Rube Goldberg Machine

Final Proposal

Team 02

Abdullah Almutairi

Naser Ahmad

Yousef Ahmad

Mohammad Abu Karbal

Fehaid Almarri

Hamad Almarri

2018 – Fall

Instructor: Dr. Sarah Oman

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

Executive Summary

Rube Goldberg Machine is an over designed machine used to perform the simple task. In this project our aim was to design and fabricate the individual steps of the Rube Goldberg Machine which are cost effective, reliable, repeatable, re-settable and unique. Customer requirements has been directly obtained from the various stakeholders. Engineering requirements are derived directly from the customer requirements. The team has developed a number of designs for the individual steps of the design. All these designs have been evaluated and the designs which scored well in the analysis have been selected for the prototyping. The team has fabricated and tested all these individual steps based on the customer's requirement. All these designs will be handed over to a team who will be combining all these steps along with their selected steps to perform some assigned task. The new technology in the form of Arduino kit, sensors and spinners etc. Have also been incorporated while developing these individual steps.

Acknowledgement

Rube Goldberg team thanks our instructor Dr. Sarah Oman, client Dr. David Trevas and our class aid, Amy Swarts for guiding our team to success and being available whenever help is needed. We are also thankful for Northern Arizona University for funding the team to build the project assigned by our client.

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

The Rube Goldberg machine (RGM) is a complicated machine which is designed using the basic engineering principle to accomplish a given task in the most innovative and entertaining manner. The machine consists of several steps where each step is triggered by the previous step. In this design, the major focus will be on applying the theoretical lessons learned in various engineering courses. The project will be of great significance to the sponsor and other stakeholders (fellow students) since it will be used to teach future Northern Arizona University Rube Goldberg (NAU RG) teams various engineering aspects and also be used as a form of brainstorming and leisure project. Other stakeholders of the project is the fellow team, since all the individual steps designed by our team will be handed over to them to further use in their project to combine all these steps to fabricate the RGM to produce the domino effect. The fun element involved will attract the attention of fellow student and it will increase the interest of the fellow students. It will also be displayed in the Under Graduate Research (UGR) building. Since a 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 to day life.

The major aim of this project is to make individual steps of a cost effective, reliable, repeatable, resettable and unique Rube Goldberg machine that will be used to accomplish a given task. 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. RGM involve the innovation, creativity and fun to watch.

1.2 Project Description

According to Wonderpolis, 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 cost effective, entertaining, reliable, repeatable, consistent and resettable 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 complexity and fun element, 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 make individual steps of a unique Rube Goldberg Machine which are cost effective, reliable, repeatable and resettable. The team is required to liaise with the clients so that they will be able to know the actual requirements which needs to be incorporated. First, there are customer requirements, and these will be obtained directly from the various stakeholders since they are the ones who will be 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 requirements to how the team is going to achieve this by prioritizing the requirements. All the requirements and HoQ are listed and explained in the following subsections.

2.1 Customer Requirements (CRs)

Customer requirements are the various requests which are submitted by the various stakeholders. The major requirements along with their weightage are presented below in **Table 1.**

Table 1: Customer requirements

Customer requirements	Weight(s)
Cost effective	3
Durable	3
Repeatable	5
Entertaining	5
Reliable	4
Resettable	5
Safe	3
Sound limit	2
Process Time	4

The steps should be cost efficient, reliable so that it will not fail during demonstration. Repeatability is another requirement since these will be displayed in the UGR building to demonstrate to the future RG teams. The steps should be complex and entertaining to the audience. The speed must have kept in such a way that the human eyes can capture every action. It should be safe and ensured that it should not pose any threat to the animals and human being. Since the major aim of the team is to design the individual steps of the RGM are entertaining and resettable to the audience hence these requirements have been assigned the highest weightage of 5 out of 5. The reliability, Durability and process timing also possess the significant importance hence the weightage of 4 out of 5 is assigned to these requirements. The minimum importance is given to the sound since the equipment used will not produce the sound which will be unbearable to the audience hence minimum weightage of 2 out of 5 is assigned.

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 2**.

Table 2: Engineering requirements

Engineering requirement	**Target values**
Number of steps	12
Process duration	6-7 seconds / step
Size	12x 12 ft
Sound	~ 20 DBs (Decibels)
Consistency	99-100%
Repeatable	100%

2.3 Testing Procedure

Testing procedures are the procedure by which the team will check whether the customer requirements are fulfilled or not. Since the engineering requirements directly correlated to the customer requirements hence the testing procedures will be relatively simple. By seeing at functional model placed at **Appendix A** in **Figure A.1** to **Figure A.6**, the number of steps and potential hazards will be directly counted respectively for testing. The process duration will be tested at the time of demonstration just by examining the time from start to finish. The size of the machine can also be measured and verified whether it is within the permissible limit. For testing the fun factor, the RGM is displayed to the fellow students and ranking can be determined by their opinion since the fun factor varies from person to person. To insure the consistency and reliability, team will run the machine number of time and data is collected for success rate of RGM. If the consistency turns out to be low, the respective steps can be modified to ensure the consistency beyond 99%. To test the reset ability, The RGM is operated many times and all the steps can be closely monitored and checked whether all the individual steps are resettable or not. During the demonstration of the RGM, the reactions of all the viewer's is monitored. It the viewers are enjoying and not looking confused, so this will be the test of the speed of the steps. If the time is within the permissible limits that means the customer requirement is fulfilled.

2.4 House of Quality (HoQ)

The 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 3.**

Table 3: 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 (RTI)			2	3	4	1	6	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

Weightage out of 5 to all the customer requirements are assigned and each engineering requirement is given the scores against the customer requirement. The weighted score are summed up to get the absolute technical importance. The speed and the number of steps turns out to be the most important with the score of 81 and 80 respectively and the least important engineering requirements turns out to be the sound with the score of 10. So, the speed and number of steps are the most critical aspect of the design which must be incorporated while designing the RGM machine.

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 engineering concepts have also been studied through the literature which can be effectively used for designing the best possible individual steps of the RGM machine. 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. 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 [2].

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 [2].

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:

3.2.2.3 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].

3.2.2.4 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].

3.2.2.5 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].

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].

3.2.3.3 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 [4].

3.2.3.4 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 [4].

3.2.3.5 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 [4].

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.**

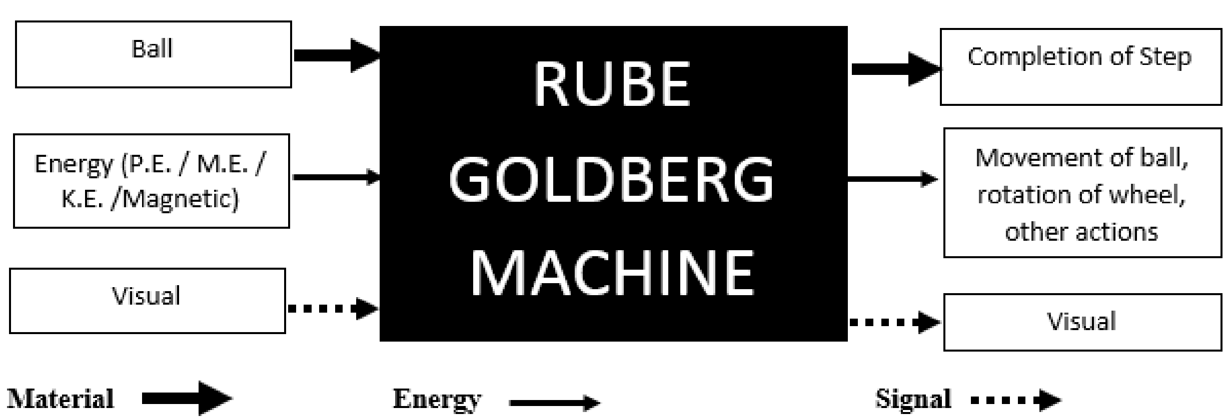


Figure 1: Black Box Model

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.

3.4.1.3 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.

Figure 2: Compression Spring [5]

3.4.1.4 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.

Figure 3: Torsional Spring [5]

3.4.1.5 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 [5]

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.

3.4.2.3 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 [6]

3.4.2.4 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.**

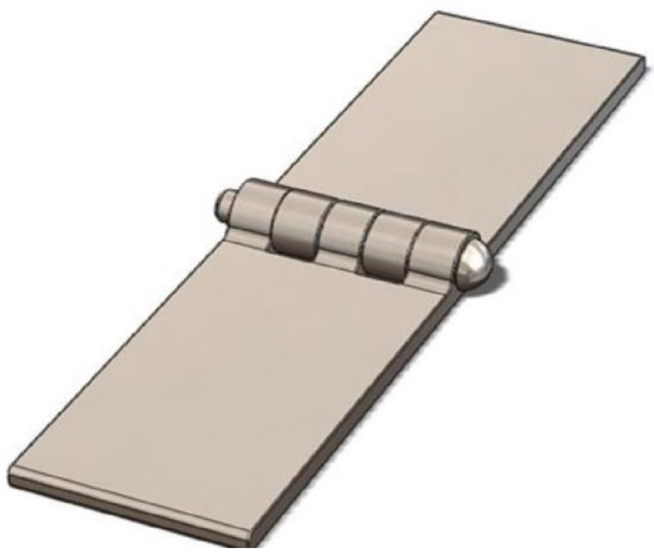


Figure 6: Aluminum Hinges

3.4.2.5 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.

3.4.3.3 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.

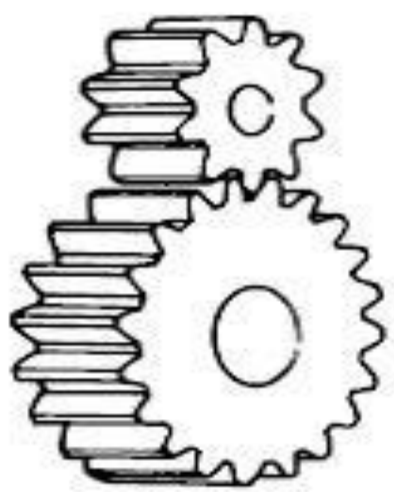


Figure 8: Spur gears [7]

3.4.3.4 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]

3.4.3.5 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. An isometric view of gear rack is presented in **Figure 10**.

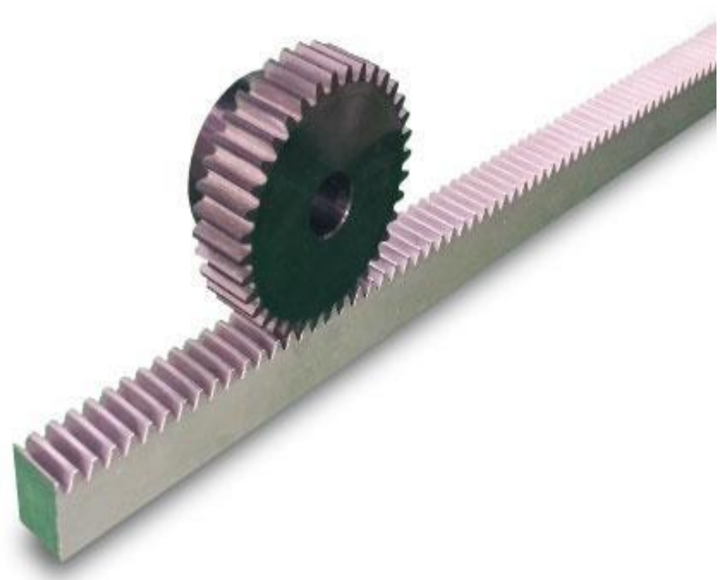


Figure 10: Gear rack [7]

3.4.4 Subsystem #4: sensors

A device which gives an output by detecting the changes in quantities or events can be defined as a sensor. These are crucial for our project to draw the attention of the audience.

3.4.4.3 Existing Design #1: Red Laser Sensor

Laser Sensor is effectively used as a distance sensor which is based on the distance. It can be effectively used to trigger the succeeding steps. As the distance of the object reaches to a certain point then a signal can be transmitted to trigger the next step. The schematic diagram is presented in **Figure 11.**

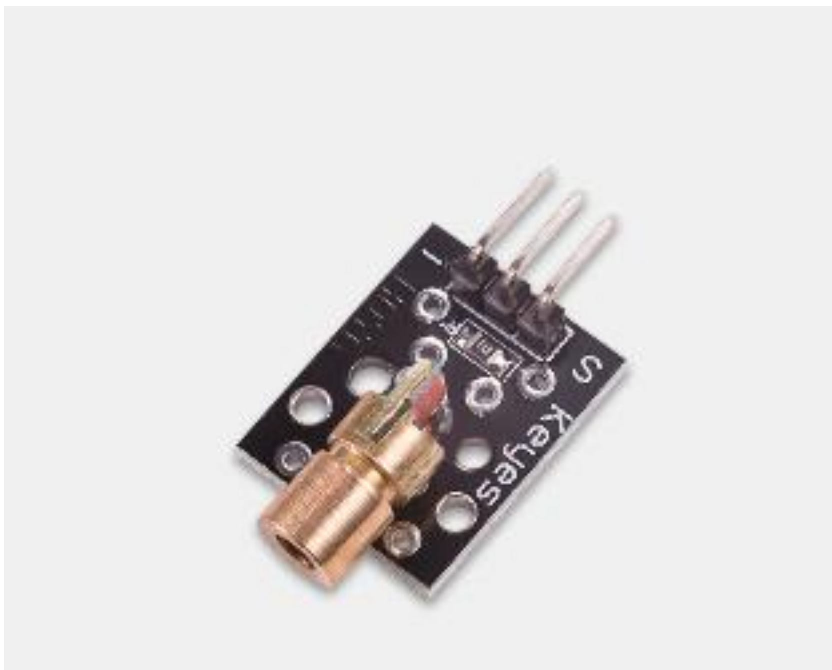


Figure 11: Red Laser Sensor [8]

3.4.4.4 Existing Design #2: Force Sensitive Touch – Square Sensor

A transducer that works on the principle similar to the sonar and estimate attributes of the target by interpreting is called as Force sensors. It can be effectively used in our project to measure the distance of a moving object. As the object passes through this, it will send the "Rube Goldberg" signal to trigger next step. A picture of Force Sensitive resistor – Square Sensor Is shown in **Figure 12**.

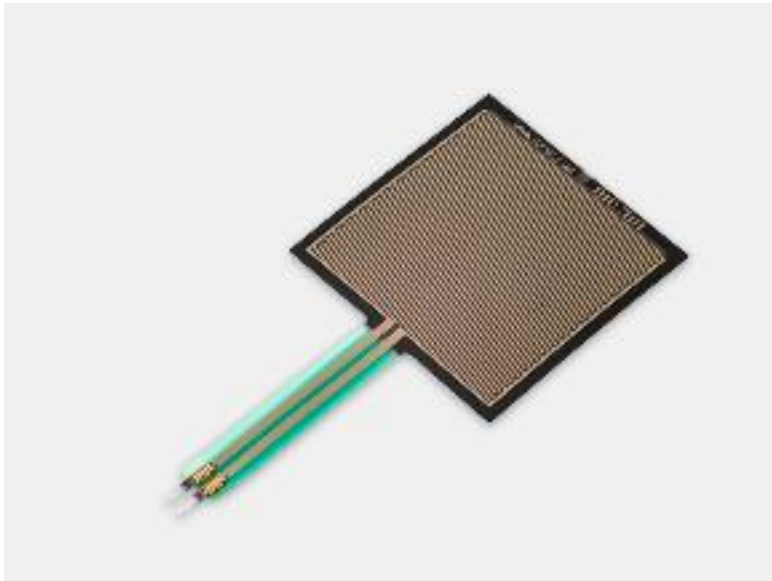


Figure 12: Force Sensitive resistor – Square Sensor [8]

3.4.4.5 Existing Design #3: Force Sensitive Resistor 0.5 Sensor

These works on the principle of resistance and capacitance. This can be effectively used in the project as a switch that are activated by the touch. This can be very useful to add the complexity and to trigger the succeeding step. Schematic diagram of the tough sensor is shown in **Figure 13.**

Figure 13: Force Sensitive Resistor 0.5 Sensor [8]

3.4.5 Subsystem #5: Aerodynamics

Aerodynamic forces are generated by flowing the air and can be effectively used for swinging the pendulum and moving any objects. The means of generating the aerodynamic forces are discussed in following subsections.

3.4.5.3 Existing Design #1: Fan

Electric fans can be crucial and important for team's project since it can be used to move the ball or toy cars which hits some other object to trigger the next step. A picture of the fan is shown in Figure 14.

Figure 14: Temperature Sensor [9]

3.4.5.4 Existing Design #2: Hair dryer

These are capable of producing the concentrated air so can be used to move the heavy object. These are also cheaper than electric fan and easily available in the market. A picture of the hair dryer is shown in **Figure 15**.

Figure 15: Temperature Sensor [10]

3.4.5.5 Existing Design #3: balloon

The compressed air when escapes through a small opening of an inflated balloon, it produces greater aerodynamic forces. Compressed air can also be used for triggering the next step. Since these are cheap and easily available in the market, it will help us to reduce the cost of making the Rube Goldberg machine. A picture of the inflated balloon is shown in **Figure 16**.

Figure 16: Temperature Sensor [11]

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**.

4.2 Design #1: Spring 1

As shown in the **Figure 17** 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.

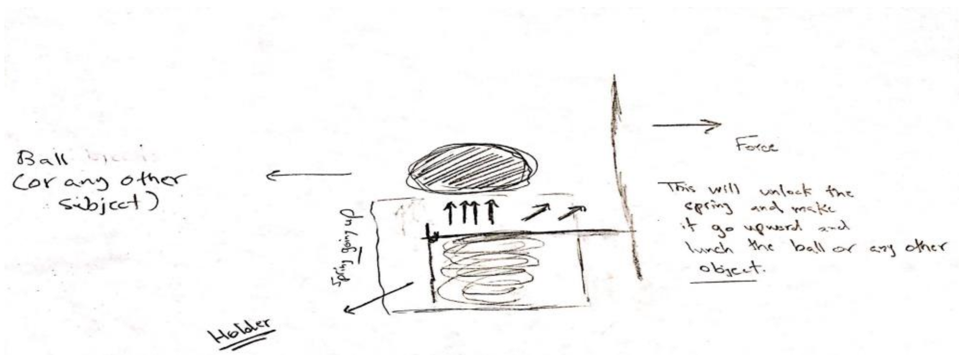


Figure 17: Spring #1

4.3 Design #2: Spring 3

The **Figure 18** 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.

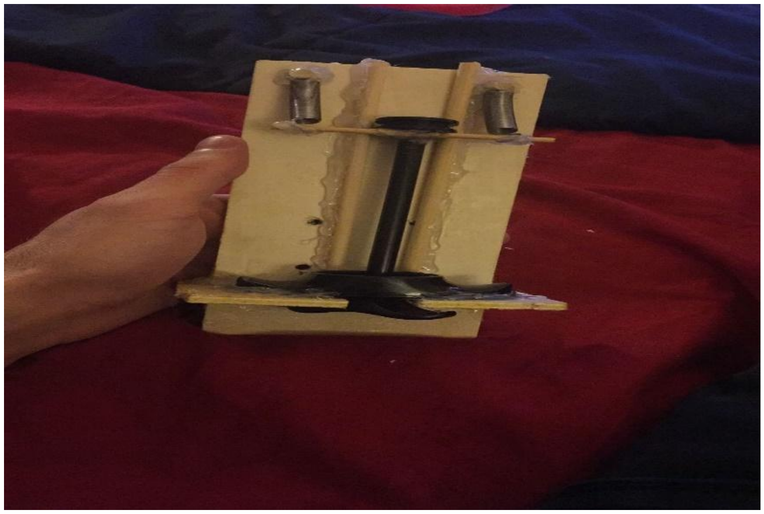


Figure 18: Spring#3

4.4 Design #3: Fluid 1

A homemade water pump is presented in **Figure 19**. 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.

