Demonstrating Newton's Laws

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Abstract

GREENtree designed apparatuses as Newtonian physics lab experiments for Laurel Tree Charter School's high school students. The project is funded by Laurel Tree Charter School and targets high school students by educating them on the fundamentals of Newton's Laws of Motion with the use of the designed equipment. The problem formation, specifications, alternative solutions, decision process, and specifications are explained.

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1 Problem Formulation

1.1 Introduction

In Section 1 the objective statement and black box model (Figure 1-1) are discussed for GREENtree's project for Laurel Tree Charter School (LTCS).

Laurel Tree Charter School's objective is to create a sustainable and accessible environment for educating children K-12 while facilitating the development of the student's social skills and responsibilities. LTCS wants a device to teach high school students the concepts of Newton's Laws of motion.

1.2 Objective

The objective of this project is to create a fun, surprising apparatus for all ages that demonstrates Newton's Laws of motion for the Laurel Tree Charter School in Arcata, California. This project will be given specific criteria by LTCS.

1.3 Black Box

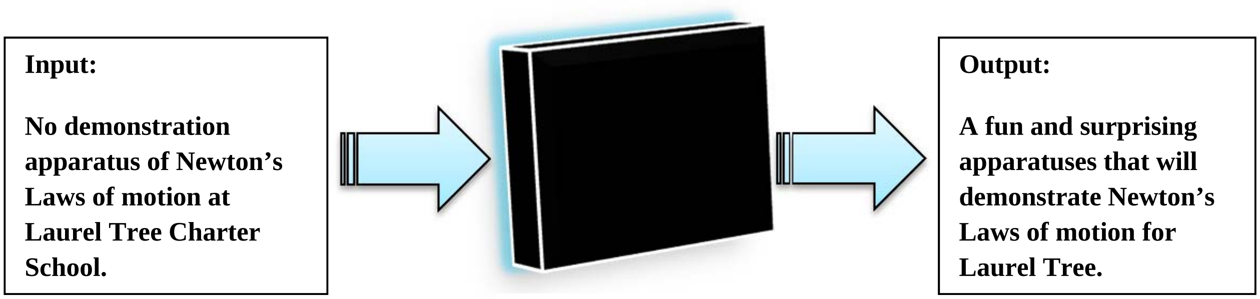


Figure 1-1: Black Box Module describing the input and the output of the project (2012, GREENtree).

2 Problem Analysis and Literature Review

2.1 Introduction

Section 2 includes the initial problem analysis for the Newton's Law apparatus for Laurel Tree Charter School. This section describes the specifications and considerations for this project, as well as, criteria and constraints that it should meet. Section 2 also includes a literature review about Newton's Laws of motion and other topics relative to the apparatus and its design.

2.2 Problem Analysis

In Section 2.2 specifications, considerations, criteria, and constraints are discussed.

2.2.1 Specifications

GREENtree formed specifications that an apparatus must meet. The specifications are listed below.

- Suitable fit through a classroom door.
- Instruction manual and schematic.
- Storage within a closet.
- Interactive lab station

2.2.2 Considerations

GREENtree formed a list of considerations to use when designing the alternative solutions in Section 3.3. The considerations are listed below.

- Low cost maintenance and materials.
- Absorption of knowledge from the experimental apparatus.
- Made out of sustainable materials like wood or metal

2.2.3 Criteria and Constraints

GREENtree developed a list of criteria and constraints for each criterion. The criteria is listed and constrained in Table 2-1.

Table 2-1: Constraints of the criteria

Criteria	Constraint
Level of sustainability	Low embedded energy in materials
Level of educational value	Must meet core standards
Accuracy and precision	Results should match theoretical outcome
Measurability	Data should be collected and quantified
Mysteriousness	Must be something mysterious, leaving students wondering
Safety	No sharp small parts and meet insurance safety standards
Durability	Ten year lifespan with interchangeable parts
Inexpensive	Must be as cost efficient as possible
Storability	Mobility and must be able to be store

2.2.4 Usage

LTCS wants an apparatus that will be durable around young children with a considered lifespan of ten to twenty years. LTCS does not want any sharp small parts on the apparatus that could lead to injury. The apparatus should be made out of sturdy and resilient material that will not wear out, or if the material does wear out it should be an easily replaceable part.

2.2.5 Production Volume

The apparatus should be replicable. It should include a schematic of how it has been designed and be made out of parts that could be readily bought or found again.

2.3 Literature Review

Relevant technical information and specific subjects pertaining to this project are explained.

2.3.1 Newton’s Laws of Motion

Newton’s three laws of motion are explained and demonstrations of the laws are discussed.

2.3.1.1 Newton’s 1st Law

The way Humboldt State University’s mechanics class textbook states Newton’s law is "In the absence of external forces and when viewed from an inertial reference frame, and object at rest remains at rest and an object in motion stays in motion with a constant velocity i.e. with a constant speed in a straight line (Serway, 1986). The first step in analyzing any mechanical system is to recognize that since the object isn’t moving by Newton’s first law, the sum of the forces on the object is zero.

