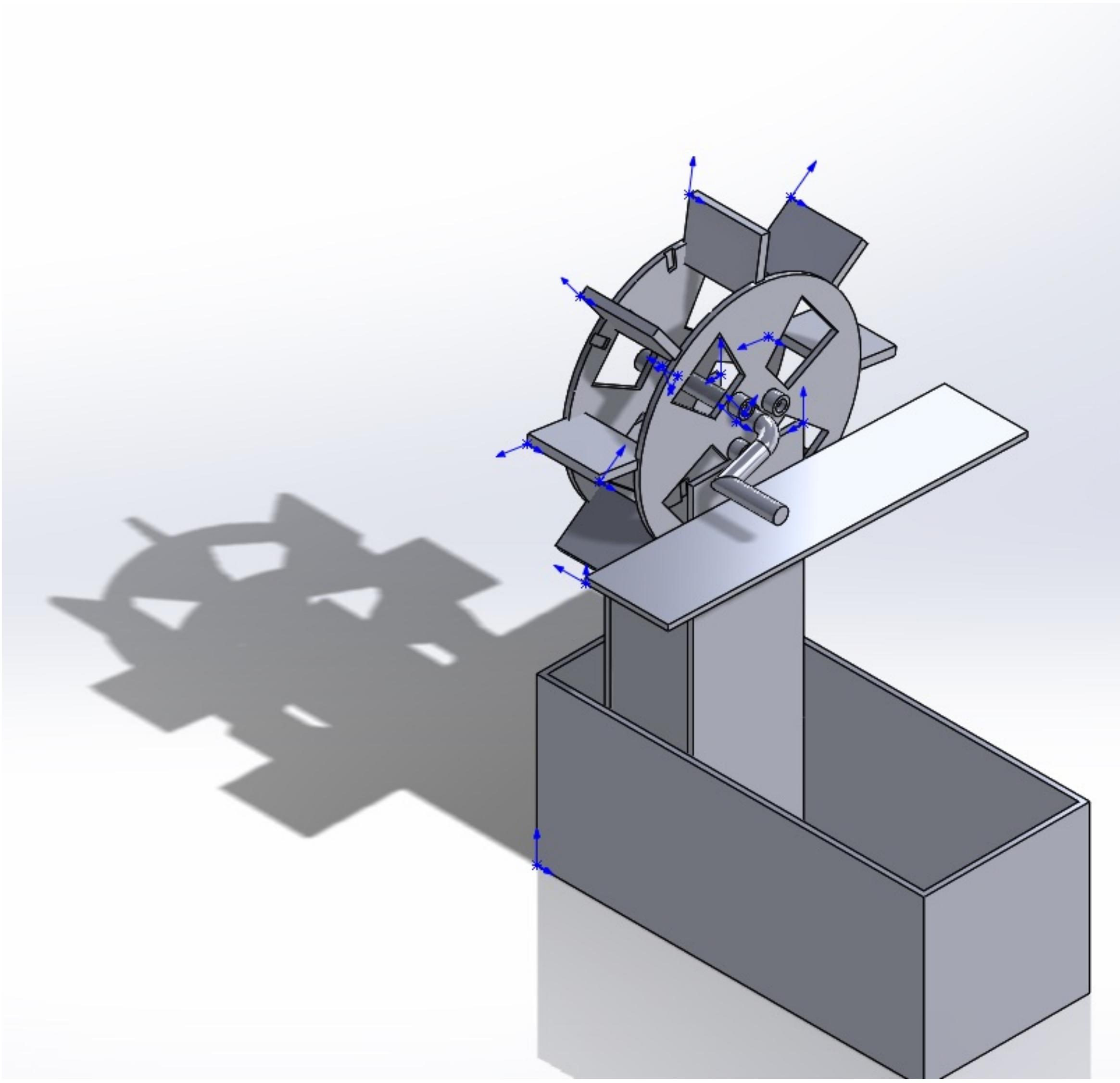

Figure 18: 3D - Model

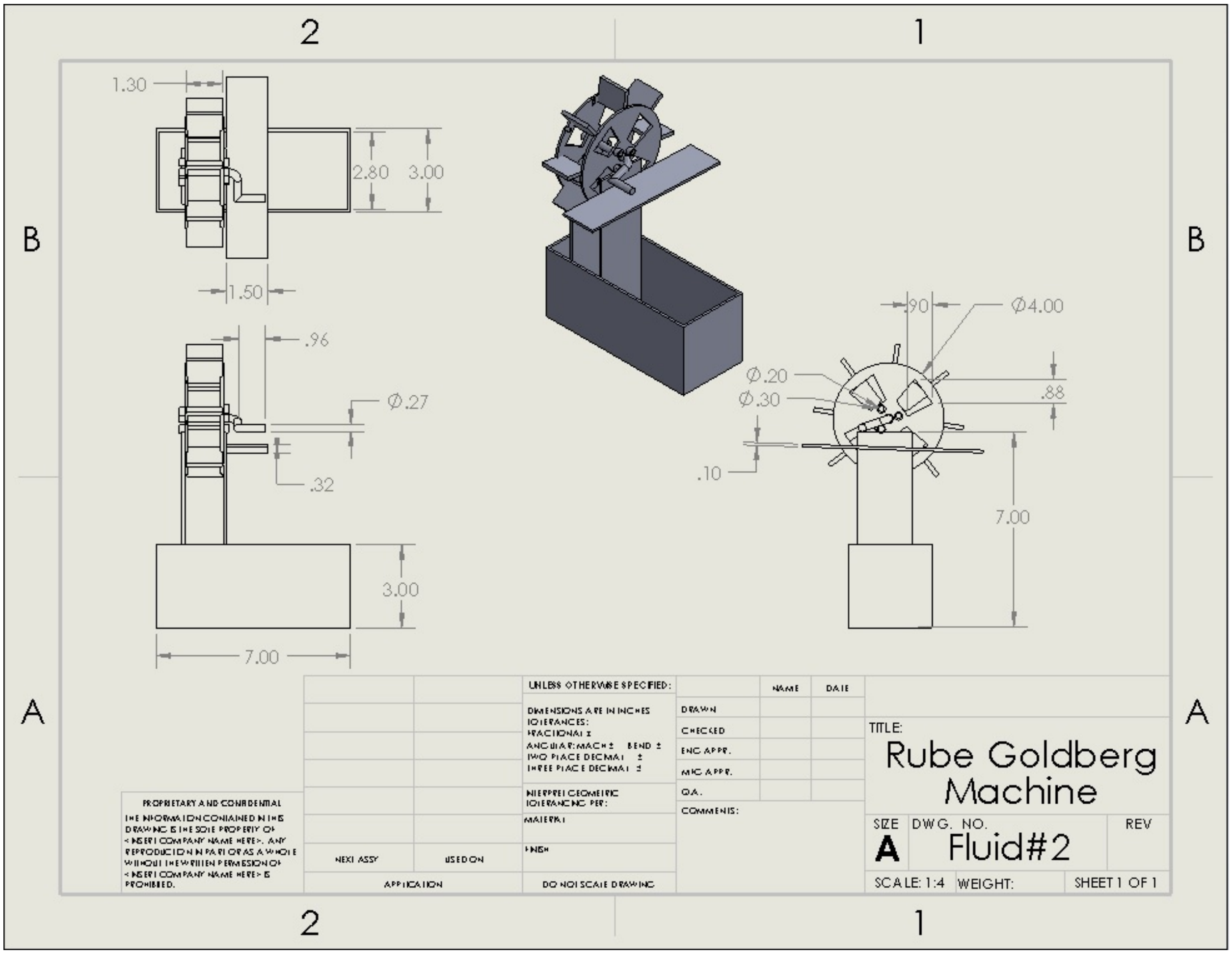

Figure 19: Engineering Drawing

5.2 Design Description

Spring Analysis:

The system consists of two parts of energy transformation. At first stage, potential energy due to spring compression is transformed to the kinetic energy. Second stage is transforming that kinetic energy again to potential energy but this time potential energy is due to elevation. In order to obtain analytical analysis, we need to call trajectory motion into game. As it is known that horizontal velocity in trajectory motion is constant. Therefore, we can easily calculate the horizontal distance after we determine the minimum initial velocity required to reach the object the desired elevation. Moreover, one wants to reach the terminal velocity when the object reach the destination in order to obtain efficiency as much as possible. As it is stated above, the mechanism has two district part. Those parts' mathematical representation is given as;

The first stage (energy due to compression of the spring)

$$U_s = \frac{1}{2}kx^2 \qquad (1)$$

where U_s is potential energy $[N\ m]$

k is the spring constant $[N/m]$
x is displacement $[m]$

The object has already potential energy due to spring. As soon as the clipper is detached, the spring released the potential energy and transform the ball as kinetic energy. Due to conservation of energy, it can be written as;

$$U_s = U_k \tag{2}$$

where U_k is kinetic energy $[N\ m]$, and its mathematical representation is;

$$U_k = \frac{1}{2}mv^2 \tag{3}$$

where m is mass of the object $[kg]$
v is velocity of the object $[m/s]$

Now, we can jump to second stage which is transforming kinetic energy to potential energy due to elevation. Let's first remember the famous potential energy formula;

$$U_p = mgh \tag{4}$$

where g is gravitational acceleration $[m/s^2]$
h is elevation $[m]$

Because of neglecting air resistance and other thermal loss, we can consider that the whole potential energy due to spring is transformed to the potential energy due to elevation. Therefore, we can skip the kinetic energy equation and we can equate the equation 1 to equation 4 as;

$$\frac{1}{2}kx^2 = mgh \tag{5}$$

As it can be understood from Equation 5, our design depends on spring constant, compressed displacement of the spring, mass of the object and target elevation. An excel file has been created for the analytical analysis in order to play with the variables to have necessary design parameters. The screenshot of the Excel file can be seen in the following figure.

Fluid Analysis:

The mathematical model for the system can be worked out by equating the energy balance in during the process. The energy required to pump the water can be worked out in the following manner.
Let us assume that the height of water column is 'h' at a particular time instant 't'. The area of the container is A_c and the density of water is ρ. Therefore, the energy required to raise the column by 'dh' is:

$$dE = \rho A_c h\ dh \tag{1}$$

The power required is given as:

$$\frac{dE}{dt} = \rho A_c h \frac{dh}{dt} \tag{2}$$

$$P = \rho A_c h\dot{h} \tag{3}$$

Therefore, the input power required to raise the water column depends upon the rate of change of height of water column and the instantaneous height of water column itself.
Among the equations governing the flow of fluid in the Rube Goldberg Machine is the Bernoulli's

principle. According to the Bernoulli's principle when there is a decrease in pressure, this leads to a corresponding increase of fluid velocity. When there is a decrease in pressure, it means that there is a decrease in the potential energy of the fluid. The Bernoulli's principle can be derived from the conservation of energy principle which states that, in any form of a steady flow, the sum of all energy forms in a fluid along a is similar at all points along that streamline. However, there is a requirement that the sum of potential energy, kinetic energy and internal energy all remains constant. In this regard, when there is an increase in the fluid speed i.e. its kinetic energy also increases. This provides enough force which is able to trigger an action within the Rube Goldberg machine. This phenomenon can be illustrated by use of Bernoulli's equation below.

$$\frac{P_1}{\rho} + \frac{1}{2}V_1^2 + gh_1 = \frac{P_2}{\rho} + \frac{1}{2}V_2^2 + gh_2 \qquad (4)$$

Where, variables with subscript 1 represent the state at the exit of container and the subscript 2 represent the state at the exit of pipe (sprinkles). Therefore, the speed of sprinkling can be obtained by assuming that there is no head pressure ($P_1 = P_2 = 0$) and the height difference between point-1 and 2 is 's'. Then,

$$\frac{1}{2g}V_1^2 + s = \frac{1}{2g}V_2^2 \qquad (5)$$

$$V_2 = \sqrt{V_1^2 + 2gs} \qquad (6)$$

The velocity at the exit of container can be estimated as:

$$Flow\ leaving\ the\ container = flow\ entering\ the\ pipe\ at\ lcoation\ 1$$

$$\rho\dot{h}A_c = \rho V_1 A_p \qquad (7)$$

Where, A_p is the cross sectional area of the pipe.

$$V_1 = \dot{h}\frac{A_c}{A_p} \qquad (8)$$

From Eq. (3) The value of $\dot{h}$ can be obtained as:

$$\dot{h} = \frac{P}{\rho A_c h} \qquad (9)$$

Therefore,

$$V_1 = \frac{P}{\rho A_p h} \qquad (10)$$

$$V_2 = \sqrt{\left(\frac{P}{\rho A_p h}\right)^2 + 2gs} \qquad (11)$$

If we assume that that the drop in height in the pipe is half the total height of water column in the container, then $s = \frac{h}{2}$ and therefore,

$$V_2 = \sqrt{\left(\frac{P}{\rho A_p h}\right)^2 + gh} \qquad (12)$$

Aerodynamics Analysis:

aerodynamics deals with the movement of air and gaseous fluids in addition to the forces acting on bodies that pass through such a fluid. For instance, in some parts of the Rube Goldberg machine, a fan is used and its rotation is used to produce wind which has a force used to move components like balls. Also, such moving air can be generated by use of a pump. When such moving air is passed through a constricted section of a pipe its speed of flow is increased. In this manner, its kinetic energy is increased at the expense of pressure energy. This relationship can be illustrated by use of the Bernoulli's equation as follows:

$P_1+\frac{1}{2}\rho v_1^2 + \rho gh_1 = P2 + \frac{1}{2}\rho v_2^2 + \rho gh_2$………………………………………. (iv) [8].

Where,

P_1 is the pressure energy.

Pv is the kinetic energy per unit volume

ρgh is potential energy per unit volume.

Sensor Analysis:

The ultrasonic sensor will help the group measure the distance between beginnings of the sensor hit until beginning of another step. Using this sensor on the project will add new ideas to the audience of how the Arduino works. It also important for the project to make a re-settable step for each steps of the project. Regarding the safety factors of the sensor component, the sensor will only work when an object come through it and then it will stop lights. Also the coding that we have used to make sure that the sensor turns off after the object pass through therefore through these two factors there will be no over heat or safety issues regarding the sensor part of the project. We believe that this sensor will help the project more in organizing what objects go through and arrange how the lights turn on and off based on what come near the infrared sensor.