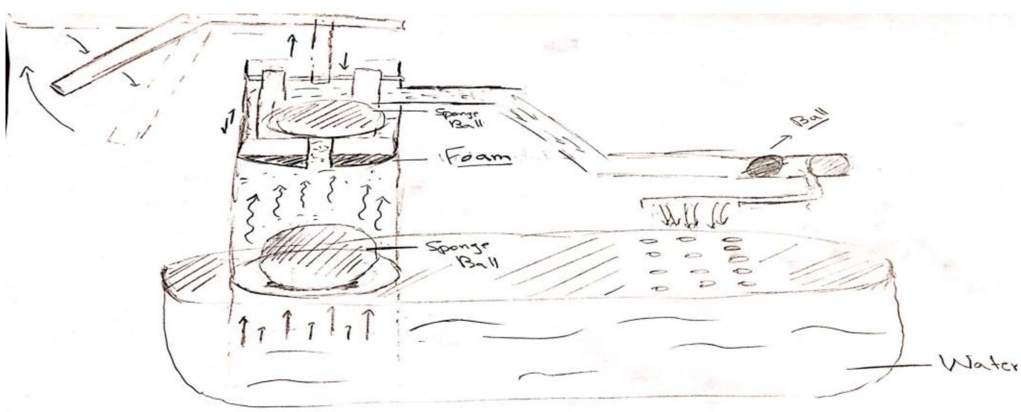


Figure 19: Fluid#1

4.5 Design #4: Fluid 2

The schematic view of the setup is presented in **Figure 20**. 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.

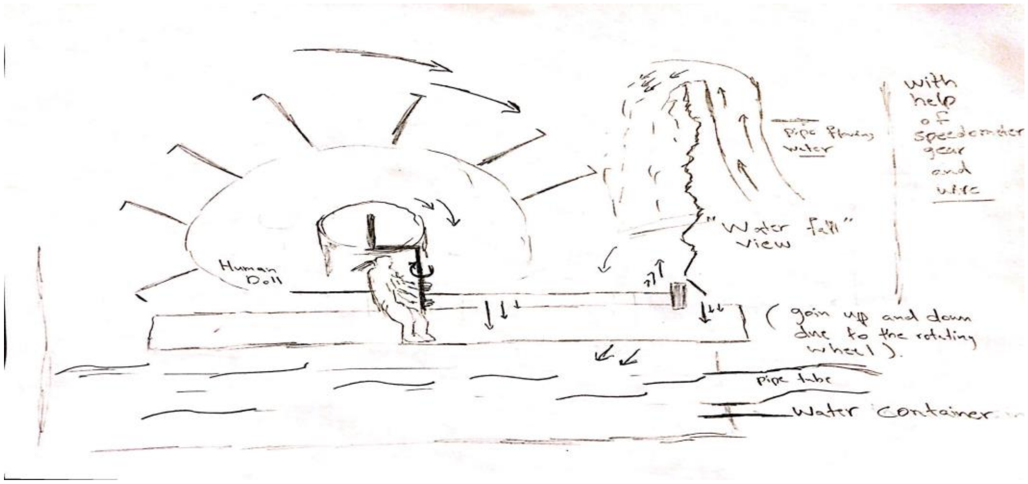


Figure 20: Fluid#2

4.6 Design #4: Fluid 3

Figure 21 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.

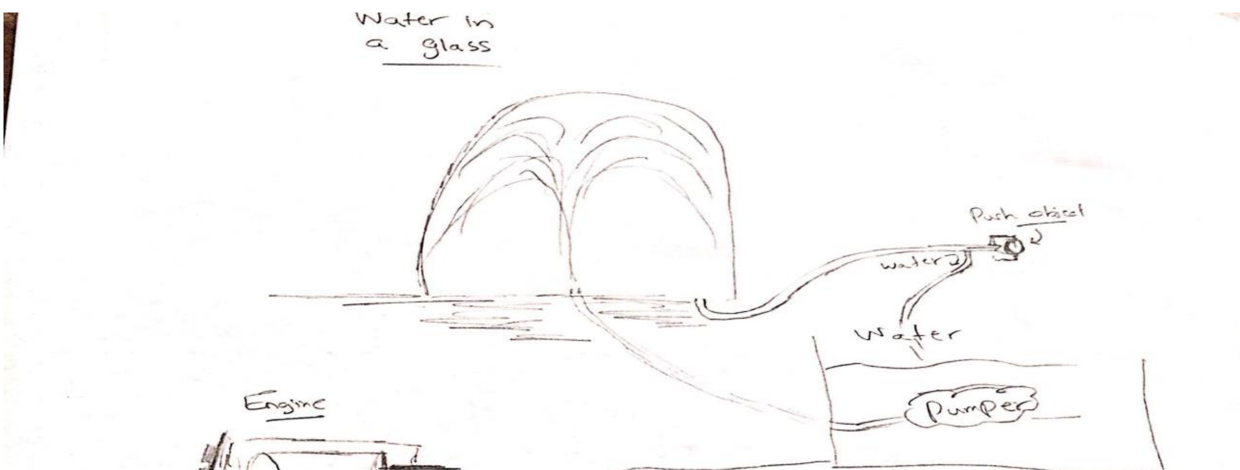


Figure 21: Fluid#3

4.7 Design #6: Sensor 1

The sketched **Figure 22** 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.

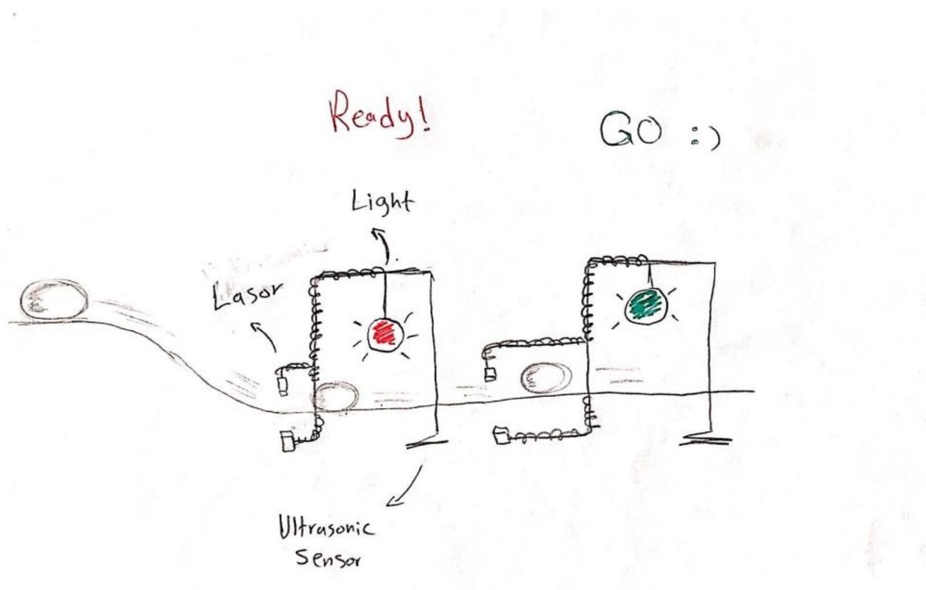


Figure 22: Sensors#1

5 DESIGN SELECTED – First Semester

In this section, the best individual setup designs which meet the client's requirements are selected. Before settling on the final designs the team must ensure that the designs selected meet 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 unique, reliable, repeatable and resettable design. 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 designs. The design those score well during the analysis are design 1 to 6. Schematic view of the selected designs are presented below in **Figure 23.**

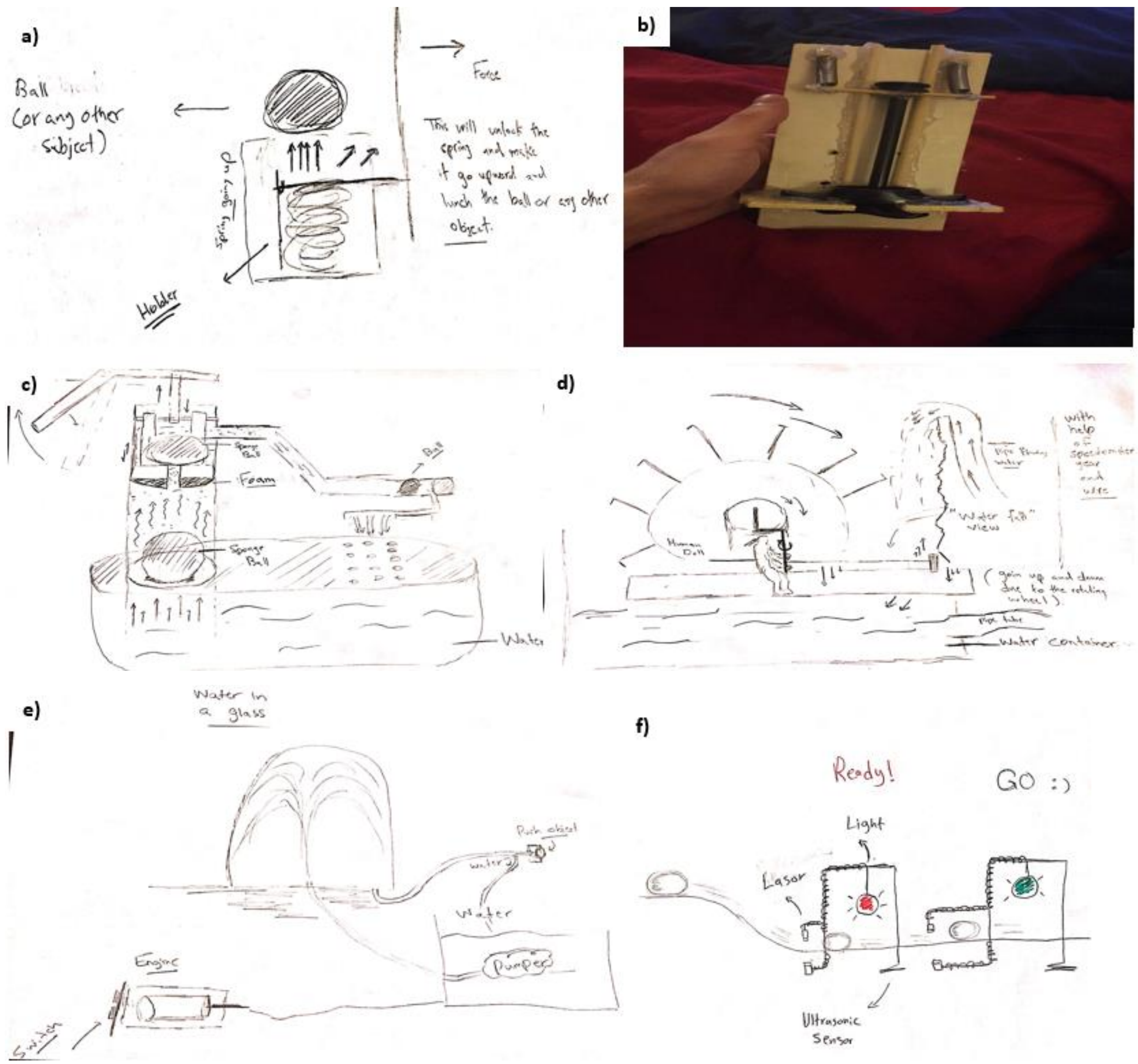


Figure 23: Schematic diagram of the selected designs

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:

5.2 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 D.** 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 multiple design from the Pugh chart analysis which are highlighted in the **Table D.1** placed at **Appendix D.**

To evaluate these 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 E.** 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.

The selected designs are satisfying the customer needs such as consistent, repeatable, resettable, safe and unique. In the next semester, teams is going to fabricate the Rube Goldberg Machine by using these proposed steps in combination with some transitional step. Designs are thoroughly explained in the next section.

5.3 Design Description

The team has listed the 6 best possible designs and made the prototype of all the individual steps. First the team members has did the theoretical analysis to finalize the parameters of design for the desired output. After finalization each team member has made the 3D-model of the assigned design with the help of SolidWorks software. During the evaluation, the team has selected the designs which got the highest score in the decision matrix on the basis of customer needs. So, all the designs meet the customer requirement. During the fabrication of prototype, the team has faced many challenges in order to make the design consistence, repeatable and resettable. Wherever the team stuck, the problem is solved in the scheduled meeting. At the end of the semester, team has been able to achieve the goal. In the next semester, the team will mainly focus to improve the design to make the project more appealing. All these individual setups will be combined with some transitional step to get the domino effects.

5.3.1 3D Model

The 3D model of all the proposed designs are presented in **Figure 23** and their engineering drawings are placed at **Appendix C.** The material used for developing the prototype is selected in such a way that it should be less costly as well as sufficient enough to meet the goal. Selection of the springs depends on the spring constant; therefore, the team has selected the spring with the same spring constant. For making the base and path way of any object, card board and wood is used since these are cheaper, easily available and easy to handle. Some of the material such as gear set, glue, elegoo kit, water and diaphragm pump and bearing ball is purchased from the amazon online store. Fidget spinners are used in the place of bearing and purchased from local stores. Spinners are cheaper and lighter than the bearing. Cooking pin is used as seen in **Figure 23 (b)** and purchased from Walmart. A detailed list of material along with the dimensions and the source from where it has been purchased is placed at **Table 4** in **Appendix G**. **Figure 24-36** shows all the new and changed 3D model design that have been made.

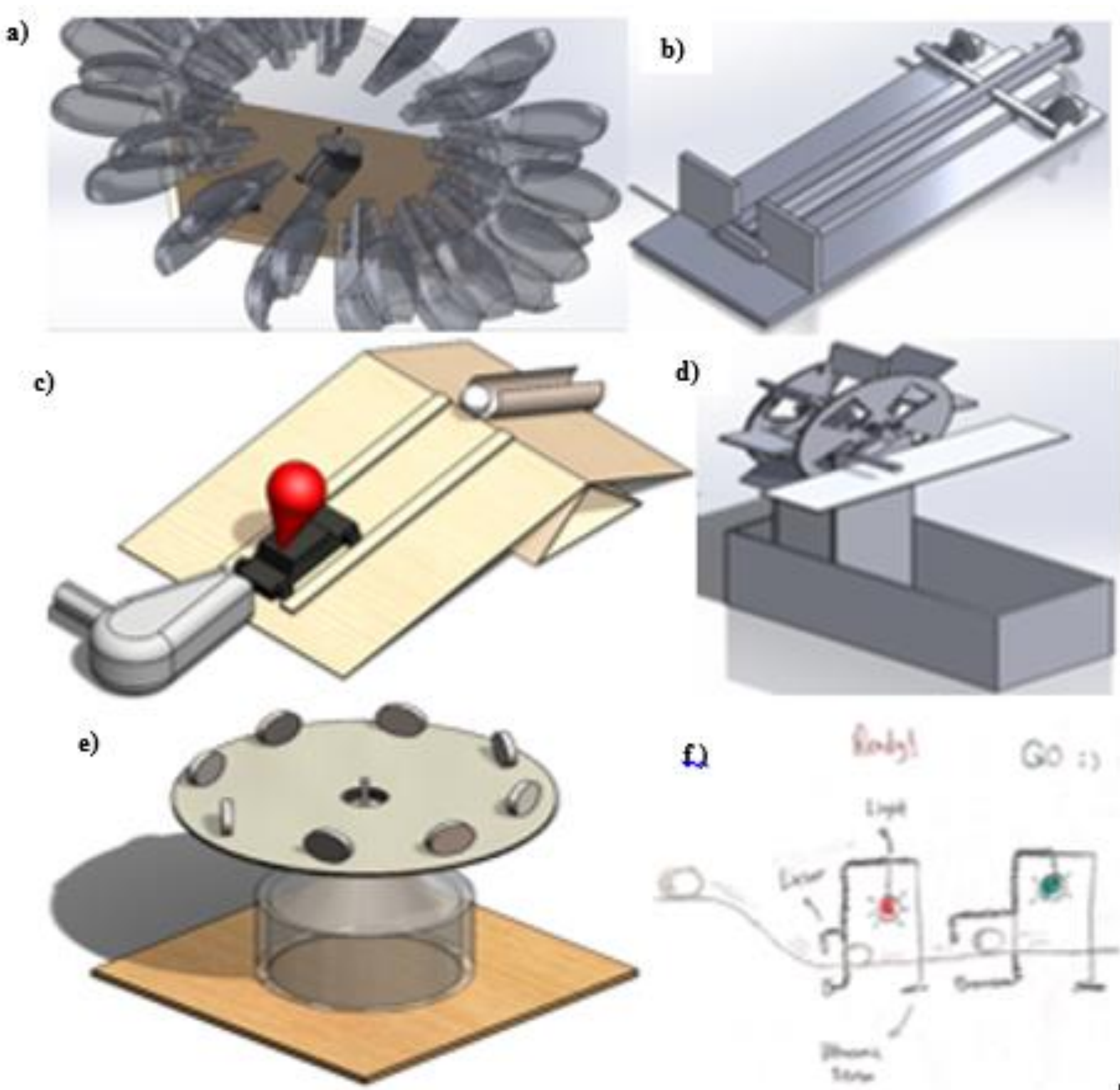
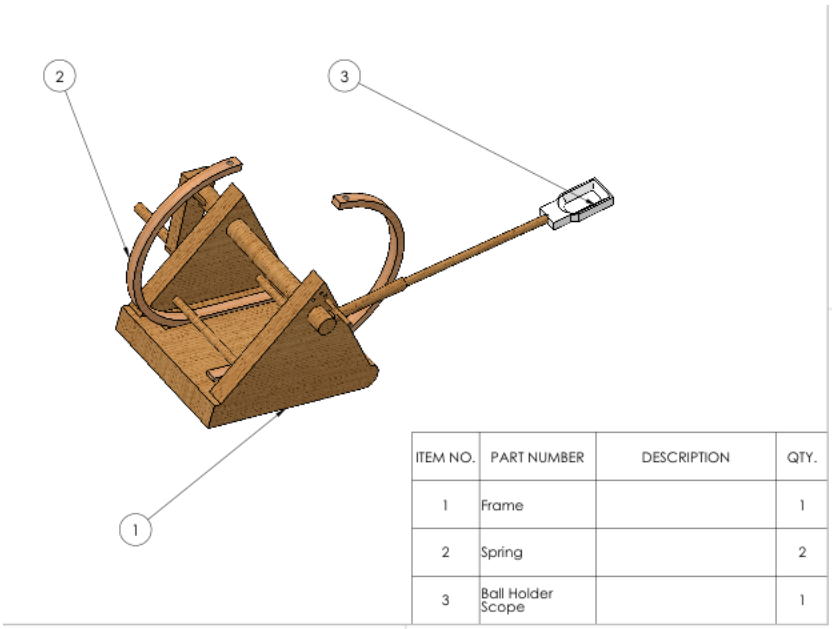