Magnetic Analysis:

The equation of magnetic field for the current has given

$$B = \frac{\mu_o I}{2\pi r}$$

And we need to find the current from the magnetic field so change the equation as

$$\mu_o I = B * 2\pi r$$

$$I = \frac{2\pi r B}{\mu_o}$$

By putting different values of magnet, we can get the current as well. Firstly, put the value of magnet as

$$B = 0.1 * 10^{-7}\,T$$

So the current with the given value can calculate as

$$\mu_o = 4\pi * 10^{-7}\,T.\frac{m}{A}$$

$$r = 0.1524\,m$$

$$I = \frac{2 * \pi * 0.1524 * 0.1 * 10^{-7}}{4\pi * 10^{-7}}$$

$$I = 0.0076\,A$$

Now take the value of magnetic field B as

$$B = 2 * 10^{-7}\,T$$

So the current with the given value can calculate as

$$\mu_o = 4\pi * 10^{-7}\,T.\frac{m}{A}$$

$$r = 0.1524\,m$$

$$I = \frac{2 * \pi * 0.1524 * 2 * 10^{-7}}{4\pi * 10^{-7}}$$

$$I = 0.1527\,A$$

Now take the value of magnetic field B as

$$B = 5 * 10^{-6}\,T$$

So the current with the given value can calculate as

$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A}$$
$$r = 0.1524\, m$$
$$I = \frac{2 * \pi * 0.1524 * 5 * 10^{-6}}{4\pi * 10^{-7}}$$
$$I = 3.8175\, A$$
Now take the value of magnetic field B as
$$B = 7 * 10^{-5}\, T$$
So the current with the given value can calculate as
$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A}$$
$$r = 0.1524\, m$$
$$I = \frac{2 * \pi * 0.1524 * 7 * 10^{-5}}{4\pi * 10^{-7}}$$
$$I = 53.4450\, A$$
Now take the value of magnetic field B as
$$B = 10 * 10^{-5}\, T$$
So the current with the given value can calculate as
$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A}$$
$$r = 0.1524\, m$$
$$I = \frac{2 * \pi * 0.1524 * 10 * 10^{-5}}{4\pi * 10^{-7}}$$
$$I = 76.35\, A$$
Now take the value of magnetic field B as
$$B = 3 * 10^{-4}\, T$$
So the current with the given value can calculate as
$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A}$$
$$r = 0.1524\, m$$
$$I = \frac{2 * \pi * 0.1524 * 3 * 10^{-4}}{4\pi * 10^{-7}}$$
$$I = 229.050\, A$$
It can stat from the above results that with the increase in value of magnetic field, current produces by the rotating disc is increasing. As we will operate a small motor from it, that will consume only 1.5 Amperes of current maximum so now calculate the value of required magnetic field that will give 1.5 amperes of current.
$$B = \frac{\mu_o I}{2\pi r}$$
As the current required is
$$I = 1.5\, A$$
$$r = 0.1524\, m$$
$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A}$$
Now put the values into the equation of B as
$$B = \frac{4\pi * 10^{-7} * 1.5}{2\pi * 0.1524}$$
$$B = 1.9645 * 10^{-6}\, Tesla$$
So we need a magnet of around 2 Tesla to produce 1.5 amperes of current that will derive the motor and motor will rotate the fins of fan to produce air that will push the next step.

Gear Analysis:

One of the major equations is the one which is related to the pitch diameter i.e. the diameter of the pitch circle. When the gear pitch is known then it is easy to calculate the pitch diameter by using the following formula:

$PD = \frac{N}{P}$……………………………………………………………………………….. (i)

Where PD is the pitch diameter; N is number of teeth of the gear and P is the diametral pitch.

For instance, if the number of teeth of a certain gear is 25 and the diametral pitch is 5 cm then the pitch diameter is 25/5 = 5.

Another equation which is related to gears is the gear ratio which is indicated as follows.

Driven Gear teeth / drive gear teeth ………………………………………………… (ii) [1]

This is crucial since it can determine the time which can be taken to complete a certain action.

In order to ensure that the gears operate in an efficient manner its torque ratio is determined by use of the following equation.

$R = T_B / T_A$ ………………………………………………………………… (iii) [2]

Where R is the gear ratio, T_B is the output torque and T_A is the input torque.

6 PROPOSED DESIGN – First Semester

The base for the prototype made of the carton of size 18 X 12 inch having thickness of 1.2 inch. The wheel is kept on the wooden board of size 6 X 4 inches. Fidget spinner attached to the shaft of the wheel is kept at the top of the wooden board and fix with the help of glue. The base for the pump is made of the wooden slat. Vinyl tube of 20-inch length is connected to the pump to pump out the water from the reservoir to the wheel. Wheel is made of the cork.

The machined will be constructed in many steps which are then placed together and fix to the base to complete the assigned task. As the switch is turned on, the pump will start pumping out the water which fall on the protruding sides attached to the wheel base. As a result, the wheel will rotate. The rotation of the wheel can be used for triggering the next step.

The detailed schedule of implementation plan is placed at **Appendix E.**

6.1 Resources

For developing the steps of the Rube Goldberg Machine, various resources need to be utilized. **Table 3** lists all such resources available to the team for implementation of the design. The list may grow further depending on the final task assigned to the team. The resources may also be included in the list which are found to be readily available over the rest of the time.

The complete bill of material with the cost of the material is presented at the **Appendix F**. The source of the cost of material is also included in the bill of material. The total cost of the material used for fabrication is turned out to be $178.56 which is reasonable.

Table 3: Resource List

Category	Resources	Location	Expertise
Personnel	Abdulla	NAU	Student
	Fehaid	NAU	Student
	Hamad	NAU	Student
	Mohammed	NAU	Student
	Naser	NAU	Student
	Yousef	NAU	Student
Technical Advisor	Dr. David Trevas	NAU	Instructor
	Amy Swartz	NAU	T.A
Facilities	NAU Engineering Building	NAU Facility	Group Meetings
	Wood Shop	Home Depot	Part Manufacturing
	Build Space	NAU engineering Lab	Part Manufacturing
Suppliers	Homco	Flagstaff, AZ	Hardware
	Home depot	Flagstaff, AZ	Lumber and Hardware
	Previously Owned	Self	Step Manufacturing

7 REFERENCES

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8 APPENDICES

8.1 Appendix A: Functional Model

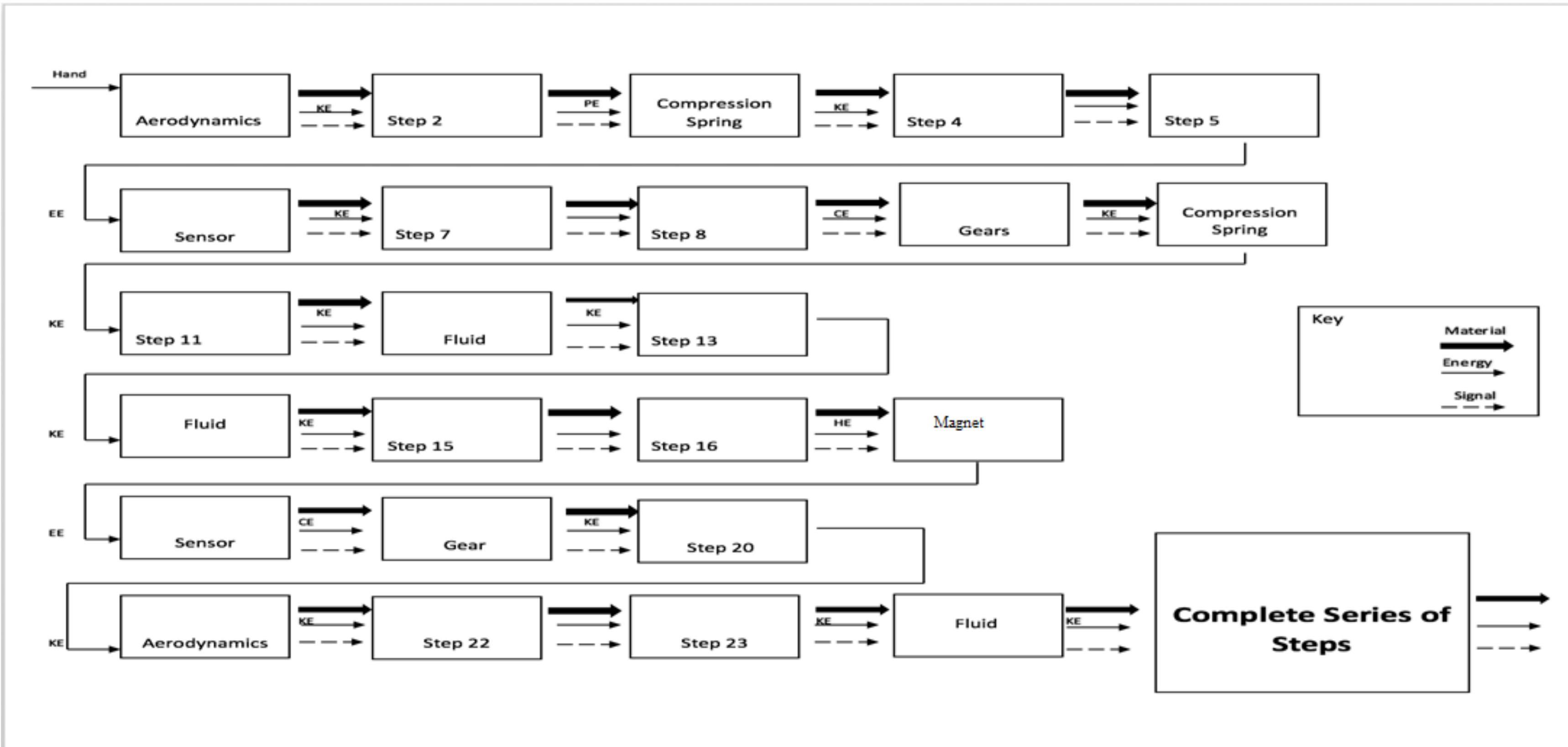


Figure A.1: Functional Model Diagram

8.2 Appendix B: Extra design

Some extra designs considered for the analysis is discussed below.

8.2.1 Design 7: Sensor 2

The steps presented in **Figure B.1** will start with the ball moving forward and it will hit the ultrasonic sensor. After that it will measure the distance between the sensor and the LED screen. The ultrasonic sensor will work by 1rduino by giving specific command to light up the LED screen. The goal is to have our group name on the LED screen. Which will be at the end of the project. We can use the lessor sensor and the LED lights to attract people.

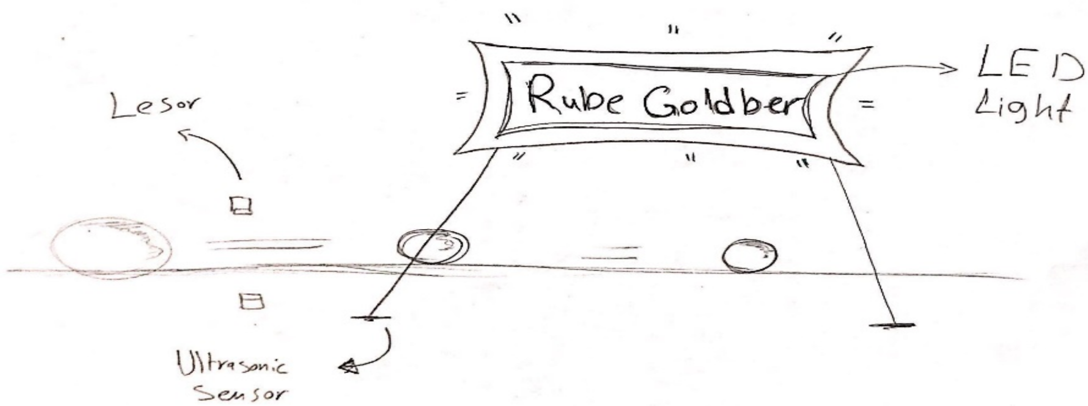


Figure B.1: Sensors#2

8.2.2 Design 8: Sensor 3

In **Figure B.2** The image below describes how the ball goes in a straight line without any issues. The ball hit the ultrasonic sensor that will measure the length from the beginning of the sensor hit until the end of the road and the sensor will give a sign to the servo to move upward so therefore it can be a straight line for the ball to go into and move to another line. Using coding by the Arduino which is attached with the sensor that give the orders for the servo to move to these specific measures that it did.

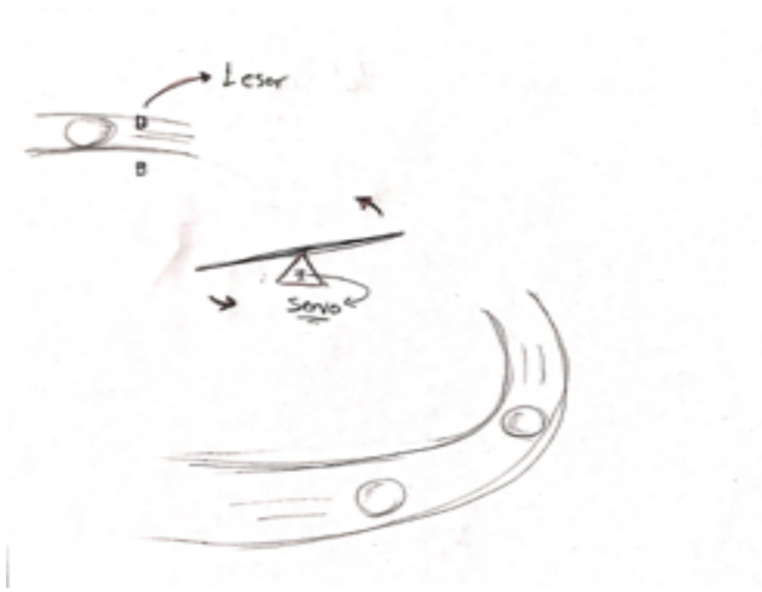


Figure B.2: Sensors#3

8.2.3 Design 9: Aerodynamics 1

The below **Figure B.3** shows that how effectively the idea of aerodynamics can be implemented for developing a Rube Goldberg machine. A fan is placed on top of the table is being rotated by the electricity. The air blows and hit the balloon place at the slanted rod, as a result the balloon starts slipping downwards and hit the book. The book will topple down and hit the one end of the seesaw. The other end of the smaller seesaw will hit the bigger seesaw where the two balls are positioned. This will trigger the movement of the ball forward which can be used as a mode of energy transfer to the next step.

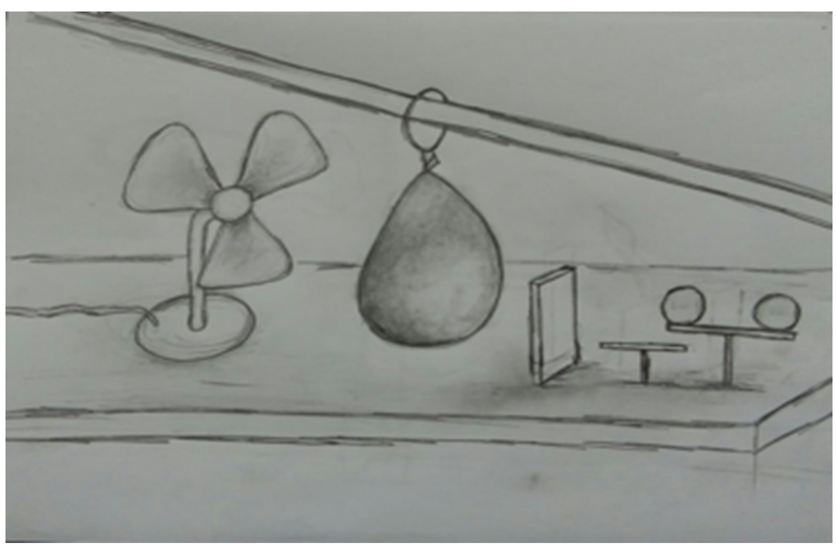


Figure B.3: Aerodynamics#1

8.2.4 Design 10: Aerodynamics 2

The **Figure B.4** shows a hair dryer which blows the air to a converging channel. At the base of the conversing channel, wheels are attached. So it starts moving forward due to the reaction of the air and hits a disc. As a result, the disc starts moving and passes through the slanted way to hit the pendulum. The pendulum starts its swing and hit the ball placed at the fix base. The ball falls from the base and starts moving forward.