Figure 24: 3D – Model of Proposed Design



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame		1
2	Spring		2
3	Ball Holder Scope		1

Figure 25: Catapult

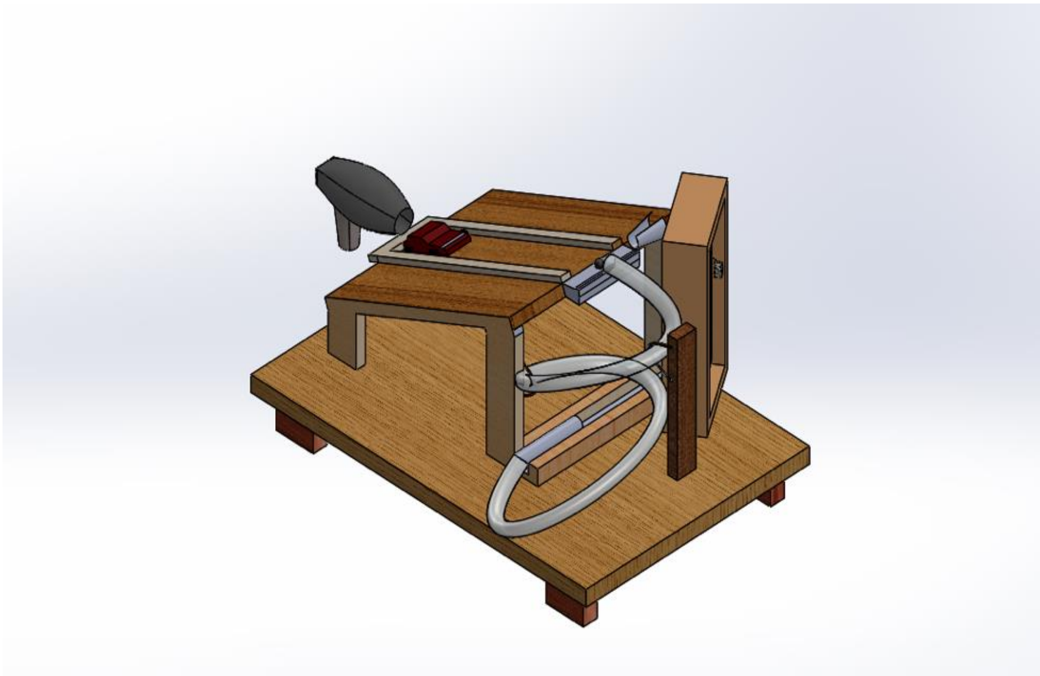


Figure 26: Aerodynamics step

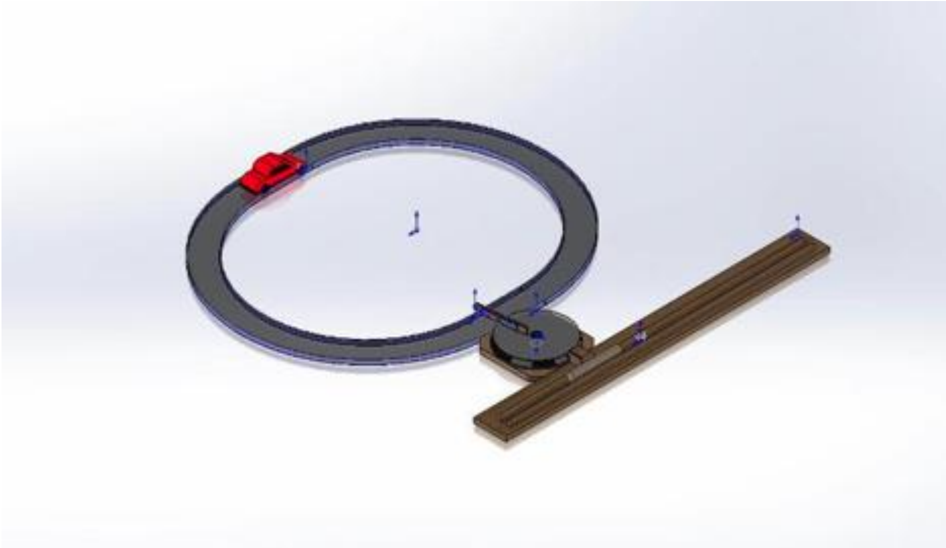


Figure 27: CD player

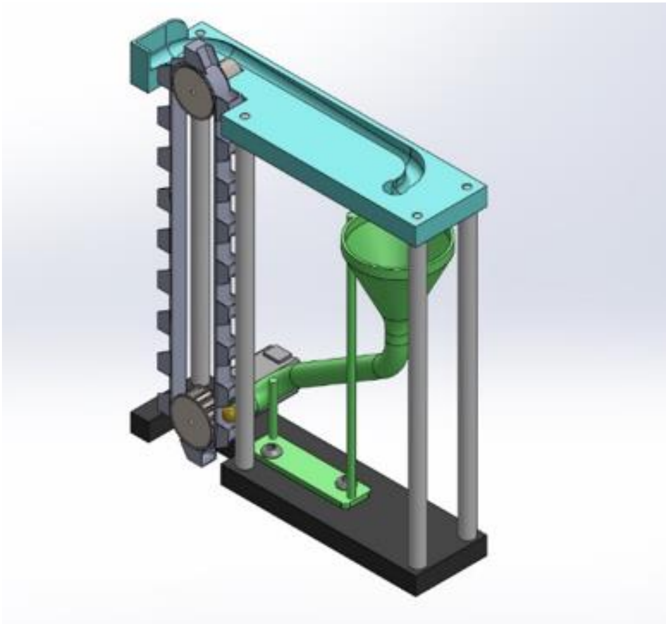


Figure 28. Escalator

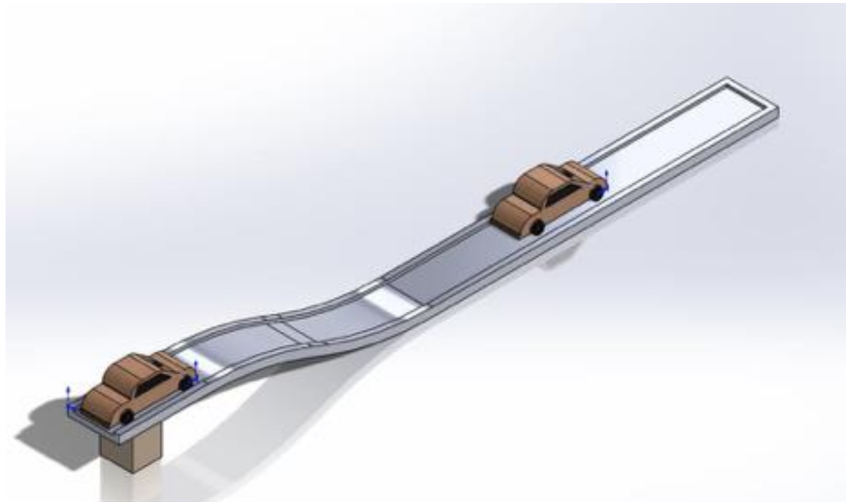
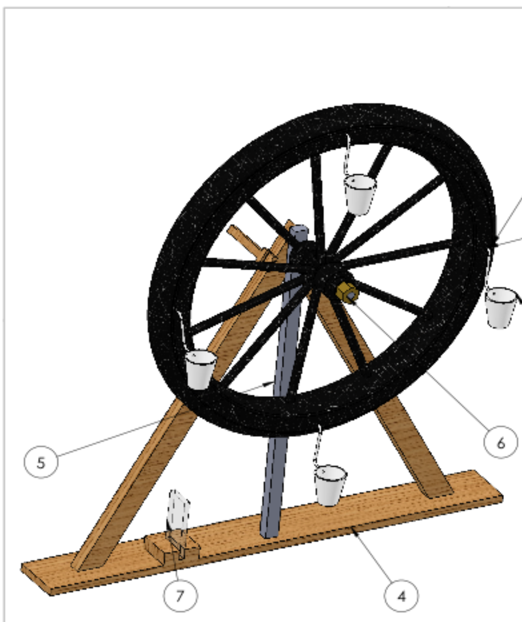


Figure 29: Car track



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bicyle Wheel		1
2	Link Wire		4
3	Cup		4
4	Wood Frame		1
5	Steel Bar Support		1
6	Nut		1
7	Glass		1

Figure 30: Bicycle Wheel

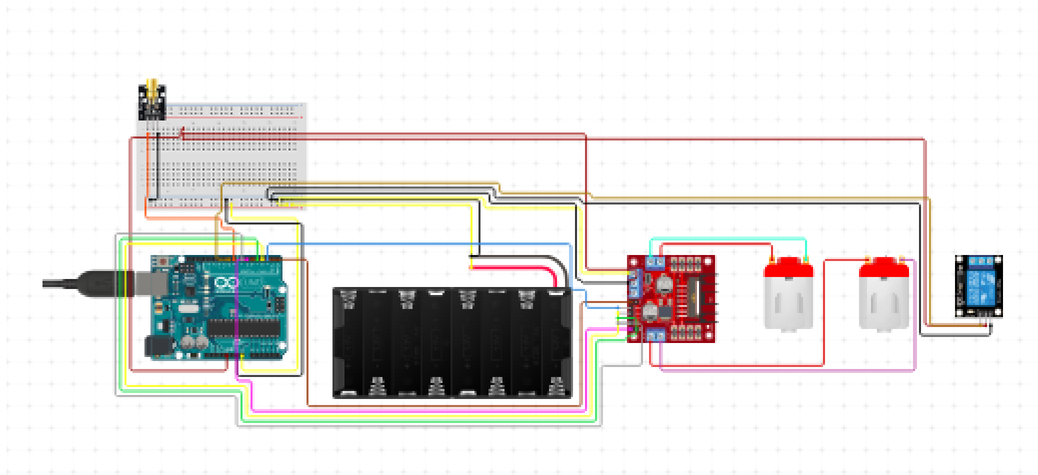


Figure 31: System for aerodynamic

-

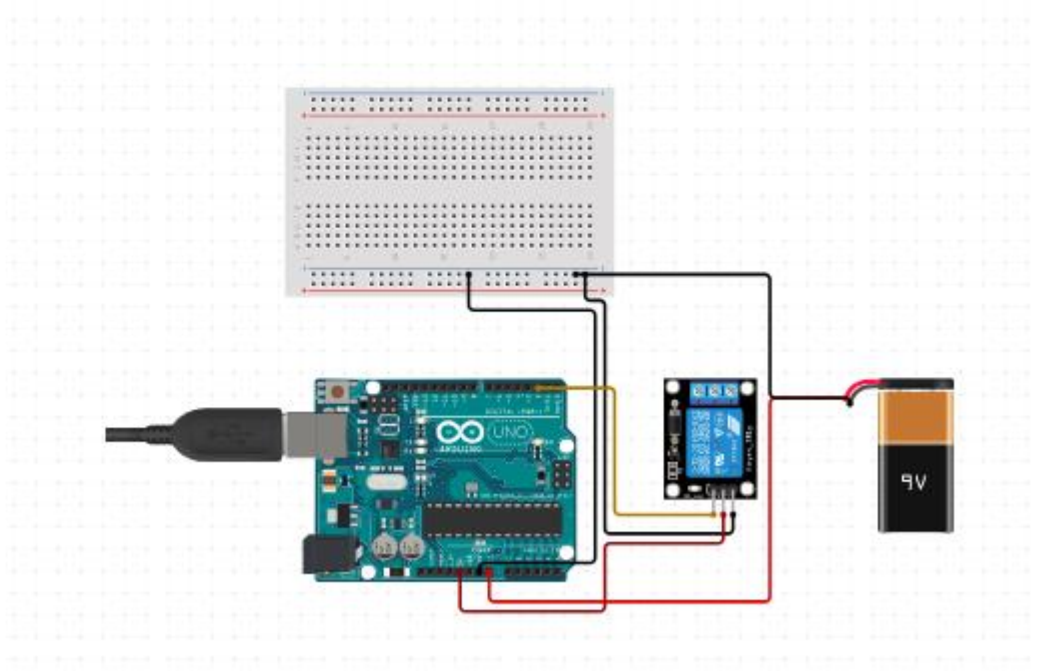


Figure 32: System for water wheel

-

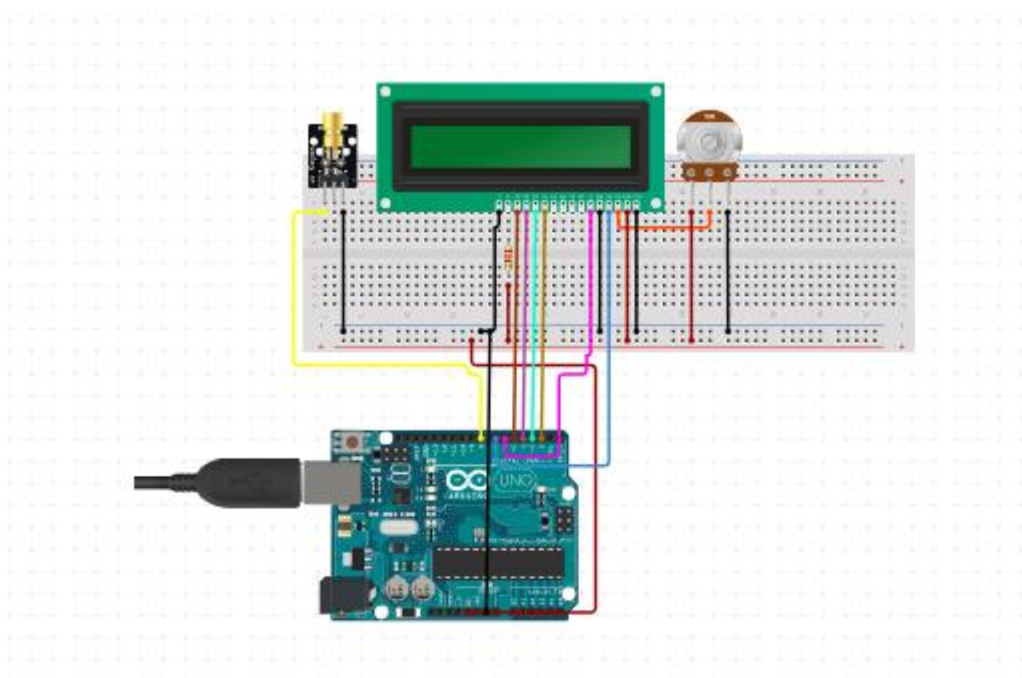


Figure 33: System for 3D escalator

-

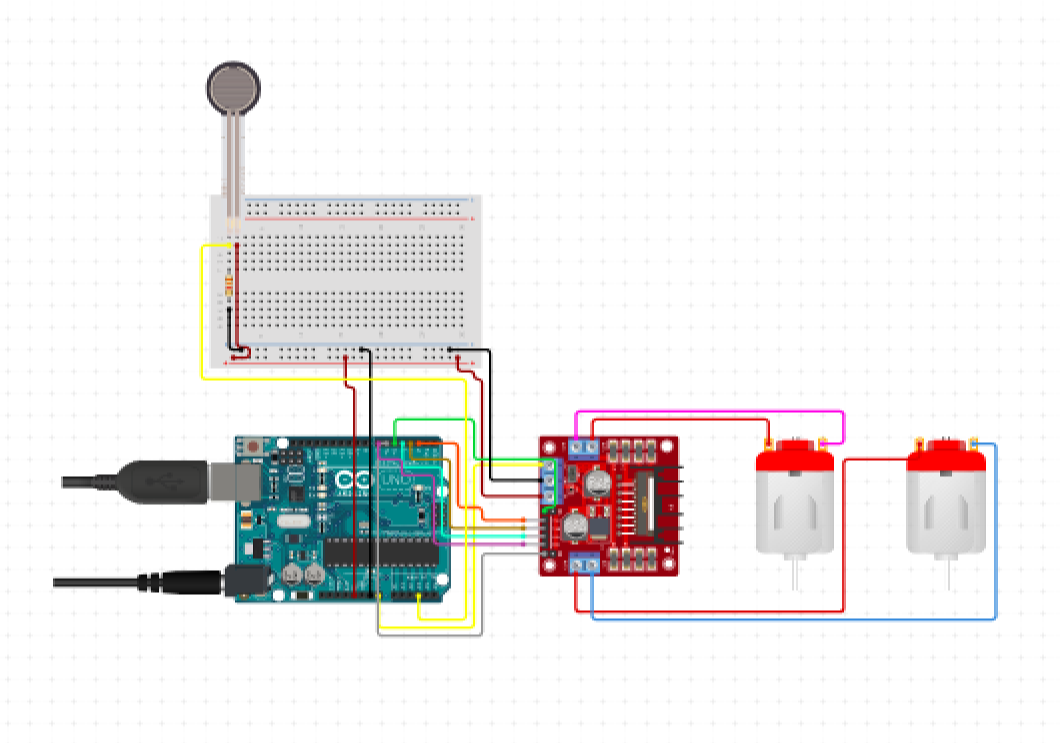


Figure 34: System for gear escalator

-

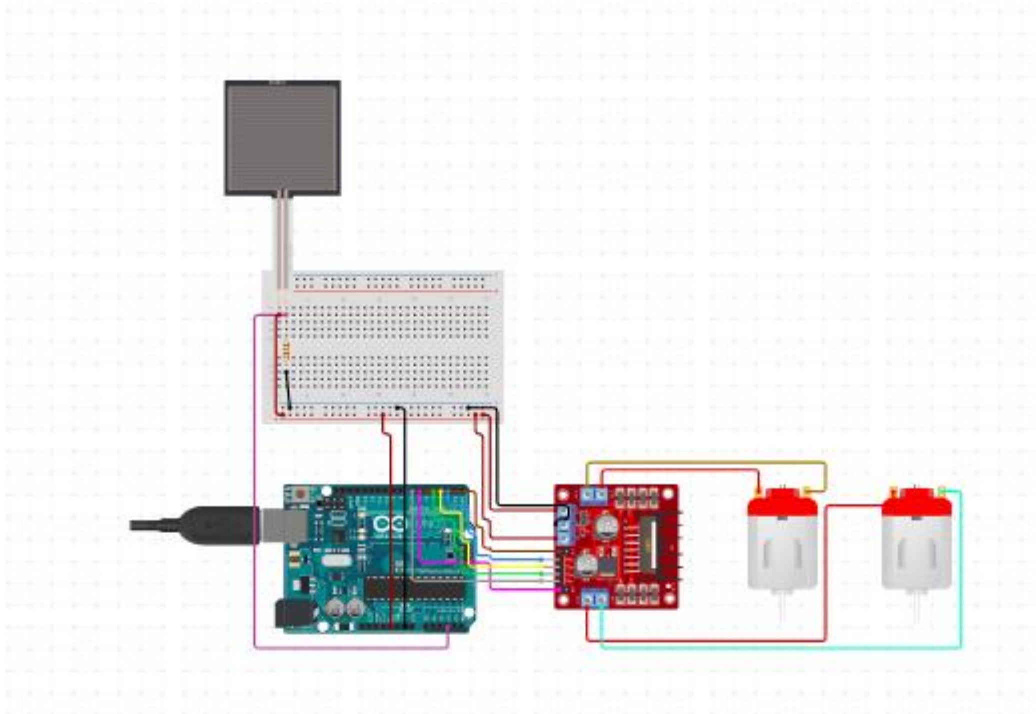


Figure 35: System for the magnet car

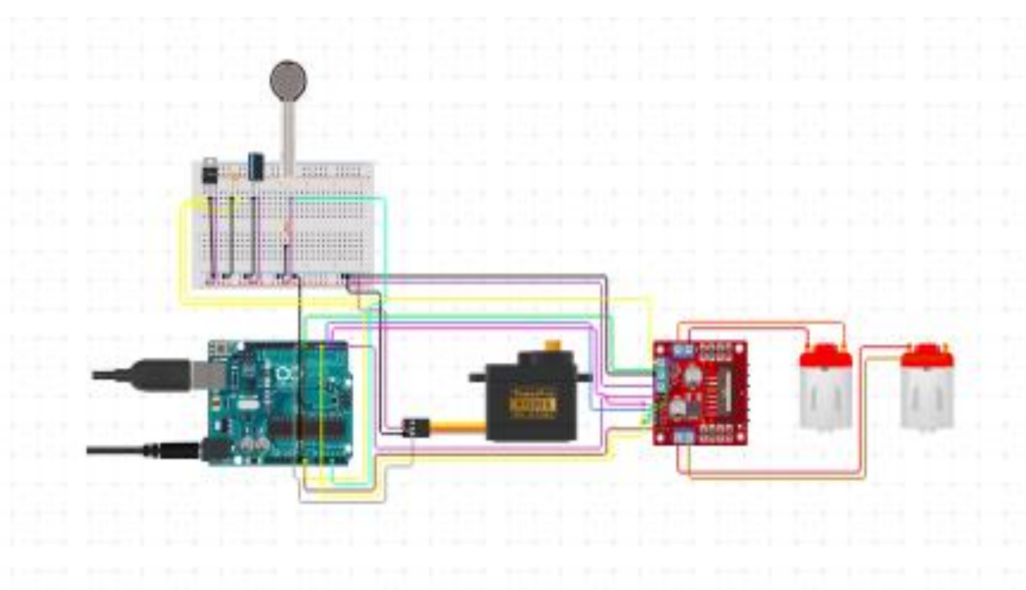


Figure 36: System for spiral staircase

-

-

5.3.2 Theoretical Analysis

All the theoretical analysis if the proposed designs are presented in subsequent sub sections.