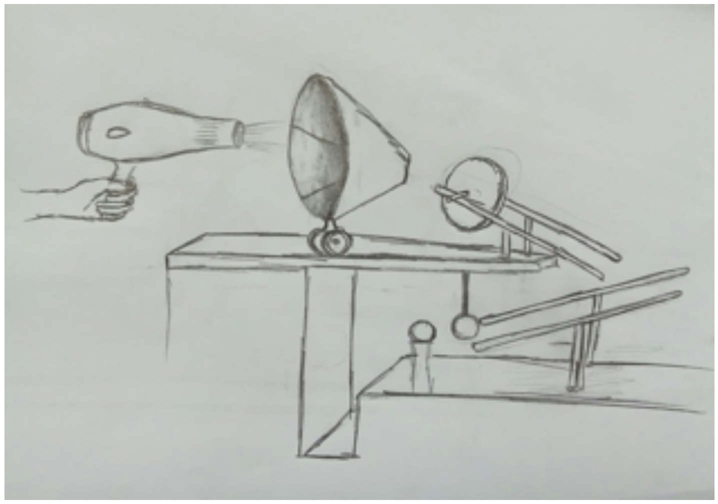


Figure B.4: Aerodynamics 2

8.2.5 Design 11: Magnet 1

The sketch of the model is shown in **Figure B.5**. As the magnetic field can effectively be used to generate the electricity without any other form of energy being consumed. So this idea is used to generate the electricity to run the fan. The speed of the fan will depend on the electricity being generated. The production of electricity depends on the size of magnet. Disc is positioned at the top of the stand. Disc with steel bar attached to it is being rotated in the magnetic field, as a result electricity is generated and supplied to the fan with the wire connected with the fan.

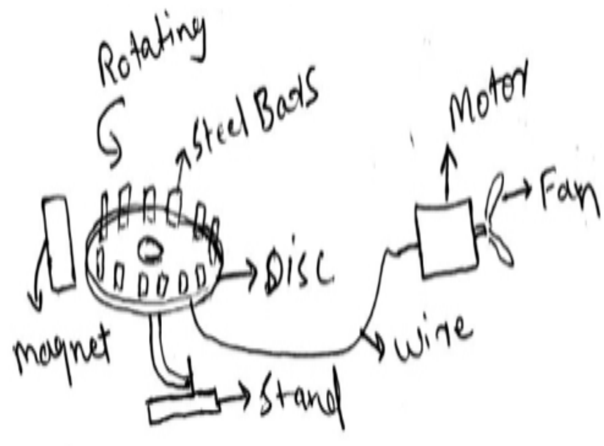


Figure B.5: Magnet#1

8.2.6 Design 12: Magnet 2

The **Figure B.6** shows the schematic diagram of the entire setup. A magnetic ball travels through a rounded channel around the disc where the small magnet are placed along the periphery. Motion of the magnetic ball triggers the circular motion of the disc which is attached to the gear assembly. Movement of the disc causes the gears to move that winds up and shortens a string attached to it which can be effectively used to remove any stopper from the next step.

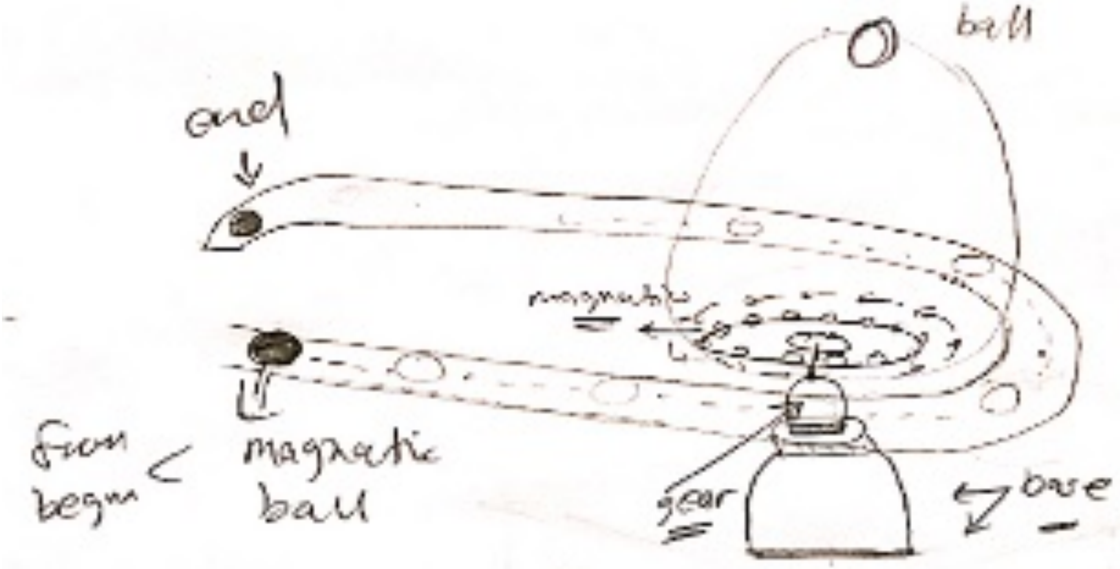


Figure B.6: Magnet 2

8.2.7 Design 13: Spring 2

In **Figure B.7** is a schematic of rope that is attached to a spring, two pulleys, and a handler. Behind the handler in the other side, would be a spinner or generator that makes the handler rotates. From the rotation movement, the pulley will pull the spring with the help of two pulleys, and after the handler makes a whole cycle it will release the spring and therefore hit another object.

Figure B.7: Spring#1

8.2.8 Design 14: Gear 1

In **Figure B.8** is a schematic of proposed device that elevate a ball from a place to another depending on fluid source. Fluid such as water could fill up the bucket to develop a weight in order to left up the wood board to certain elevation. The bucket will have holes on the base, so it could empty after the step is done and will be considered as resettable. This step is entertaining but it's not reliable since the ball could fall from the wooden board.