5.3.2.3 Spring Analysis

The system consists of two parts of energy transformation. At first stage, potential energy due to spring compression is transformed into the kinetic energy of the ball. 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 analyze the trajectory motion. 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) [12]

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

where U_s is potential energy
k is the spring constant
x is displacement

The object has already potential energy due to spring. As soon as the clipper is detached, the spring released the potential energy transform into the kinetic energy of the ball. Due to conservation of energy, it can be written as; [13]

$$U_s = U_k \quad (2)$$

Where, U_k is kinetic energy, and its mathematical representation is;

$$U_k = \frac{1}{2}mv^2 \quad (3)$$

Where, m is mass of the object
v is velocity of the object

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;

$$U_p = mgh \quad (4)$$

Where, g is gravitational acceleration
h is elevation

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

$$\frac{1}{2}kx^2 = mgh \quad (5)$$

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.

5.3.2.4 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 '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 [14]:

$$dE = \rho A_c h \, dh \quad (6)$$

The power required is given as:

$$\frac{dE}{dt} = \rho A_c h \frac{dh}{dt} \quad (7)$$

$$P = \rho A_c h \dot{h} \quad (8)$$

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 [15].

$$\frac{P_1}{\rho}+\frac{1}{2}V_1^2+gh_1=\frac{P_2}{\rho}+\frac{1}{2}V_2^2+gh_2 \qquad (9)$$

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,

$$\frac{1}{2g}V_1^2+s=\frac{1}{2g}V_2^2 \qquad (10)$$

$$V_2=\sqrt{V_1^2+2gs} \qquad (11)$$

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

$$Flow\ leaving\ the\ container = f\square ow\ entering\ the\ pipe\ at\ lcoation\ 1$$

$$\rho\dot{h}A_c=\rho V_1 A_p \qquad (12)$$

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

$$V_1=\dot{h}\frac{A_c}{A_p} \qquad (13)$$

From Eq. (8) The value of $\dot{h}$ can be obtained as:

$$\dot{h}=\frac{P}{\rho A_c h} \qquad (14)$$

Therefore,

$$V_1=\frac{P}{\rho A_p h} \qquad (15)$$

$$V_2=\sqrt{\left(\frac{P}{\rho A_p h}\right)^2+2gs} \qquad (16)$$

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,

$$V_2=\sqrt{\left(\frac{P}{\rho A_p h}\right)^2+gh} \qquad (17)$$

5.3.2.5 Aerodynamic 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 [15]:

$$P_1+\frac{1}{2}\rho v_1^2 + \rho gh_1 = P2 + \frac{1}{2}\rho v_2^2 + \rho gh_2 \quad (18)$$

Where,
P_1 is the pressure energy.
Pv is the kinetic energy per unit volume
ρgh is potential energy per unit volume.

5.3.2.6 Sensor Analysis

The touch 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 pass over 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. It also will help to connect the DC motor and servo motor with each step so we can make them self-settable. However, the issue on the sensor part is we have to find the distance to pass the ball it with the correct way so, the sensor car works clearly.

5.3.2.7 Magnetic Analysis

The equation of magnetic field for the current has given [16]

$$B = \frac{\mu_o I}{2\pi r} \quad (19)$$

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

$$\mu_o I = B * 2\pi r \quad (20)$$

$$I = \frac{2\pi r B}{\mu_o} \quad (21)$$

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

$$\mu_o = 4\pi * 10^{-7}\, T.\frac{m}{A} \quad (22)$$

$$r = 0.1524\, m$$

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

$$I = 0.0076\, A$$

Now take the value of magnetic field B as

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

So the current with the given value can calculate from equation (22):

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

$$r = 0.1524\ \square$$

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

$$I = 0.1527\, A$$

Now take the value of magnetic field B as

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

So the current with the given value can calculate from equation (22):

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

$$r = 0.1524\, m$$

$$I = \frac{2 * \pi * 0.1524 * 5 * 10^{-6}}{4\pi * 10^{-7}}$$

$$I = 3.8175\, A$$

Now take the value of magnetic field B as

$$B = 7 * 10^{-5}\, T$$

So the current with the given value can calculate from equation (22):

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

$$r = 0.1524\, m$$

$$I = \frac{2 * \pi * 0.1524 * 7 * 10^{-5}}{4\pi * 10^{-7}}$$

$$I = 53.4450\, A$$

Now take the value of magnetic field B as

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

So the current with the given value can calculate from equation (22):

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

$$r = 0.1524\, m$$

$$I = \frac{2 * \pi * 0.1524 * 10 * 10^{-5}}{4\pi * 10^{-7}}$$

$$I = 76.35\, A$$

Now take the value of magnetic field B as

$$B = 3 * 10^{-4}\, T$$

So the current with the given value can calculate from equation (22):

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

$$r = 0.1524\, m$$

$$I = \frac{2 * \pi * 0.1524 * 3 * 10^{-4}}{4\pi * 10^{-7}}$$

$$I = 229.050\, A$$

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 from the equation (19) 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.

5.3.2.8 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 [17]:

$$PD = \frac{N}{P} \tag{23}$$

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.

Gear ratio = Driven Gear teeth / drive gear teeth (24)

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.

$$R = T_B / T_A \tag{25}$$

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 water wheel prototype shown in **Figure 20** 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 F.**

6.2 Resources

For developing the steps of the Rube Goldberg Machine, various resources need to be utilized. **Table 4** 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 G**. 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 4: 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 Implementation

The variety of manufacturing methods have been employed in successfully fabrication of all the selected steps. The following sub sections includes the manufacturing process utilized for fabricating all the individual steps. The design changes if any will also be presented in the following subsections.

7.2 Manufacturing

The manufacturing process employed for fabrication the individual steps are presented in following subsection.

7.2.1 Water Wheel

The water wheel presented below in **Figure 37** is made by using the cardboard. First two wheel of diameter 12 inch and the rectangular plates are cut from the card board. The rectangular plates are glued by applying the glue presented in BOM around the periphery of both the wheels. Spinners are attached to the outside surface of the wheel and supported at the vertical base of the card board only. A home like structure is also made from the card board. The pump and the battery is kept inside the house to enhance its looks. The PVC pipes is taken to connect the pump from reservoir and the outlet of the pump is taken out of the house to pump the water at the surface of the wheel. The whole assembly is fixed to the plastic container directly bought from the local stores to remove the possibility of water spilling out.

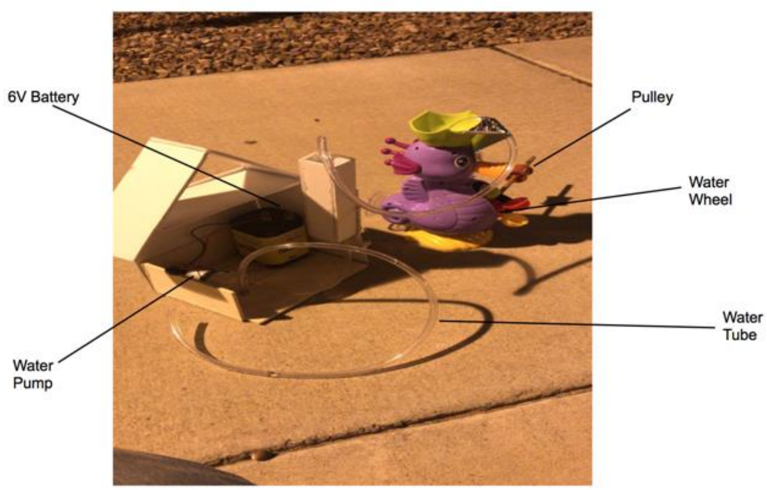


Figure 37: Water Wheel

7.2.2 Catapult

The material used to fabricate the catapult is wood which can easily be seen in **Figure 38**. The triangular pieces are cut from the 1-inch-thick board and fixed to the wooden base of 8 inch. A wooden handle of approximately one inch is attached the shaft which passes through the triangular pieces of the wood. A thread is attached at the both side of the shaft. The catapult arm is made by fixing a spoon at the far end of the arm from the shaft. The handle is attached to store the energy by winding up the thread at the periphery of the shaft. An object/ball will be placed at the spoon to launch.

Figure 38: Two different view of the catapult

7.2.3 Bucket Attached to the wheel

A wooden base of 40 X 6 X 1 inch is cut and an L shape frame is made of the two plank and fixed to the wooden base. A vertical support is also provided to strengthen the structure. A shaft of bicycle wheel is fixed to the vertical support. The four number of bucket is purchased and placed at the equal distance around the periphery of the wheel. The wheel rotates as the bucket is filled with any object.

Figure 39: Bicycle wheel

7.2.4 Car hitting the ball

The design of an individual setup is presented in **Figure 40**. The step utilizes a normal and an automatic car and the flexible track. Both the cars and the track are purchased from the local stores. At the end of the pathway a wooden stick plank is placed which is attached to the 5 inch diameter disc. The disc is kept at the friction less surface. The pathway of metallic ball is made of the wooden plank. A plank of 40 X 3 X 1 inch is cut from the plank and two wooden strips of length equal to the length of the wooden plank is placed 1 in apart from each other and glued on top of the wooden plank. This plank will work as the path of the ball and the strips will prevent the ball to fall out of the wooden plank. This setup includes a circular stick of 1 in diameter and 6 in length which hits the ball to trigger the movement of the ball.

Figure 40: setup of car hitting the ball

7.2.5 Car hitting the another car

The setup shown in **Figure 41** requires the 3 cars placed at the same path way. First car is placed at the slant height and a stopper of wood is place. As the stopper is removed, the car travels at the speed and hits another car. The cars and the purchased directly from the local market. The track is made of the plastic board. A wooden piece of 2 in height is cut and placed at the one end of the track to provide the slant height to the car. A tape is used to fix the path of the car to the ground.

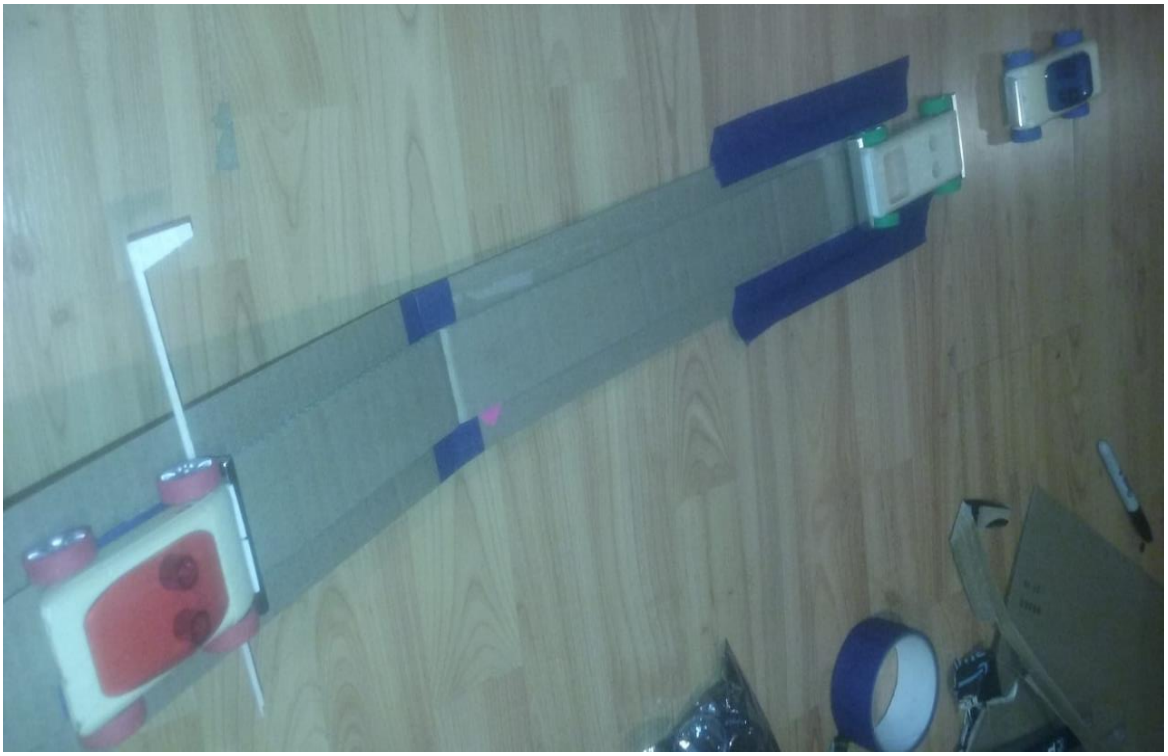


Figure 41: Car hitting another car

7.2.6 Arduino Kit

The setup shown in **Figure 42** includes an Arduino kit, sensor, white board, the LED screen, DC motor and the wire. While implementation connections are made to light the screen at the end of the process. A code is developed and fed into the system. When a particular step is complete, the sensor will give the signal to give the output of end of the process. This system is one of more systems using by Arduino on this project. **Figure 43** showing the another system including most of steps on this project

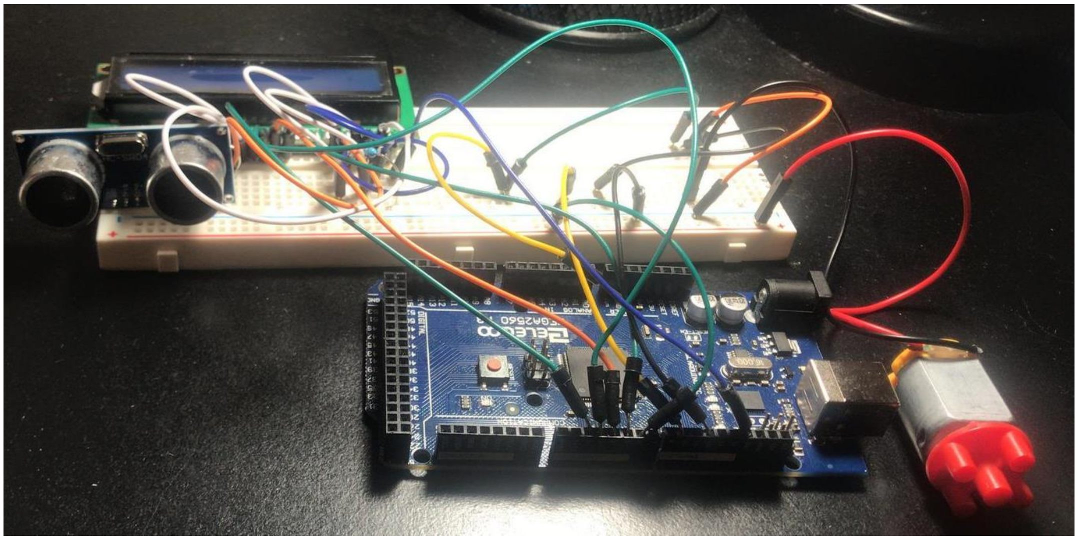


Figure 42: Arduino Kit

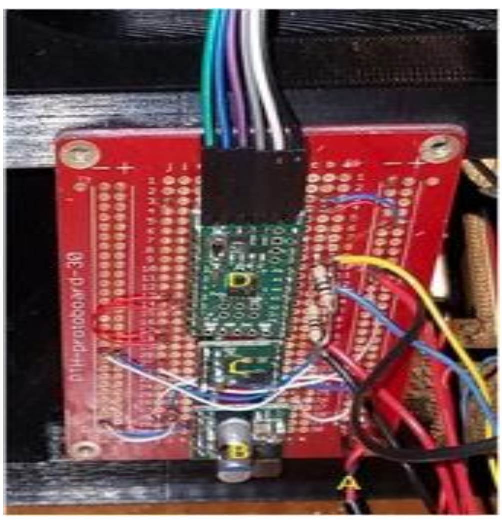


Figure 43a: System for 3D escalator

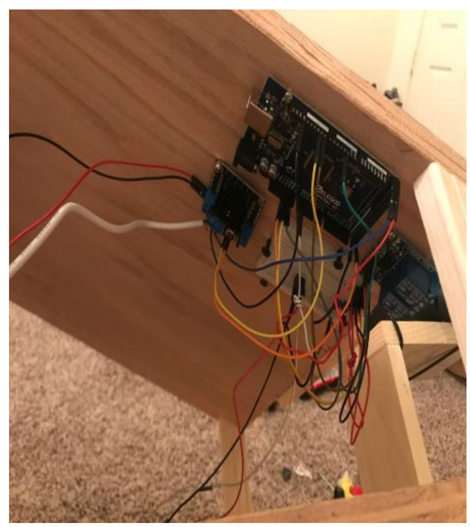


Figure 43b: System for aerodynamic

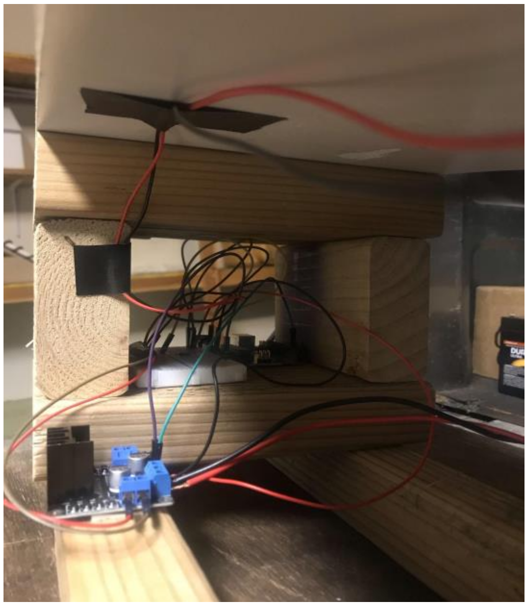
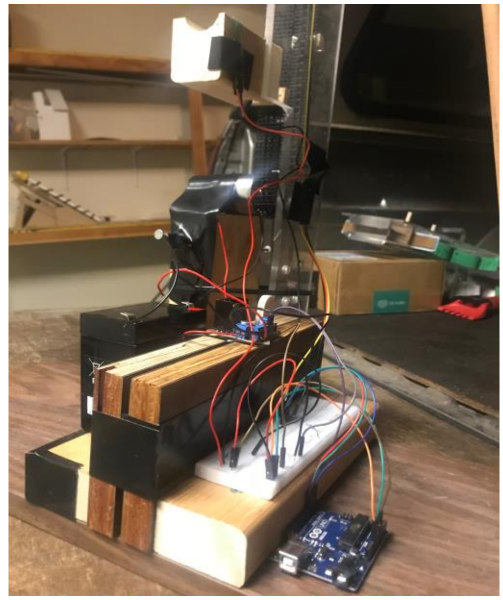


Figure 43c: System for the magnet car



igure 43d: System for gear escalator

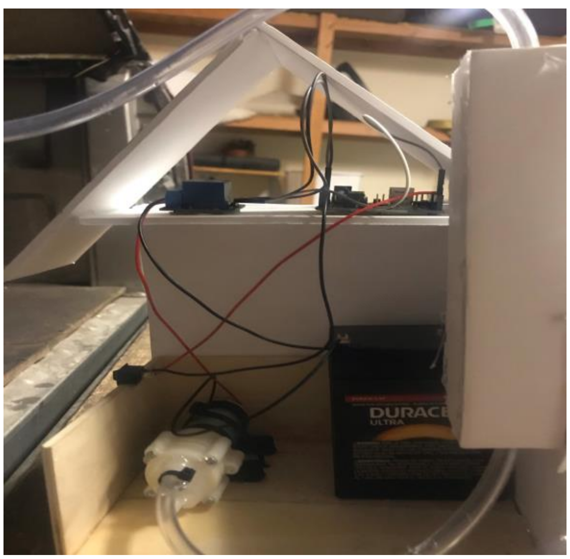


Figure 43e: System for water wheel

Figure 43f: System for the catapult

7.2.7 Aerodynamics

The steps presented in **Figure 44** utilizes the concept of aerodynamics. First of all 3 wooden board of size 2 ft X 2 ft X 0.5 in are cut from the wooden plank and arranged to make the triangular frame. A car is kept at the slant height of the board. A hair dryer is used to push the car. A ball is kept at the top of triangular frame. The two wooden strip of 0.5 X 0.5 in is fixed by the nails trough out the wooden plank to form the pathway for the car.

Figure 44: Aerodynamics

7.2.8 Gear Mechanism

The setup shown in **Figure 45** utilizes the concept of Spur Gear of 4.5 in diameter. The gear and the pulley is directly purchased from the market. A wooden piece of size 1.5 X 0.75 X0.5 in is fixed to the pulley. A curved U shape structure is attached to the wooden piece which supports the ball. As the gear rotates the ball climbs up and will fall down when the curved wire and wooden piece assembly reaches to the top of assembly.

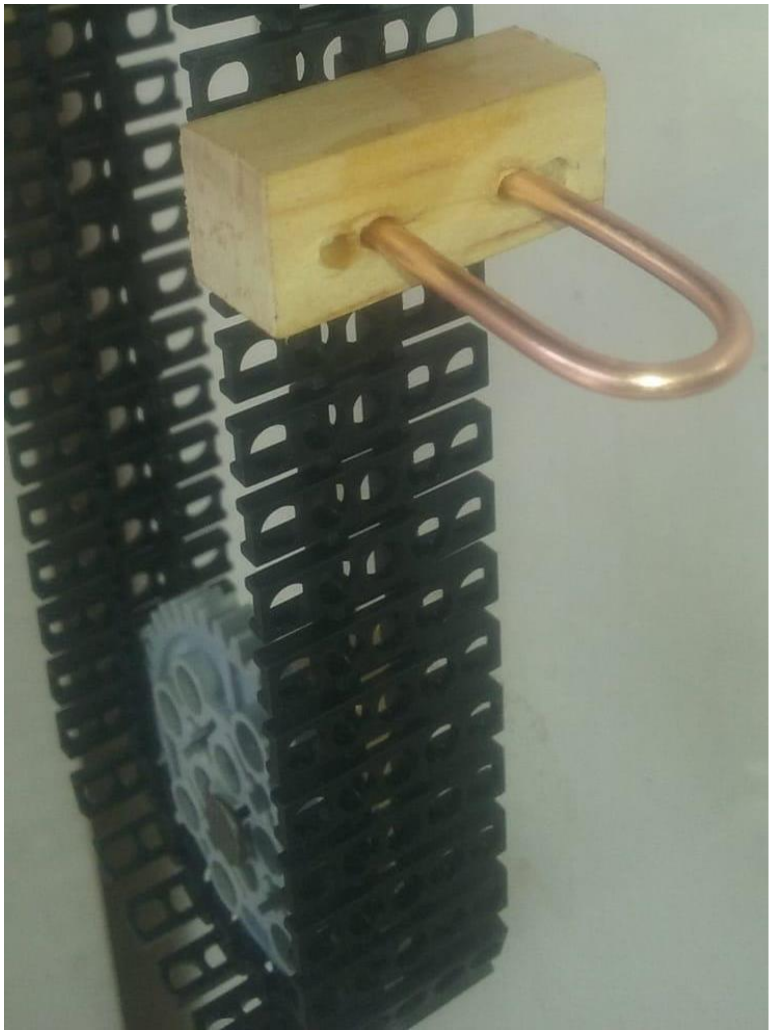


Figure 45: Gear Mechanism

7.2.9 Wood Spiral Staircase Design

Different views of the spiral staircase step design have been presented in **Figure 46**. As seen in the figure, A DC motor is connected to a PVC pipe and a thick rope is wrapped around the pipe in the spiral shape. As motor rotates, a ball will travel from the bottom to the top with the help of rope and falls on the stairs, and on the last stair there is a sensor that will turn off the DC motor and makes another servo move which will trigger the next step.

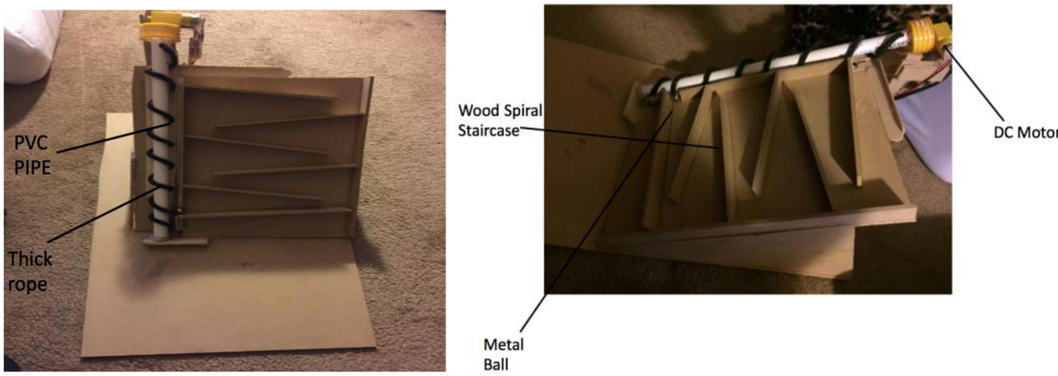


Figure 46: Different views of the spiral staircase step

7.3 Design Changes

Since, innovative ideas keeps popping up into the mind, Design of the individual steps also needs to be modified. All the design changes made during the yearlong project have been explained in this section along with reason of changes.

Initially the team has thought that the movement of first car will be initiated after removing the stopper, the motion of the subsequent car will be started due to hitting action of previous car.

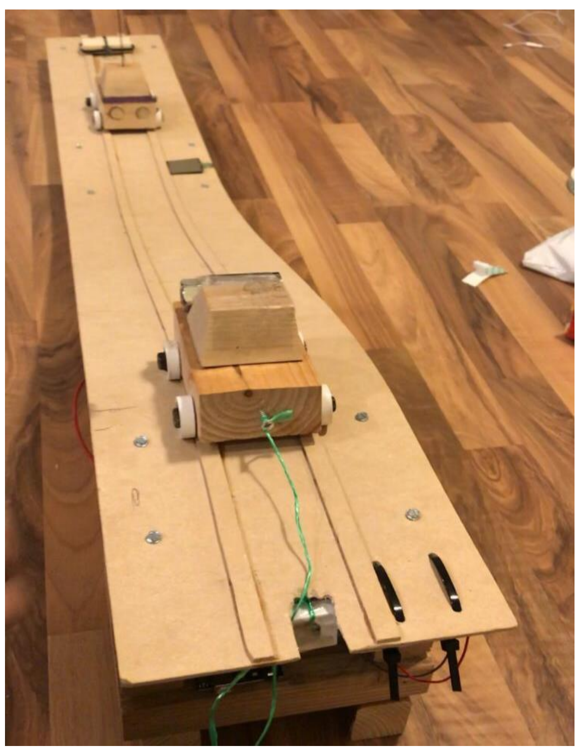


Figure 47: Car hitting another car

But during the manufacturing the change in the design has been made by changing the triggering mechanism of the last car on the track. A magnet is placed on both the cars parked at the plane surface and the movement of the last car will be due to the repelling action of the magnet. Minor changes have also been made and implemented during the testing of the individual step. The track of the car presented in **Figure 47** have been changed to make it look more appealing.

Similarly in the aerodynamic step, changes have been made to make the design resettable. Initially the concept was such that the car will go downward in the opposite side after reaching to the top whose kinetic energy will trigger the next step. During this semester, a glass filled with water placed at the top. The car will hit the glass and comes back to the original position. The car travel due to the blowing action of the air with the blower. The water will spill over the plate and recollected at the bottom reservoir. The changes made in this report is clearly and can be seen by comparing the **Figure 38** and **Figure 39.** In the **Figure 45** a ball is placed at the top which will be triggered when the car will hit the ball at the top. The ball will travel along the curved path and eventually collected at the base of the reservoir.

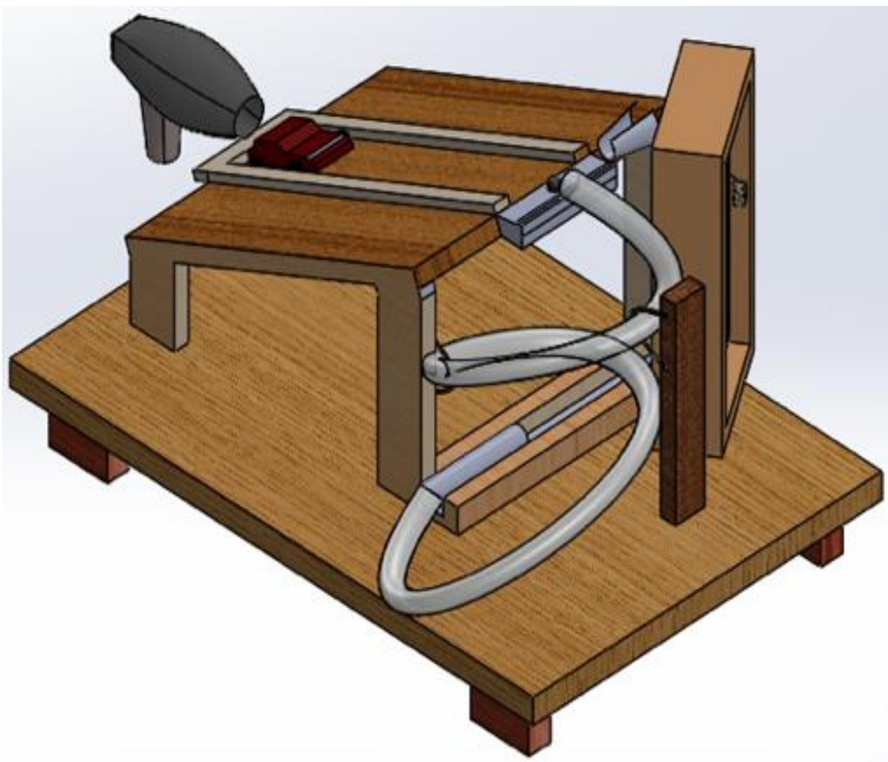


Figure 47: Aerodynamics

8 Testing

All the individual step designs are tested based on the customer requirement. Following are the methodology envisaged and results obtained during the testing:

- **Size:** it is a measurable quantity. The dimensions are measured with the help of a measuring tape. The team found out that all the steps are within the limits specified by the customers.
- **Resettability:** All the steps are demonstrated many times to find out whether the steps are reaching to its initial position after its completion or not. If the team is able to restart the steps without any human interference, then only the steps are considered re-settable. The team found out that all the individual steps of RGM are resettable.
- **Time duration:** The steps are demonstrated and the time duration of each individual steps have been measured with the help of stop watch. The team demonstrated the steps many time and the average time has been considered to reduce the human error. The team found out that the time duration of the steps ranges between 0.75-1.78 seconds which is well within the requirement projected by the customers.
- **Reliability:** Team has demonstrated the steps 10 times and recorded the number of times each steps failed. The team found out that none of the steps failed or needed human intervention except the water wheel step. The water wheel step failed once due to the discharge of batteries which runs the pump. This can also be removed by regular maintenance of the steps.
- **Entertaining:** to test it the steps are demonstrated in front of the audience and their expression were analyzed. The team found out that the steps were not that much entertaining. This may be because of the individual step when all these steps will be combined to perform some simple task then it will definitely please the audience.
- **Safety:** safety has also been tested by demonstrating it repeatedly. Team found out that all the steps are safe since the steps did not harmed the environment or the audience.

9 Conclusions

In this yearlong project the team's goal was to design, to implement and to fabricate the individual steps of the Rube Goldberg Machine which can be combined to complete a simple task. The main highlights of this project is that all the individual steps designed are reliable, repeatable and resettable. The team has also successfully implemented the technological innovation happening worldwide in the form of Arduino kit, coding, sensors and fidget spinners etc. which will make the steps eye appealing and will also attract the audience. The team is successfully designed the individual steps according to the customer requirements and most importantly within the allocated project. The further success of the project depends on the fellow team when all these steps will be combined to perform some assigned task in the Rube Goldberg competition. The following sub-sections explains about the contributors to the project success and also the areas of the improvements. The following sub-section also includes whether the ground rules and coping strategies stated in the team's charter were followed or not in order to achieve the goals.

9.2 Contributors to the project Success

Most important contributors of the project are all the team members who remained focus, committed and motivated in a yearlong project to make it grand success. Each team members has been contributed towards the success of the project by actively participating in the group meeting and brain storming sessions, performing a thorough research on the assigned task. An extensive research was carried out by each team member individually in order to make the project repeatable, resettable and unique by seeing the videos available at YouTube and the various competition organized around the world. Each team member has come up with the basic ideas of steps for making the Rube Goldberg Machine. Since, each student has his own perspective and way of understanding, solution to the problem is suggested by another team member that are unique in their own way. The team made a combined effort to reach to the best possible solution under the supervision of various stakeholders. The team has selected 20 designs based on the various engineering component such as spring, water wheel, gear, magnet, aerodynamics, and sensors. The Pugh chart was used for the initial phase to remove the ideas which do not score well during the analysis. Decision matrix has been employed to reach out the 6 best possible designs which score well on the customer requirements.

The team has followed all the rules during the last semester and coping strategies whenever a team member got stuck at some point. The team has actively participated in all the discussion during the weekly scheduled meetings on Thursday morning as laid down in the team's charter which turned out to be the best positive of the team. The discussion helped the team to dig out the best from each team member. The project manager has coordinated well during the entire semester which was essentially desired while working as a team. Each member of the team was punctual in attending all the meetings and coordinated well with all the stakeholder. Everyone has faced some difficulties while making the prototype but eventually solved the problem within the deadline by devoting the extra time to the project. The time management and punctuality were the best positive which came out during the project.

Although, ground rules were set to avoid any inconvenience but still team faced some potential barriers including misunderstanding and communication problems. Coping techniques agreed upon by the team members to overcome these barriers were swapping of roles to cope for misunderstanding and to get enrolled in English courses to cope for communication problems due to language issues. All of us successfully acted upon the technique of swapping positions so each member could understand all the perspective of our problem and get to know the in-depth knowledge of it.

9.3 Opportunities for Improvement

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. Rube Goldberg Machine encourages the out of the box thinking which always provides the opportunities and areas for improvement. The team can also improve the aesthetic of each step to attract the audience.

Since, no product can have all everything perfect. Each product has its own pros and cons. It may have really good quality but with high price. On other hand, it may be cheaper but not with the best quality or finish. So, compromises have to be made not only by designers or manufacturers but also by customers. Same was the case with our project performance. The project or product we built had a negative point that it was not that cheap. Although, we didn't use very expensive sensors or something much costly, but we did used all the material best of their type with classical finish so the project could attract the customers. This not only required some extra money but extra-concentration as well along with the advice of experts. Moreover, one more negative point was about the project it was not very easy to move it from one location to another. But since it was easy to set it on a new location with experts in a much shorter time as compared to other designs so the second negative didn't really become cause of the problem related to the project performance.

As for the part of time management and miscommunication, the team will suggest to make some organizational changes that would be in favor of students in future. There should ample time provided to students to have discussion on their projects and they may be able to find a much better approach. The team would also suggest which could be employed is to make students visit different manufacturing centers related to their projects so they could understand how a practical scenario is different from the perfect designs we make on paper or on software. This will also provide students with exposure of how a manufacturing center really works how much they have to work on their product so they may come with a different and much better solution of the problem of project.

The team has faced a problem was that the team had to learn the working of Arduino and ultrasonic sensor and also how to code to make this stuff work appropriately as needed for the project but team did all the coding effectively by devoting some extra time. If the student would have some previous knowledge of Audrino Kit and it's coding, that would have definitely helped the team to save some time which can be utilized for some other activity. The reports writing and presentation skills could have been better in order to influence the audience.