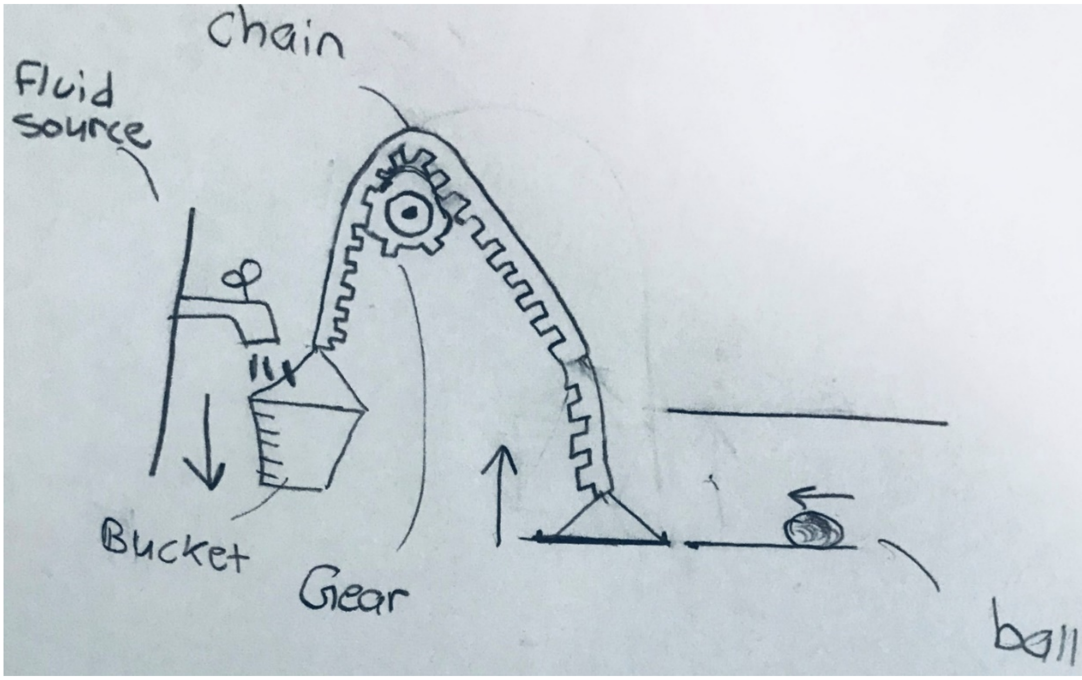


Figure B.8: Gears#1

8.2.9 Design 15: Gear 2

The sketch on the **Figure B.9** shows a design that can move a target from one place to another. A gear that rotates will have a track in both sides and the ball will be on that track. The small gear is attached to a Dc motor while the big gear is attached to a shaft that is fixed on a board of wood. After doing the prototype the team figured out that the gears should be in mesh in order for the large wheel to rotate. It has to maintain an average speed not slow nor too high to be reliable. This step is resettable since it will keep rotating powered by AAA batteries and has a switch to turn on and off.

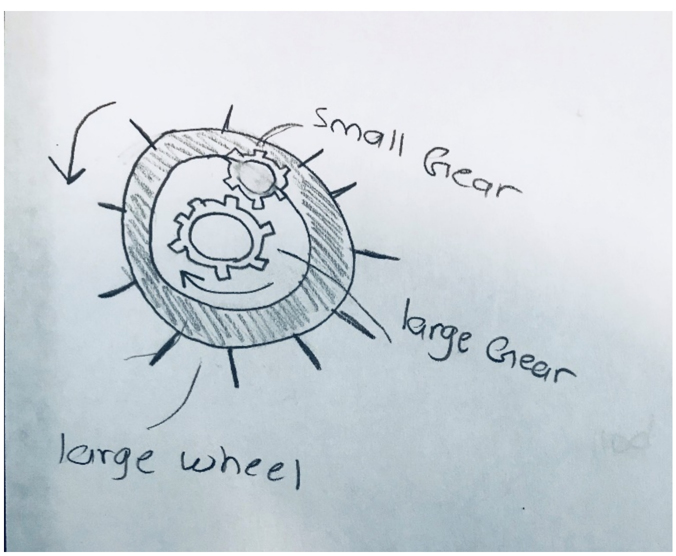


Figure B.9: Gears#2

8.2.10 Design 16: Aerodynamics 3

Schematic diagram of the setup is presented in **Figure B.10.** The machine starts when the mobile phone placed below the hair dryer vibrates during an incoming call. Vibration of the ball triggers the movement of the ball placed at slanted path and ball falls on the bucket which is attached to the switch of the hair drier. As a result, hair dryer is switched on due to weight of the ball and start blowing the air which propells the car till it hits the golf ball which results in movement of the golf ball. The movement of the golf ball can be used for triggering the next step.

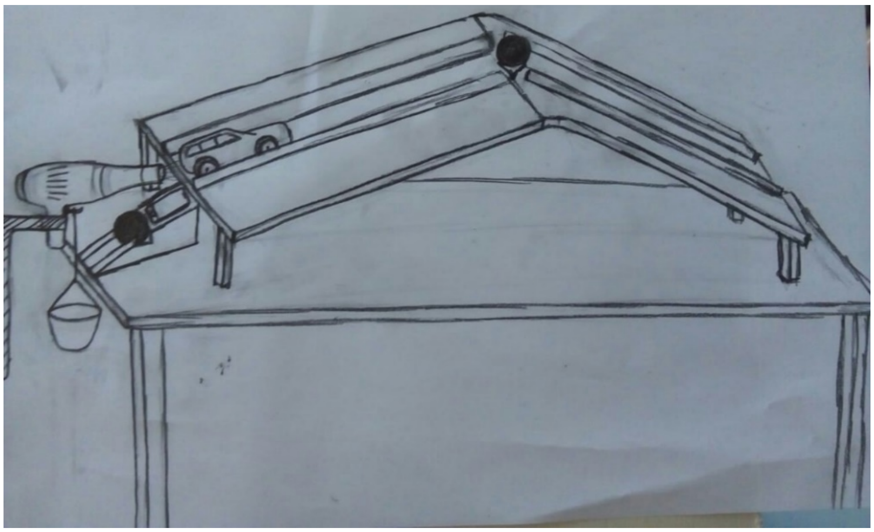


Figure B.10: Aerodynamics 3

8.3 *Appendix C: Pugh Chart*

Table C.1: Pugh Chart

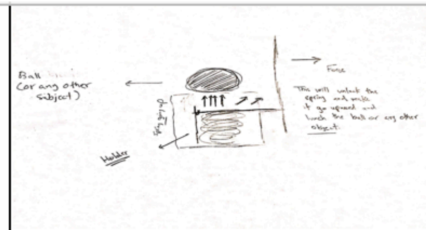
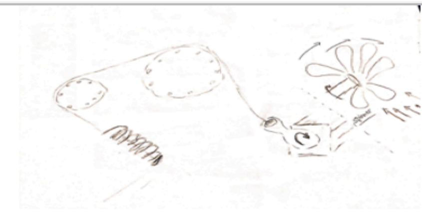
			
	Ultimate Rube Goldberg Step	**Spring #1**	**Spring #2**
Reliability	**D A T U M**	+'	-'
Durability		+'	-'
Resetable		-'	+'
Cost effective		S	-'
Entertaining		-'	+'
Safety		S	S
Sound		S	S
Timing		+'	S
Number of Pluses, +		3	2
Number of Minuses, -		2	3
Overall Score		**1**	**-1**

Figure C.1.1

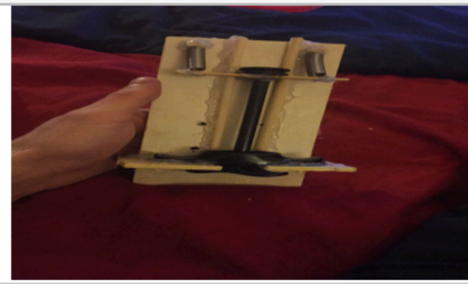
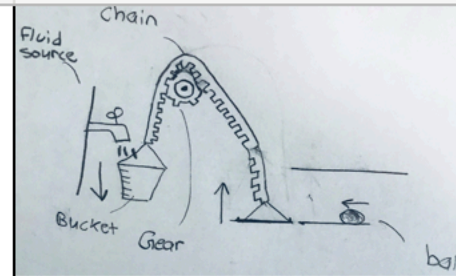
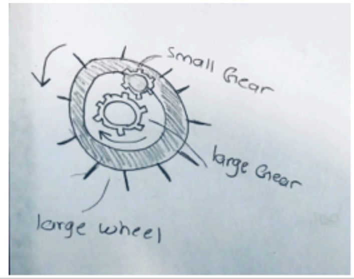
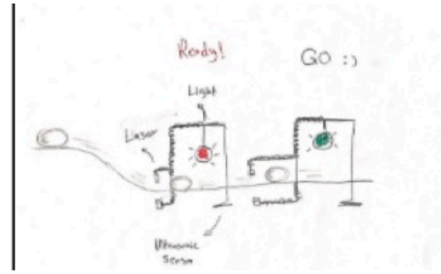
		
	Spring #3	**Gears #1**
Reliability	S	S
Durability	+'	S
Resetable	-'	+'
Cost effective	+'	-
Entertaining	+'	-
Safety	S	S
Sound	S	S
Timing	S	+'
Number of Pluses, +	3	2
Number of Minuses, -	1	2
Overall Score	**2**	**0**