The team has learnt quite a lot from the yearlong project and gained a handful of experience of practical things. Major learnings of the project are listed below:

a) An effective and efficient way of doing research.
b) Effective way to tackle the problem
c) Team work and effective management skills
d) Deriving the engineering requirements from the customer requirement.
e) The use of different shortlisting techniques of the concept such as Pugh Chart and Decision matrix
f) Basics of engineering concepts such as the spring, magnet, fluid mechanics, and aerodynamics which are used in day to day life.
g) Importance of prototyping to enhance the quality of the product.
h) Report writing and presentation skills

Figure 48: Aerodynamics

10 References

[1] Wonderpolish.org. (2018). *What is a Rube Goldberg Machine?*. [online] Available at: https://wonderopolis.org/wonder/what-is-a-rube-goldberg-machine [Accessed 5 Aug. 2018]

[2] Cefns.nau.edu. (2018). *Rube Goldberg Machine competition*. [online] Available at: https://www.cefns.nau.edu/capstone/projects/ME/2018/RubeGoldberg/index.html [Accessed 5 Aug. 2018]

[3] YouTube. (2018). *2018 Rube Goldberg Machine Contest Champions: Purdu PSPE.* [online] Availble at: https://www.youtube.com/watch?v=zPVH2admAuw [Accessed on 1 Aug. 2018]

[4] *"Purdue American Society of Mechanical Engineers – West Lafayette – 2017 – Rube Goldberg", Rubegoldberg.com, 2017*. [Online]. Available at : https://www.rubegoldberg.com/teams/purdue-american-society-of-mechanical-engineers-west-lafayette-2017/ [Accessed on 31 Jul. 2018]

[5] Staff, C. (2018). *Four Different Types of Springs*. [online] Creativemechanisms.com. Available at: https://www.creativemechanisms.com/blog/four-different-types-of-springs.

[6] Emkablog.co.uk. (2018). *New EMCA hinge with adjustable torque.* [online] Available at: https://www.emkablog.co.uk/new-friction-hinge-with-adjustable-torque/ [Accessed on 31 Jul 2018]

[7] KHK Gears. (2018). *Types of Gears.* [online] Available at: https://khkgears.net/new/gear_knowledge/introduction_to_gears/types_of_gears.html [Accessed on 1 Aug 2018]

[8] ElProCus – Electronics Project for Engineering Students (2018). What are Different Types of Sensors with Circuit?. [online] Availble at: https://www.elprocus.com/types-of-sensors-with-circuits/ [Accesed on 24 Aug 2018]

[9] Amazon.com. (2018). [online] Available at: https://www.amazon.com/Honeywell-HTF090B-Turbo-Personal-Black/dp/B00YU0W3CY/ref=sr_1_11_sspa?ie=UTF8&qid=1535445287&sr=8-11-spons&keywords=electric+table+fan&psc=1 [Accessed 24 Aug. 2018]

[10] Amazon.com. (2018). [online] Available at: https://www.amazon.com/Conair-Keeper-Folding-Handle-Retractable/dp/B009ZPMPGI/ref=sr_1_2_sspa?ie=UTF8&qid=1535445883&sr=8-2-spons&keywords=cheapest+hair+dryer&psc=1 [Accessed 24 Aug. 2018].

[11] Celebrationsnsw.com. (2018). *Blue Balloon Latex (Inflated) - Celebrations NSW Pty Ltd*. [online] Available at: http://celebrationsnsw.com/74-blue-balloon-latex-inflated.html [Accessed 24 Aug. 2018].

[12] Physics.bu.edu. (2018). [online] Available at: http://physics.bu.edu/~duffy/ns549_fall07_notes08/springenergy.html [Accessed 24 Aug. 2018].

[13] Chem.wisc.edu. (2018). *Kinetic and Potential Energy*. [online] Available at: https://www.chem.wisc.edu/deptfiles/genchem/netorial/modules/thermodynamics/energy/energy2.htm [Accessed 24 Aug. 2018].

[14] Hyperphysics.phy-astr.gsu.edu. (2018). *Pressure*. [online] Available at: http://hyperphysics.phy-astr.gsu.edu/hbase/pber.html [Accessed 28 Aug. 2018].

[15] Pritchard, P., Leylegian, J., Bhaskaran, R., Mitchell, J. and Fox, R. (2015). *Fox and McDonald's Introduction to Fluid Mechanics, 9th Edition*. New York: Wiley.

[16] Softschools.com. (2018). *Magnetic Field Formula*. [online] Available at: http://www.softschools.com/formulas/physics/magnetic_field_formula/343/ [Accessed 25 Aug. 2018].

[17] Google.co.in. (2018). [online] Available at: https://www.google.co.in/url?sa=t&source=web&rct=j&url=https://nptel.ac.in/courses/112106137/pdf/2_7.pdf&ved=2ahUKEwiqr6nqwo_dAhVJeisKHbCCAIUQFjATegQIBhAB&usg=AOvVaw2sQDCrAjxpG-IcvINr6cWx [Accessed 25 Aug. 2018].

11 APPENDICES

11.2 Appendix A: Functional Model

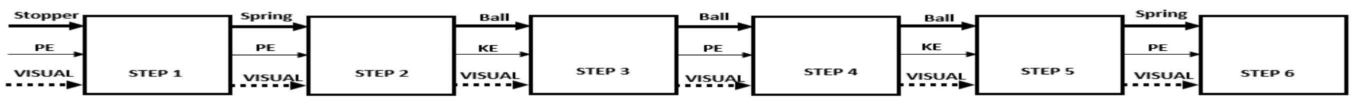


Figure A.1: Functional Model for spring # 1

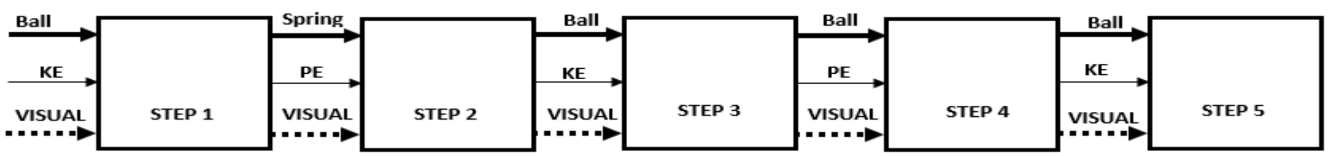


Figure A.2: Functional Model for spring # 3

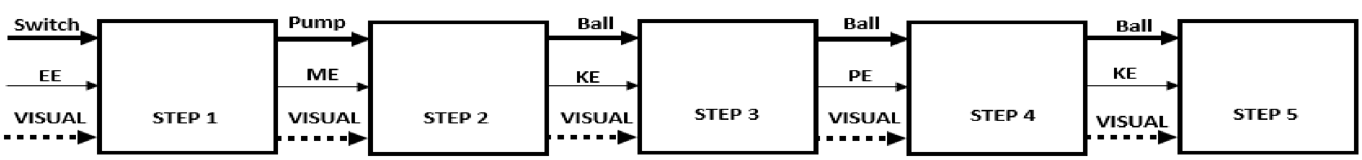


Figure A.3: Functional Model for fluid # 1

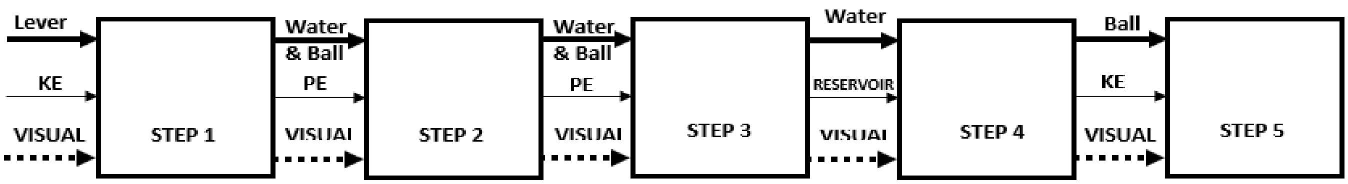


Figure A.4: Functional Model for fluid # 2

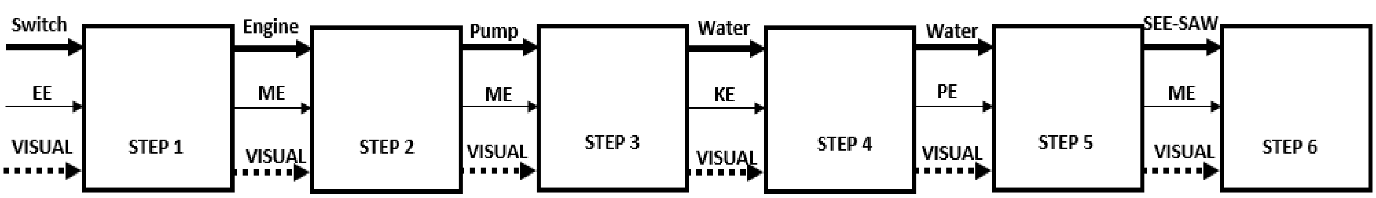


Figure A.5: Functional Model for fluid # 3

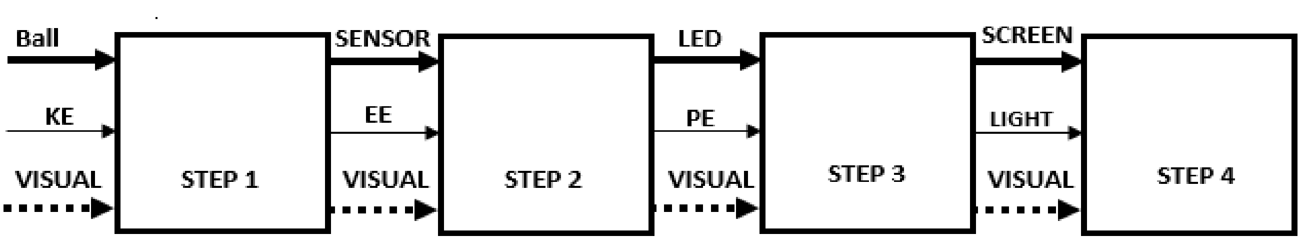


Figure A.6: Functional Model for sensor # 1

Separate functional model for all the 6 proposed design is presented in **Figure A.1** to **Figure A.6.**

11.3 Appendix B: Extra design

Some extra designs considered for the analysis is discussed below.

11.3.1 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 Arduino 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.

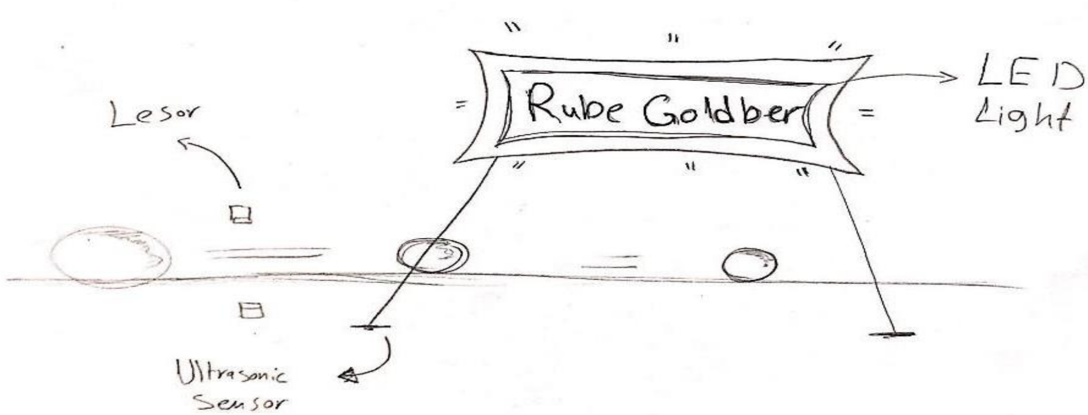


Figure B.1: Sensors#2

11.3.2 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.

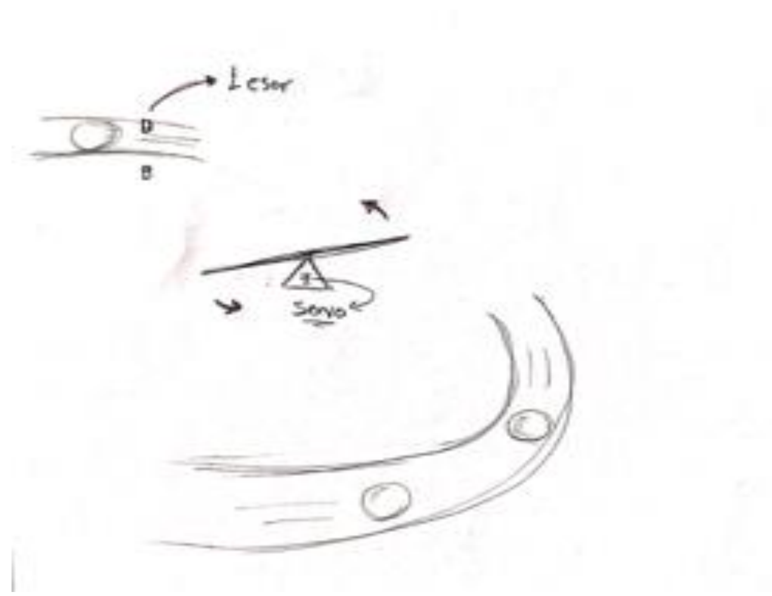


Figure B.2: Sensors#3

11.3.3 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.

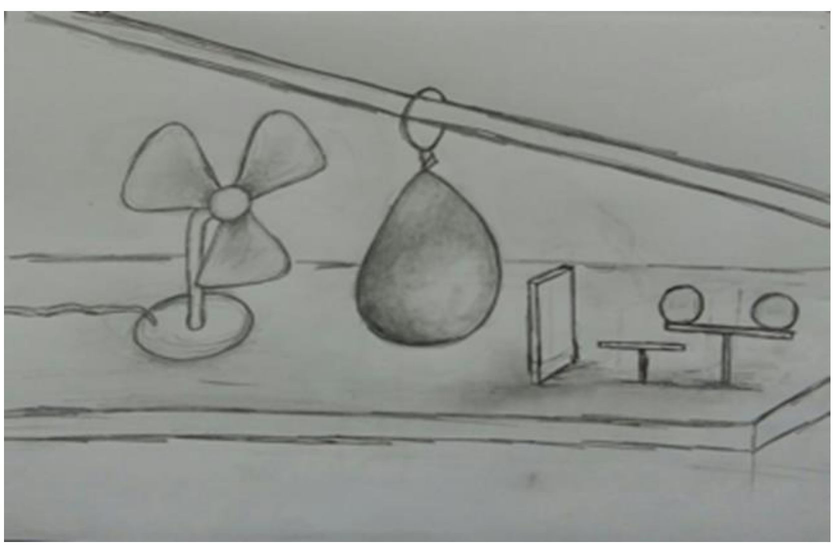


Figure B.3: Aerodynamics#1

11.3.4 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.

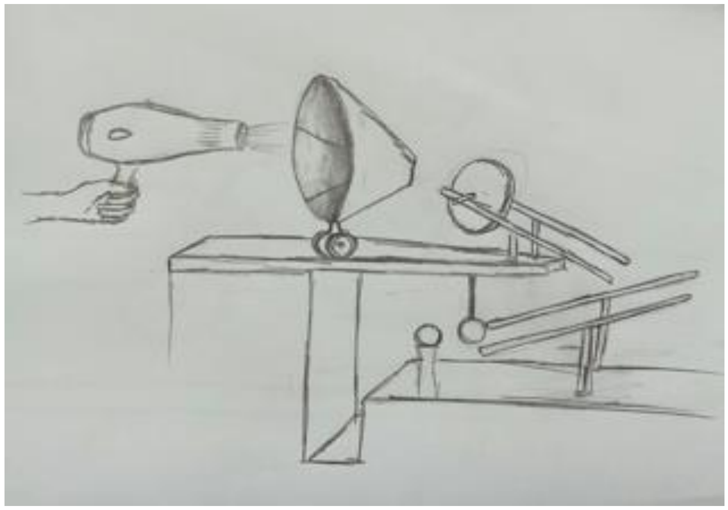


Figure B.4: Aerodynamics 2

11.3.5 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.

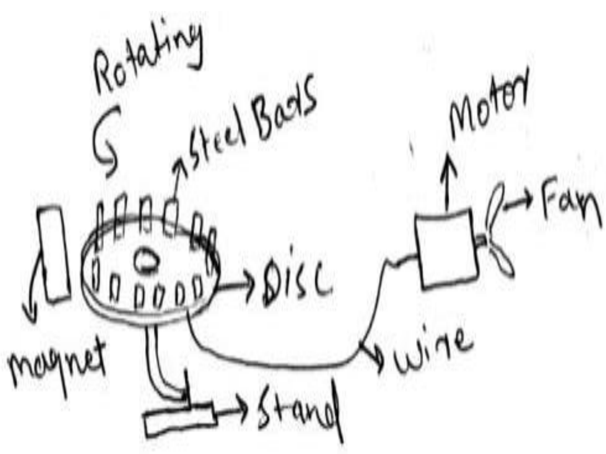


Figure B.5: Magnet#1

11.3.6 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.

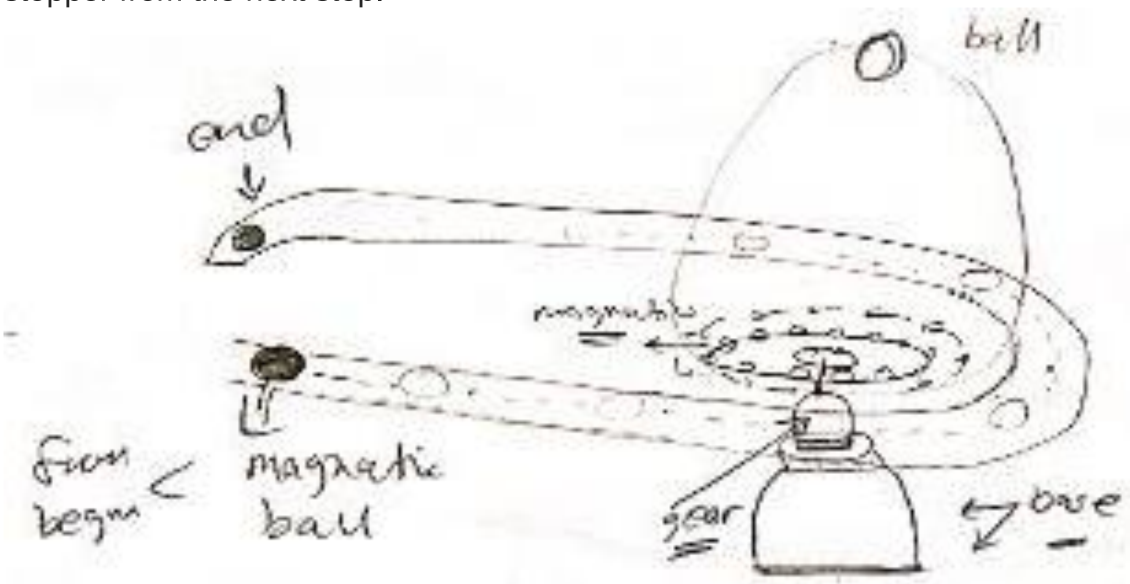


Figure B.6: Magnet 2

11.3.7 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.