Figure C.1.2





	Gears#1	Sensors#1
Reliability	+'	-'
Durability	+'	-'
Resetable	-	+'
Cost effective	-	S
Entertaining	S	+'
Safety	S	S
Sound	S	+'
Timing	-'	S
Number of Pluses, +	2	3
Number of Minuses, -	3	2
Overall Score	**-1**	**1**

Figure C.1.3

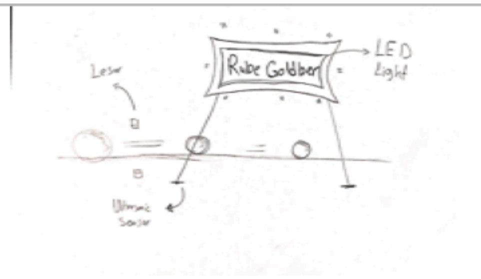
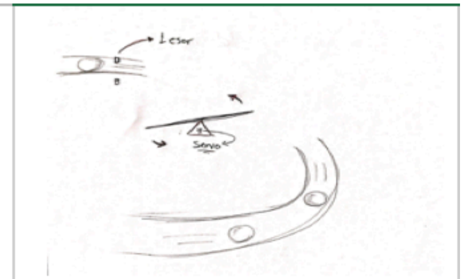
		
	Sensors#2	**Sensors#3**
Reliability	-'	-'
Durability	-'	-'
Resetable	-'	-'
Cost effective	S	S
Entertaining	+'	+'
Safety	S	S
Sound	+'	+'
Timing	S	S
Number of Pluses, +	3	2
Number of Minuses, -	3	3
Overall Score	**0**	**-1**

Figure C.1.4

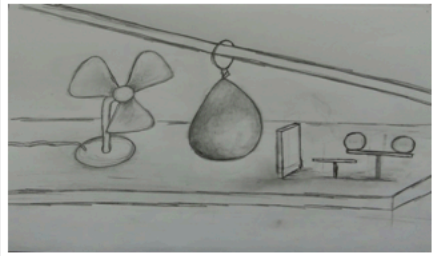
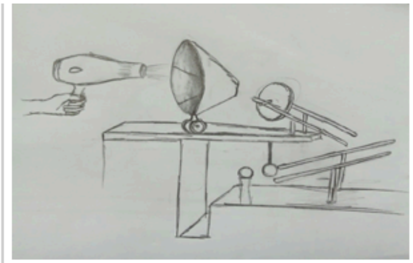
		
	Aerodynamics#1	**Aerodynamics#2**
Reliability	+'	+'
Durability	+'	+'
Resetable	-'	-'
Cost effective	S	S
Entertaining	-'	-'
Safety	S	S
Sound	S	S
Timing	S	S
Number of Pluses, +	2	2
Number of Minuses, -	2	2
Overall Score	**0**	**0**

Figure C.1.5

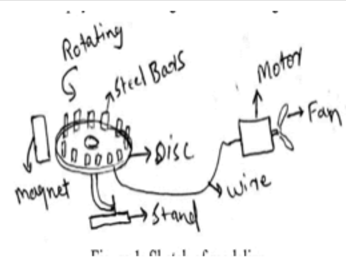
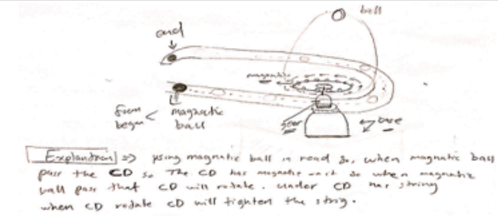
		
	Magent #1	**Magnet #2**
Reliability	-'	-'
Durability	-'	-'
Resetable	-'	-'
Cost effective	S	S
Entertaining	+'	+'
Safety	S	S
Sound	S	S
Timing	S	S
Number of Pluses, +	1	1
Number of Minuses, -	3	3
Overall Score	**-2**	**-2**

Figure C.1.6

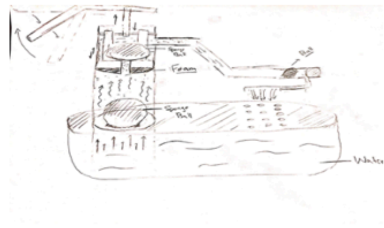
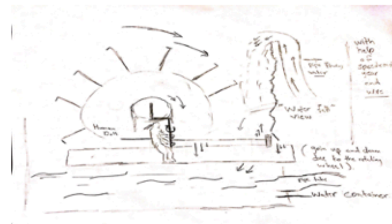
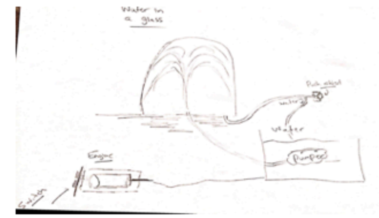
			
	Fluid #1	**Fluid #2**	**Fluid #3**
Reliability	-'	+'	+'
Durability	-'	+'	+'
Resetable	+'	+'	+'
Cost effective	+'	+'	-'
Entertaining	+'	+'	+'
Safety	S	S	S
Sound	S	S	S
Timing	S	S	S
Number of Pluses, +	3	4	4
Number of Minuses, -	2	0	1
Overall Score	**1**	**4**	**3**

Figure C.1.7

8.4 Appendix D: Decision Matrix

Table D.1: Decision Matrix

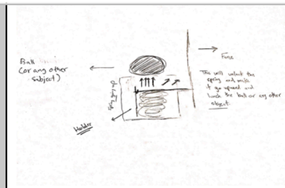
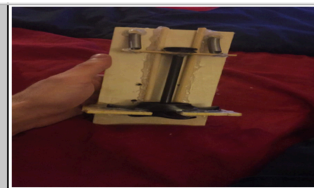
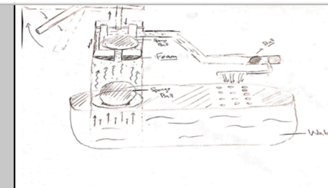
		 Spring #1		 Spring #3		 Fluid #1	
Customer Requirements	**Weight %**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost effective	5	5	25	5	25	5	25
Durability	4	2	8	3	12	3	12
Entertaining	2	3	6	4	8	4	8
Reliability	3	3	9	3	9	3	9
Resetable	3	3	9	3	9	4	12
Safety	5	5	25	5	25	5	25
Sound	3	3	9	4	12	4	12
Timing	5	2	10	3	15	3	15
Total			**101**		**115**		**118**
Designer		**Naser**		**Naser**		**Yousef**	