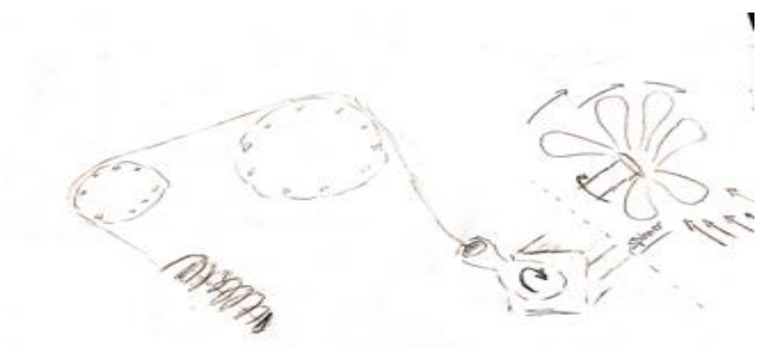


Figure B.7: Spring#1

11.3.8 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.

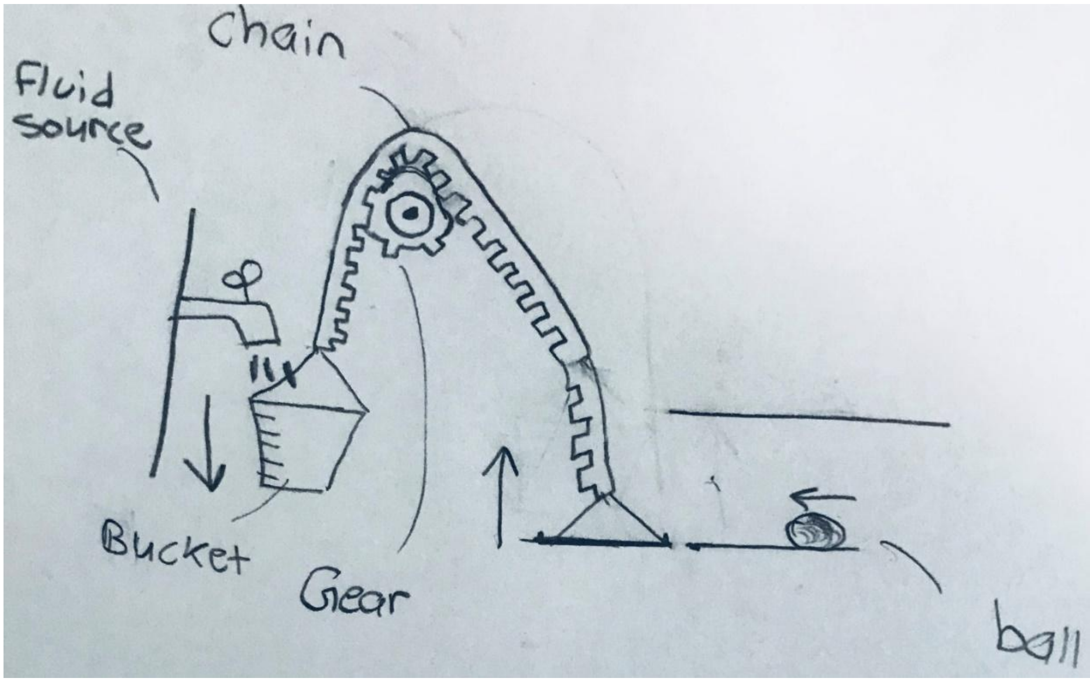


Figure B.8: Gears#1

11.3.9 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.

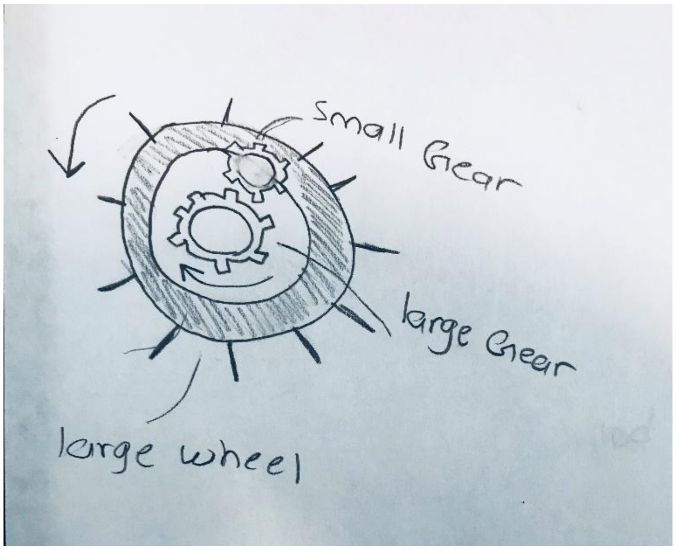


Figure B.9: Gears#2

11.3.10 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.

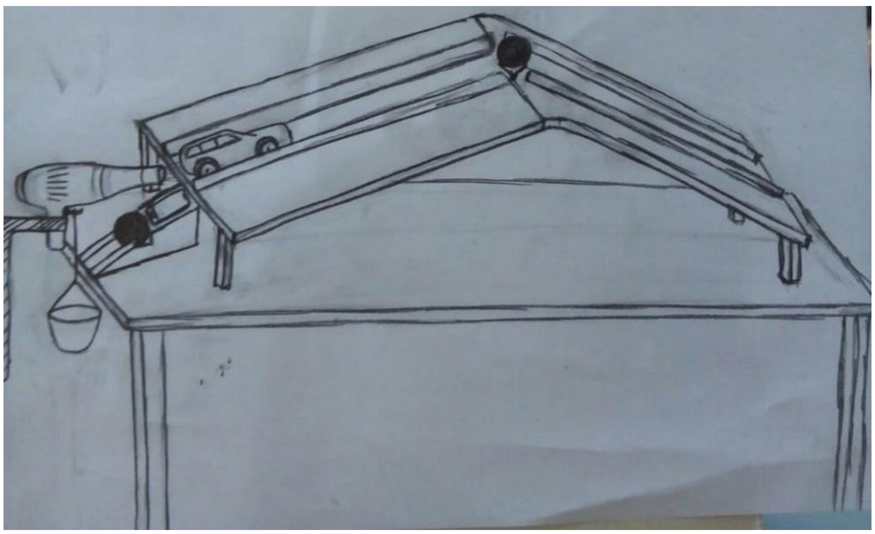


Figure B.10: Aerodynamics 3

11.4 Appendix C: Engineering Design of proposed design

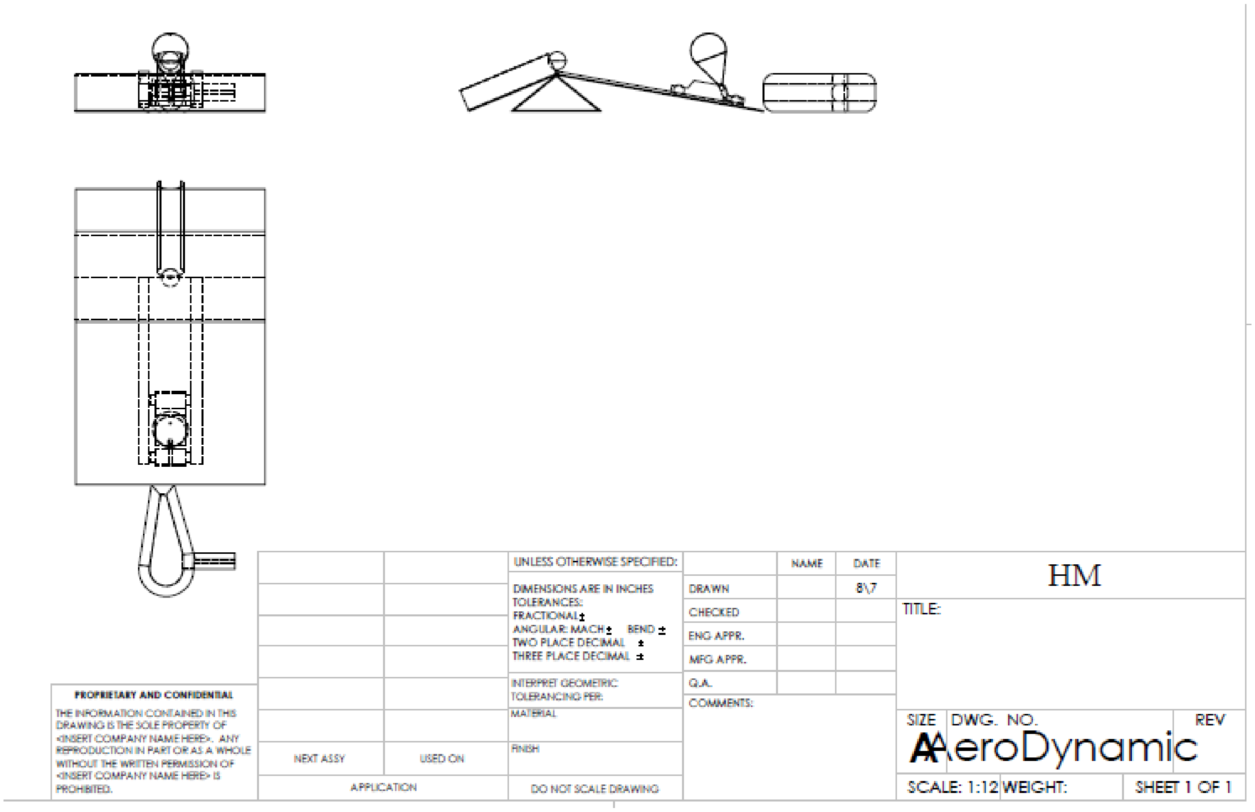


Figure C.1: Aerodynamics 3

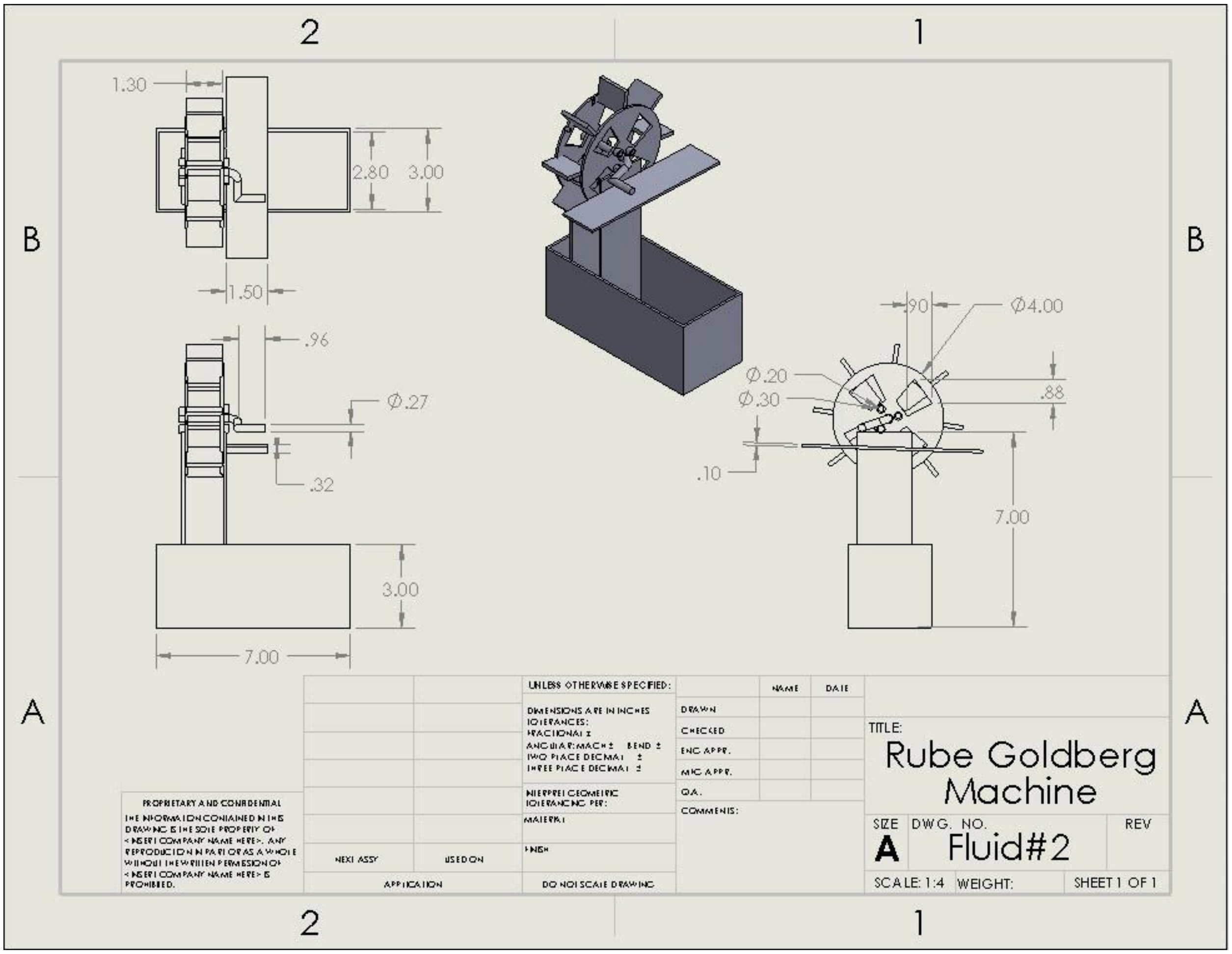


Figure C.2: Fluid #2

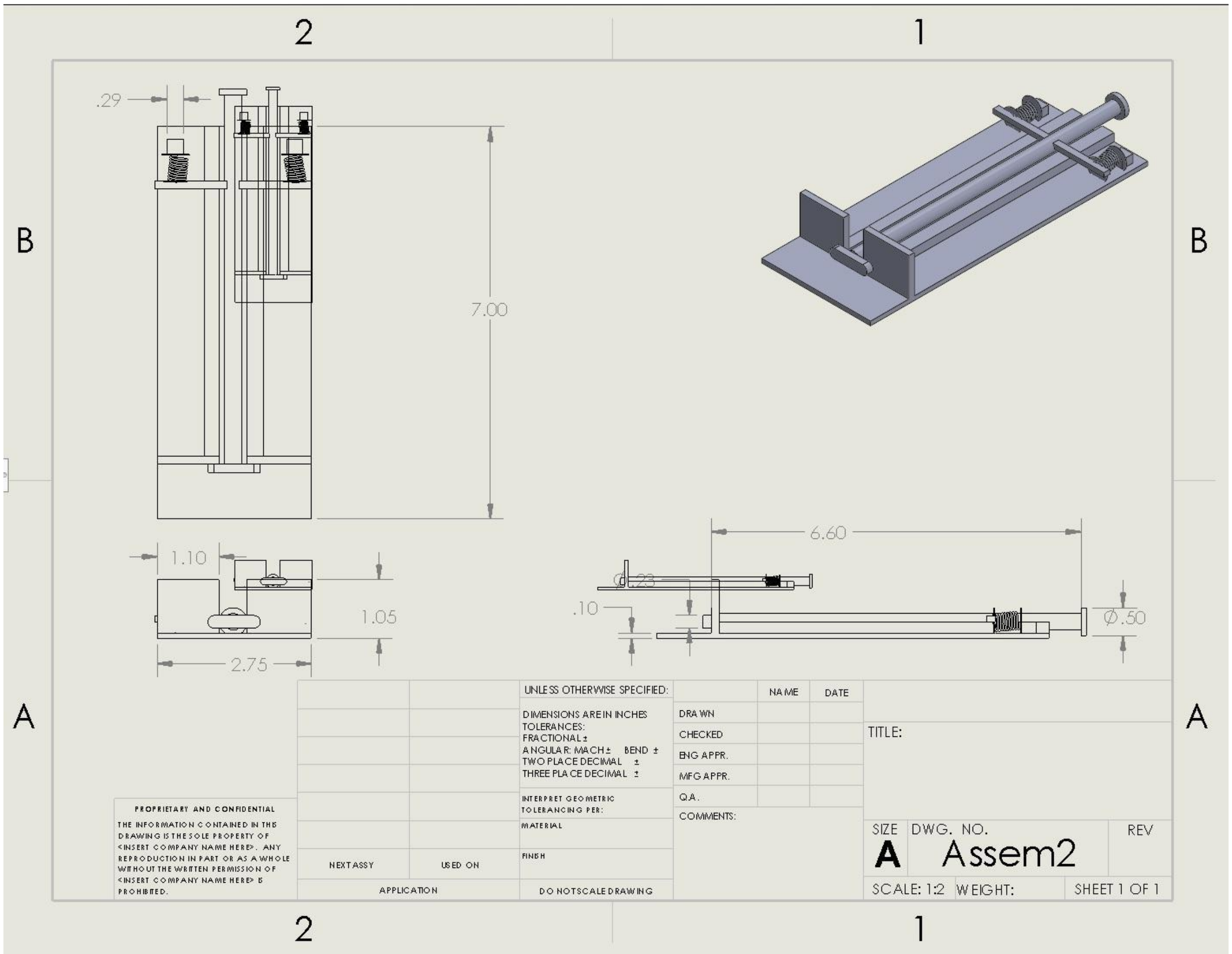


Figure C.3: Spring #3

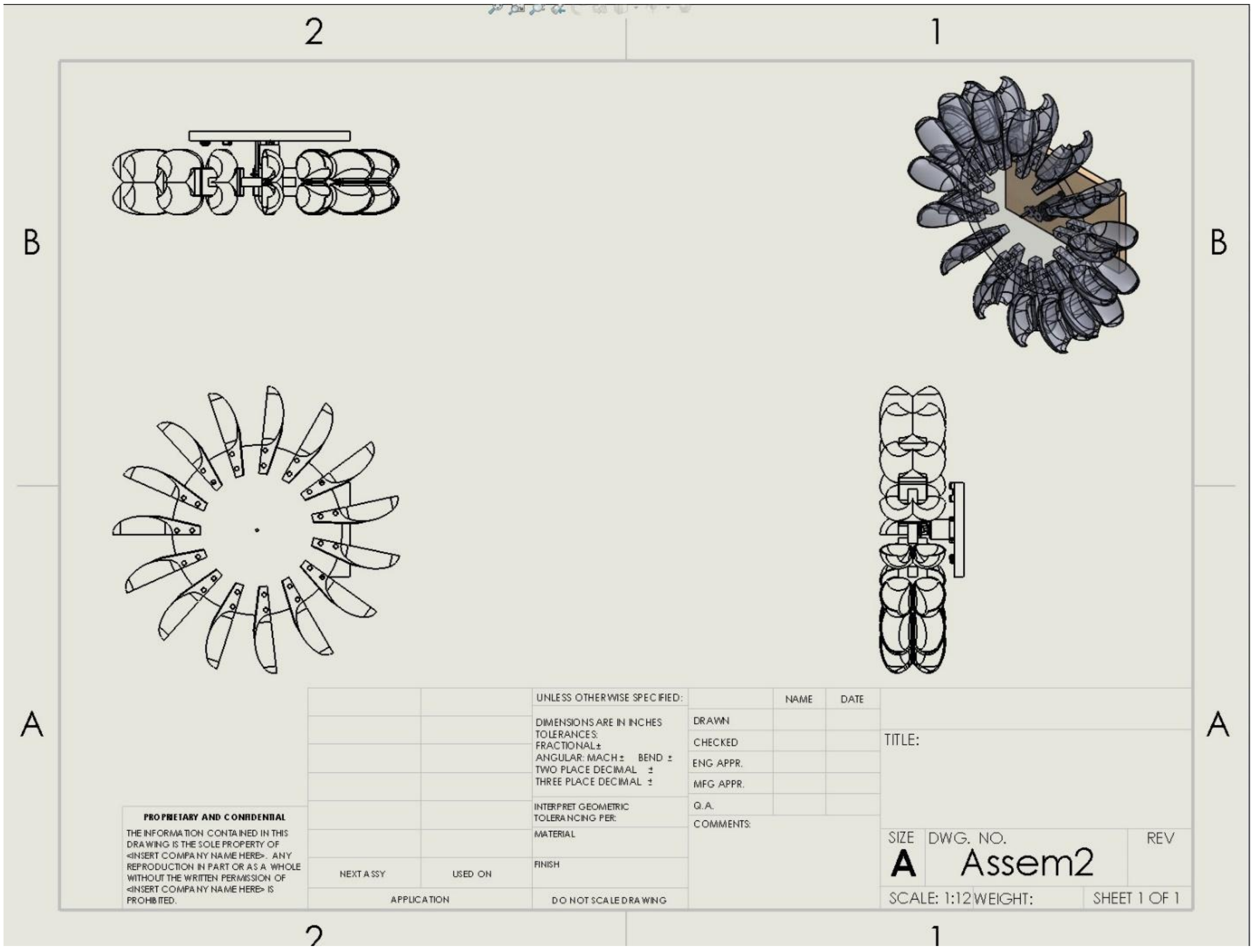


Figure C.4: Gear #2

11.5 Appendix D: Pugh Chart

Table D. 1(a): Pugh Chart

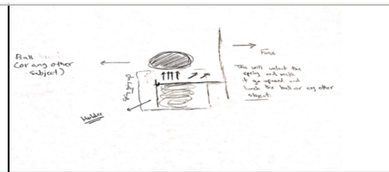
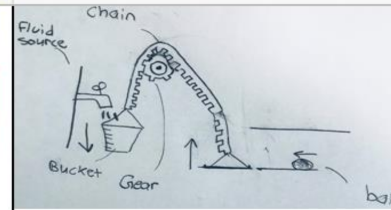
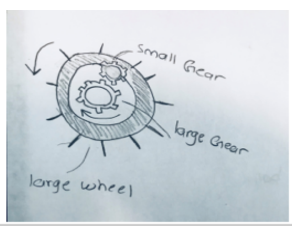
			
	Ultimate Rube Goldberg Step	**Spring #1**	**Spring #2**
Reliability	**D**	+'	-'
Durability	**A**	+'	-'
Resetable	**T**	-'	+'
Cost effective	**U**	S	-'
Entertaining	**M**	-'	+'
Safety		S	S
Sound		S	S
Timing		+'	S
Number of Pluses, +		3	2
Number of Minuses, -		2	3
Overall Score		**1**	**-1**

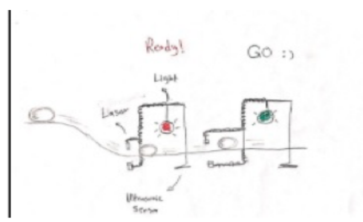
Table D. 1(b): Pugh Chart



	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**

Table D. 1(c): Pugh Chart





	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**

Table D. 1(d): Pugh Chart

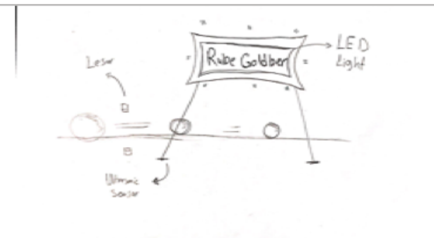
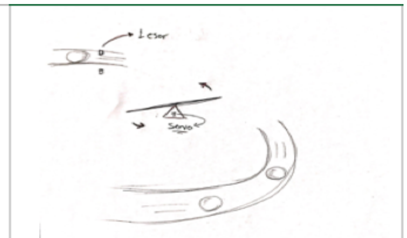
		
	Sensors#2	**Sensors#3**
Reliability	-'	-'
Durability	-'	-'
Resetable	-'	-'
Cost effective	S	S
Entertaining	+'	+'
Safety	S	S
Sound	+'	+'
Timing	S	S
Number of Pluses, +	3	2
Number of Minuses, -	3	3
Overall Score	**0**	**-1**

Table D. 1(e): Pugh Chart

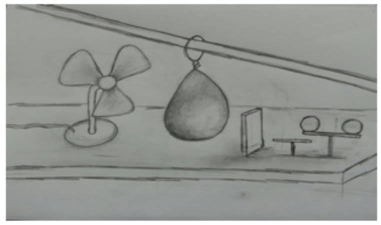
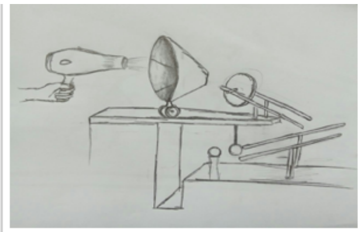
		
	Aerodynamics#1	**Aerodynamics#2**
Reliability	+'	+'
Durability	+'	+'
Resetable	-'	-'
Cost effective	S	S
Entertaining	-'	-'
Safety	S	S
Sound	S	S
Timing	S	S
Number of Pluses, +	2	2
Number of Minuses, -	2	2
Overall Score	**0**	**0**

Table D. 1(f): Pugh Chart

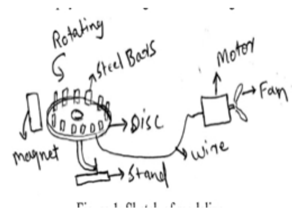
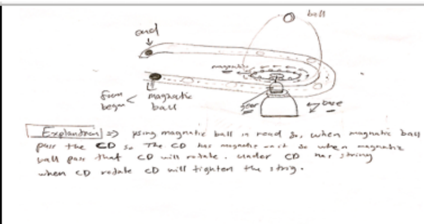
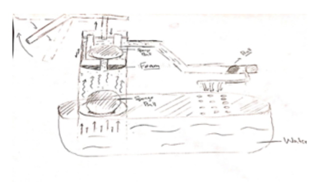
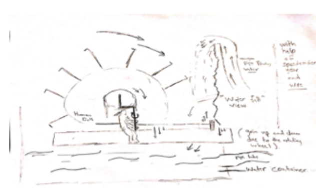
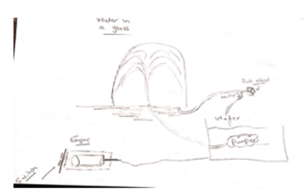
		
	Magent #1	Magnet #2
Reliability	-'	-'
Durability	-'	-'
Resetable	-'	-'
Cost effective	S	S
Entertaining	+'	+'
Safety	S	S
Sound	S	S
Timing	S	S
Number of Pluses, +	1	1
Number of Minuses, -	3	3
Overall Score	**-2**	**-2**

Table D. 1(g): Pugh Chart

			
	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**

In the Pugh chart, the customer requirement are listed at the left and scores of positive (+), negative (-) and satisfactory is given. Score is calculated by deducting the number of minus from the positive and shortlisted the design which has the positive scores. 6 designs out of 20 designs have scored more than 0 which comprises of spring, fluid and sensor. All these selected designs are further evaluated with the help of decision matrix.

11.6 Appendix E: Decision Matrix

Table E. 1(a): Decision Matrix

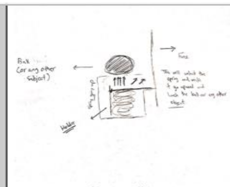
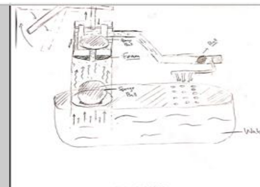
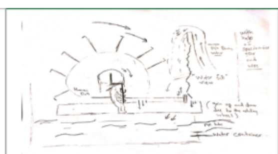
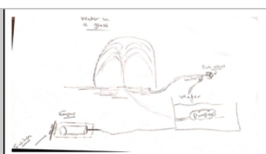
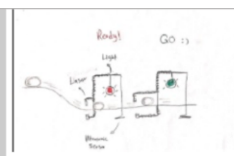
		 Spring #1		 Spring #3		 Fluid #1	
Customer Requirements	**Weight %**	**Score**	**Weighted Score**	**Score**	**Weighted Score**	**Score**	**Weighted Score**
Cost effective	5	5	25	5	25	5	25
Durability	4	2	8	3	12	3	12
Entertaining	2	3	6	4	8	4	8
Reliability	3	3	9	3	9	3	9
Resetable	3	3	9	3	9	4	12
Safety	5	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**	

Table E. 1(b): Decision Matrix

	 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**	

As shown in the Table D. 1(a), the customer requirements are listed at the left and the respective weightage out of 5 is given. The scores is given to the selected designs and their respective weighted scores were calculate by multiplying the score by their respective weightage. The designs which scores well are selected as the final steps and fabricated the prototype for validation of concept.

11.7 Appendix F: Schedule of implementation task

Figure F. 1(a): Schedule of implementation task

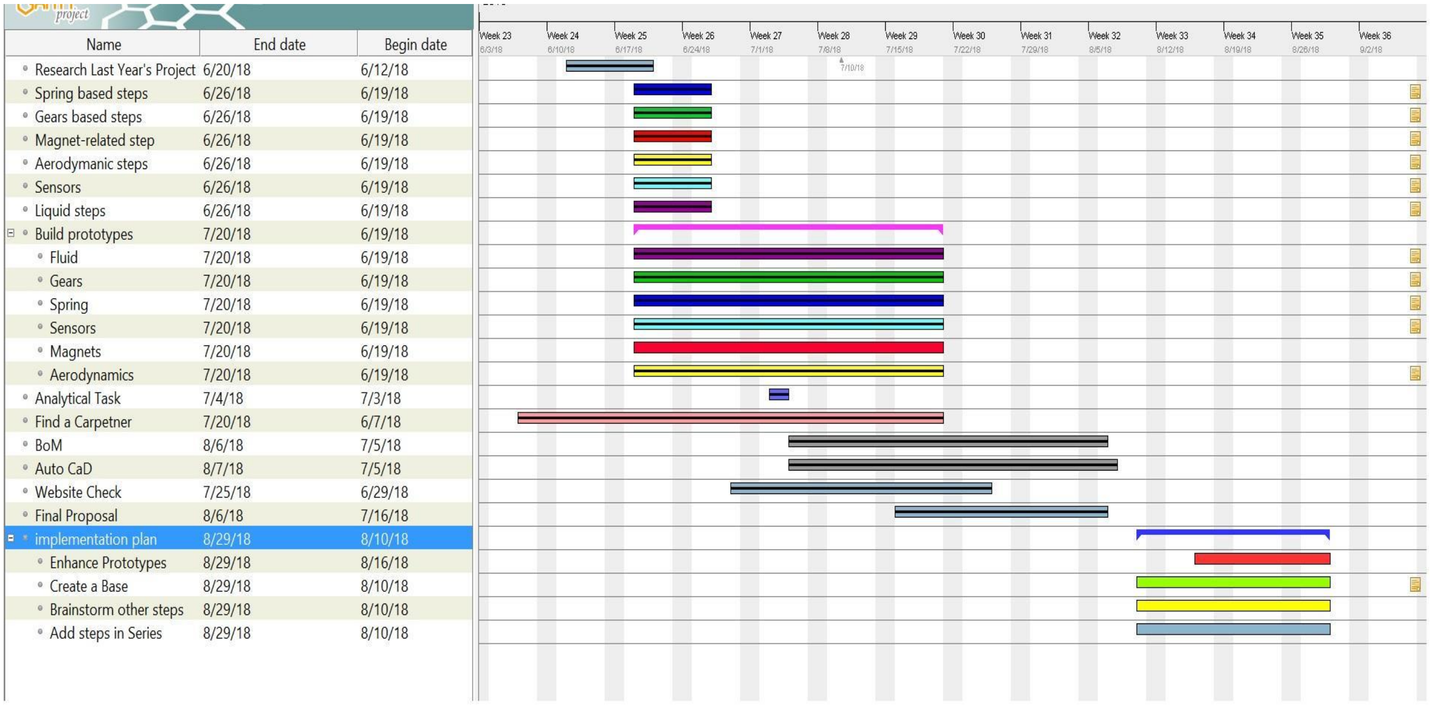
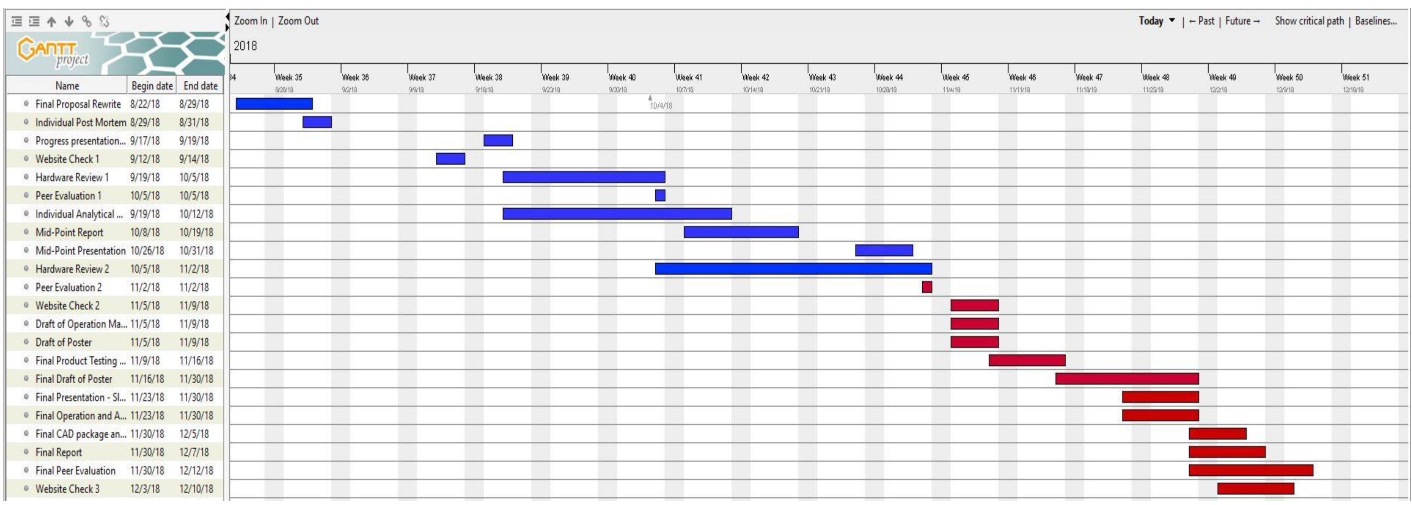


Figure F. 1(b): Schedule of implementation task



11.8 Appendix G: Bill of materials

Table G.1: Bill of materials

			Bill of Materials				
			Rube Goldberg Team				
Part #	**Part Name**	**Qty**	**Description**	**Functions**	**Material**	**Dimensions**	**Cost**
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
2	Wood Board	1	Attach items on top of board		Wood	6 x 4 inches	$3.99
3	Gorilla 7500101 Super Glue	1	To glue items	Self-Adhesive	Rubber	0.9 x 3.4 x 6.6 inches	$3.79
4	ELEGOO KIT	1	A set of items we need to design the electric cericle	Develop arduino on specefic items	Sensors, arduino	13.7 x 8.4 x 1.9 inches	$59.99
6	Balloon car	1	The car has ballon that help it to move		Plastic	7*3.5*1.5	$8.50
7	Cardboard	1	It is the base of the prototype		Carton	18x14x12-Inch	$2.77
8	Golf ball	1	It is used to hit he target		Plastic,rubber	1.68 inches in diameter	$9.80
9	Tape	1	To attach the part with each other		Plastic	2.5 inches	$2.18
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
12	Magnet Pack	1	6 of them are small which are on CD		Iron	(6) 0.51 x 1.93 inches	$8.99
13	CD	1	It is on top of DC motor, using to rotate it		Plastic	4.72 inches	$0.99
15	Wood slats	2	Base for the spring launcher and Diaphragm Pump		Wood	7.25 x 2.8 x 0.25	$4.88
16	Wood sticks	1	Path for the ball and bases		Wood		$2.47
17	Kabub sticks	1	Path for the ball and bases		Wood		$3.97
18	Water and Air Diaphragm Pump	1	Water pump		Metal	95mm(L)x47mm(W)x36mm(H)	$7.68
19	Vinyl tube	1	Tube for the Water pump		Poly-vinyl Chloride(PVC)	20inch Length	$4.93
20	Chrome Steel Bearing Balls	1	Ball		Steel	15.9mm	$12.95
21	PVC cap pipe	1	Base for the launcher		PVC	1/2 in. x 10 ft	$2.20
22	Fidget spinner	2	Fidget spinner		Plastic	DIAMETER: 2.95 inches. Thickness: 0.31 inches	$2.00
23	Springs	1	Small pack of different types of springs		Steel	Different types	$4.37
24	Injector Syringe Needle	1	Spring launcher		Steel	Stainless steel Size: 22cm x 7cm (L x W)	$7.59
25	Rayovac Lantern Battery 6V	1	Battery for the Diaphragm Pump		Steel	6V	$4.59
26	BLAGOO Interactive Running Water Bath Sprinkle Dragon Toy	1	Toy		plastic		$16.94
27	*Stepper Motor Nema 17 Bipolar 40mm*	3	Motors		metal		$12.99
28	Skateboard Bearings	1			steel		$9.59
29	*Steampunk Gears Charms Pendant Clock Watch Wheel Gear for Crafting*	1	Gears		Plastic		$9.99
30	Bruder Conveyor Belt	1	Belt		rubber		$33.73
31	100 Lego TREAD LINKS + 16 GEARS Kit	1	Gears		plastic		$19.99
32	Lego 100 pcs Technic TREAD LINKS	1	plastic chain		plastic		$11.99
33	Gorilla 3034502 Hot Glue Sticks	1	Glue				$7.97
34	loral Colored Aluminum Craft Wire		Aluminum Wires		Aluminum		$11.99
35	Jumbo Natural Finish Craft Sticks	1			Wood		$1.60
36	*Hiware 10 Pairs Reusable Chopsticks Set*	1			metal		$6.99
37	Corobuff Solid Color Corrugated Paper Roll	2			Paper		$20.02
38	Chrome steel Bearing Balls	1			steel		$11.50
39	4 x TT Motor UniHobby 3-6V Uniaxial DC Gear Motor with Robot Wheels	1			plastic		$16.95
40	2 of installGear Universal Car Power Door Lock Actuators	2	Actuators		metal		$9.57
41	Everest Brand Heavy Duty Linear Actuator 4" inch Stroke 225 Pound Max Lift DC 12v 12 Volt	2	Actuators		metal		$77.42
42	UCTRONICS DC 12V Programmable Multifunction Time Delay Relay	6	Arduino kit		metal		$25.98
43	9V AA Battery Pack with Leads, 6 x 1.5v AA Battery Case Holder	2	battery holder		plastic		$10.99
44	EG STARTS Happ Style 1 Player / 2 Player Start & Home Push Buttons With Micro Switch For	1	button switch		plastic		$6.99
45	LEGO 10pc Technic axle set	1			plastic		$6.99
	TOTAL BUDGET						$508.74