Figure D.1.1

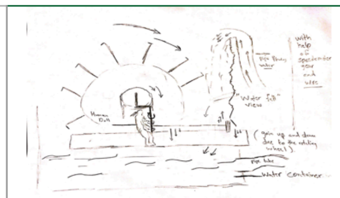
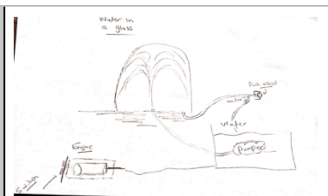
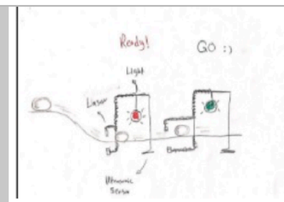
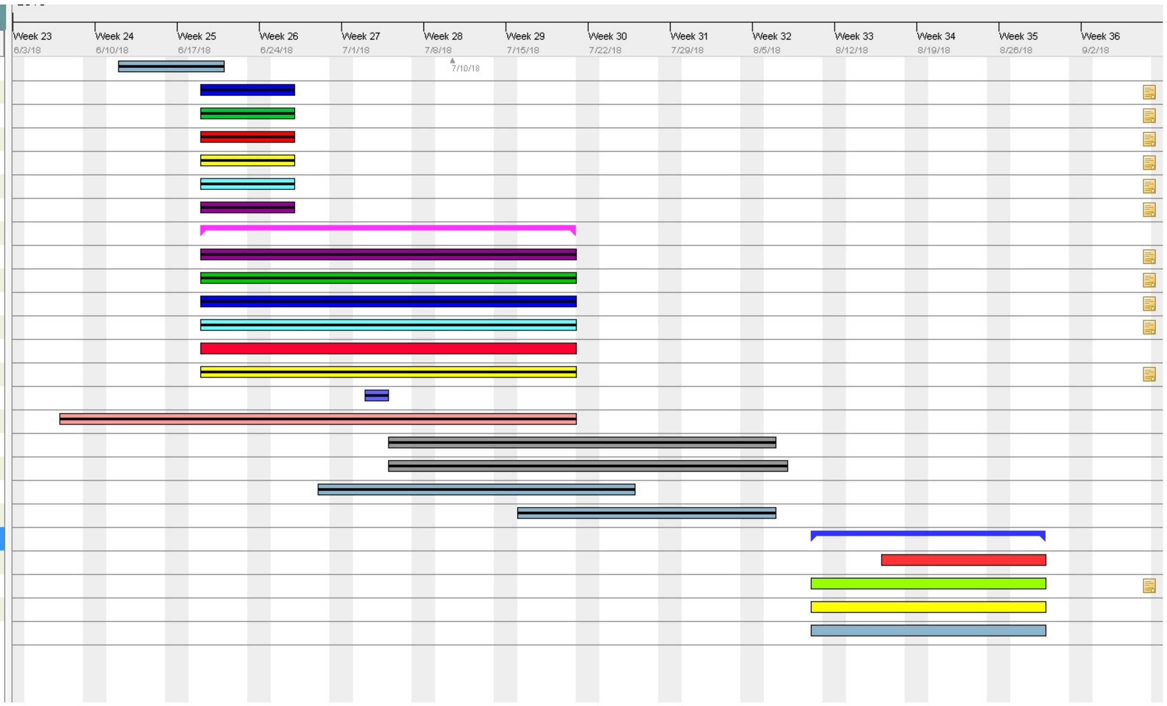
	 Fluid #2		 Fluid #3		 Sensor #1	
Customer Requirements	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost effective	5	25	4	20	4	20
Durability	4	16	4	16	3	12
Entertaining	5	10	4	8	3	6
Reliability	4	12	3	9	3	9
Resetable	5	15	4	12	4	12
Safety	5	25	5	25	5	25
Sound	4	12	4	12	4	12
Timing	4	20	4	20	3	15
Total		**135**		**122**		**111**
Designer	**Yousef**		**Yousef**		**Abdullah**	

Figure D.1.2

8.5 *Appendix E: Schedule of implementation task*

Name	End date	Begin date
Research Last Year's Project	6/20/18	6/12/18
Spring based steps	6/26/18	6/19/18
Gears based steps	6/26/18	6/19/18
Magnet-related step	6/26/18	6/19/18
Aerodymanic steps	6/26/18	6/19/18
Sensors	6/26/18	6/19/18
Liquid steps	6/26/18	6/19/18
Build prototypes	7/20/18	6/19/18
Fluid	7/20/18	6/19/18
Gears	7/20/18	6/19/18
Spring	7/20/18	6/19/18
Sensors	7/20/18	6/19/18
Magnets	7/20/18	6/19/18
Aerodynamics	7/20/18	6/19/18
Analytical Task	7/4/18	7/3/18
Find a Carpetner	7/20/18	6/7/18
BoM	8/6/18	7/5/18
Auto CaD	8/7/18	7/5/18
Website Check	7/25/18	6/29/18
Final Proposal	8/6/18	7/16/18
implementation plan	8/29/18	8/10/18
Enhance Prototypes	8/29/18	8/16/18
Create a Base	8/29/18	8/10/18
Brainstorm other steps	8/29/18	8/10/18
Add steps in Series	8/29/18	8/10/18



8.6 Appendix F: Bill of materials

Table E.1: Bill of materials

Bill of Materials								
Part #	Part Name	Qty	Description	Functions	Material	Dimensions	Cost	Link to Cost estimate
1	EUDAX 6 set	1	A set of gears, wires and DC motors	Motor, rotational energy	Plastic, metal	7.1 x 4.5 x 1.5 inches	$9.99	https://www.amazon.com/gp/product/B077WWS63B/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1
2	Wood Board	1	Attach items on top of board		Wood	6 x 4 inches	$3.99	Home Depot
3	Gorilla 7500101 Super Glue	1	To glue items	Self-Adhesive	Rubber	0.9 x 3.4 x 6.6 inches	$3.79	https://www.amazon.com/Gorilla-7500101-Super-Brush-Nozzle/dp/B01A7AVQKA/ref=sr_1_10?s=industrial&ie=UTF8&qid=1533356283&sr=1-10&keywords=super+glue
4	ELEGOO KIT	1	A set of items we need to design the electric circuit	Develop arduino on specific items	Sensors, arduino	13.7 x 8.4 x 1.9 inches	$59.99	https://www.amazon.com/EL-KIT-008-Project-Complete-Ultimate-TUTORIAL/dp/B01EWNUUUA/ref=sr_1_2_sspa?ie=UTF8&qid=1533364119&sr=8-2-spons&keywords=elegoo&psc=1
6	Balloon car	1	The car has balloon that help it to move		Plastic	7*3.5*1.5	$8.50	Walmart
7	Cardboard	1	It is the base of the prototype		Carton	18x14x12-Inch	$2.77	Walmart
8	Golf ball	1	It is used to hit the target		Plastic, rubber	1.68 inches in diameter	$9.80	Walmart
9	Tape	1	To attach the part with each other		Plastic	2.5 inches	$2.18	Walmart
10	Hair dryer	1	The source of the air that helps moving the car		Main part is plastic	3.6 x 9.1 x 10.6 inches	$9.94	Walmart
12	Magnet Pack	1	6 of them are small which are on CD		Iron	(6) 0.51 x 1.93 inches	$8.99	Home Depot

13	CD	1	It is on top of DC motor, using to rotate it		Plastic	4.72 inches	$0.99	Target
15	Wood slats	2	Base for the spring launcher and Diaphragm Pump		Wood	7.25 x 2.8 x 0.25	$4.88	Walmart
16	Wood sticks	1	Path for the ball and bases		Wood		$2.47	Walmart
17	Kabub sticks	1	Path for the ball and bases		Wood		$3.97	Walmart
18	Water and Air Diaphragm Pump	1	Water pump		Metal	95mm(L) x47mm(W)x36mm(H)	$7.68	https://www.amazon.com/gp/product/B0744FWNFR/ref=oh_aui_detailpage_o02_s00?ie=UTF8&psc=1
19	Vinyl tube	1	Tube for the Water pump		Poly-vinyl Chloride(PVC)	20inch Length	$4.93	Walmart
20	Chrome Steel Bearing Balls	1	Ball		Steel	15.9mm	$12.95	https://www.amazon.com/gp/product/B00EYUTB2A/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1
21	PVC cap pipe	1	Base for the launcher		PVC	1/2 in. x 10 ft	$2.20	Home Depot
22	Fidget spinner	2	Fidget spinner		Plastic	DIAMETER: 2.95 inches. Thickness: 0.31 inches	$2.00	Gas station
23	Springs	1	Small pack of different types of springs		Steel	Different types	$4.37	Home Depot
24	Injector Syringe Needle	1	Spring launcher		Steel	Stainless steel Size: 22cm x 7cm (L x W)	$7.59	Walmart
25	Rayovac Lantern Battery 6V	1	Battery for the Diaphragm Pump		Steel	6V	$4.59	Walmart
Total Cost Estimate:							**$178.56**	