$\sum F= 0$

One popular demonstration of inertia is set up with a mass hanging on a string from a ceiling and a string of the same material hanging from the mass. A slow pull on the lower string will break the upper string, but a quick tug on the lower string will break the lower string. This is because of inertia. The mass resists the change in acceleration from the quick jerk and the difference in forces is placed on the lower string. If the mass is pulled slowly, then at each instant the difference in forces on the bottom string and the mass will be little, so the force is carried through the mass to the upper string as seen in Figure 2.1 (Caplan, 2004).

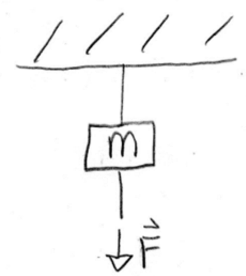


Figure 2-1: Mass suspended by a string with a string hanging from it (2012, J. Quick)

2.3.1.2 Newton’s 2nd Law

Newton’s second law is the central idea of his theory of motion. According to the second law, the acceleration of an object is determined by two quantities; the net force acting on the object and the mass of the object. In other words, the acceleration of an object is directly proportional to the magnitude of the imposed force and also inversely proportional to the mass of that object. The acceleration vector is in the same direction of the applied force vector. A Newton is the standard metric unit for the force involved or also called kilograms meters per second squared. Newton’s second law is expressed in the iconic scientific equation:

$\sum F=ma.$

The important thing to understand about this law is that the mass of an object is inversely proportional to its acceleration. This means that the mass of that object is a property that causes it to resist a change in its motion as it is accelerating (Hewitt, 2009).

2.3.1.3 Newton's 3rd Law

Newton's third law states, "for every action, there is an equal and opposite reaction." There is always action and reaction forces, or two objects exerting a force on each other. As stated in the law, the two forces have opposite directions and their magnitudes are equal. This law is universal to all types of forces whether they are contact interactions, or interactions at a distance. Contact interactions include normal, frictional, tensional, and applied forces. Gravitational, electrical, and magnetic forces are all interactions that occur at a distance (Stern, 2004).

In Static Mechanics, Newton's third law is an essential law in the mathematical interpretation of forces governing engineering designs. The current interpretation of Newton's third law according to Meriam's Engineering Static Mechanics textbook states, "The forces of action and reaction between interacting bodies are equal in magnitude, opposite in direction, and collinear" (Meriam, 2006). The lack of attention to the third law results in error in any design. If an object is in equilibrium, then there are two equal and opposite forces acting against each other. For example, if a pen is sitting on a desk the pen exerts a downward force upon the desk. The desk exerts a force upward of equal magnitude but in the opposite direction. This is why the pen remains at rest, or the pen and desk are in static equilibrium. The fundamental equation of statics mechanics is derived from this example where the sum of the forces equals zero. In this fundamental equation of statics there is no acceleration of the pen or the desk where all of the objects are at rest (Meriam, 2006).

2.3.2 Physics Vocabulary

2.3.2.1 Units

System International is a committee that sets the international standards for units (SI units). Units must be defined so that they represent the same thing everywhere in the universe. A meter is defined as the distance light travels in a vacuum in 1/299,792,458 seconds. A kilogram is defined as the mass of a platinum-iradian alloy cylinder in the International Bureau of Weights and Measures in serves, France. One second is defined as 9,192,631,770 times the period of vibration from a Cesium-133 atom (Serway, 1986).

Another system of units is the United States customary units. US units are defined in terms of SI units. Common US units are the yard, foot, and pound. One pound is defined to be $\frac{1}{2.2062234}$ of a kilogram. 1 yard is defined as $\frac{3600}{3937}$ of a meter. 1 Yard contains exactly 3 feet (Astin).

2.3.2.2 Mass

Mass is how much an object resists a change in velocity. Mass and weight are different quantities due to one accounting for the amount of atoms are in said structure and the another taking into account gravity (Hewitt, 2009). The standard SI unit of mass is the kg and the standard US customary unit is the slug (Serway, 1986).

2.3.2.3 Acceleration

Acceleration is how fast velocity is changing over time, with negative change meaning slowing down and positive change meaning speeding up. This means acceleration is the derivative of velocity with respect to time. Acceleration is measured by distance over time squared. Meters per second squared is the standard

SI measurement for most physics equations. The standard US units for acceleration is feet per second squared (Serway, 1986).

2.3.2.4 Force

The definition in LTCS's physics textbook states that a force is a push or a pull (Hewitt, 2009). The way HSU's engineering mechanics Statics textbook defines force is the action of one body on another (Meriam, 2007). Force is calculated as the acceleration of a body times its mass, the SI unit for force is a Newton or kilogram meter per second squared. The US customary unit of force is the pound (Serway, 1986).

2.3.2.5 Net Force

The net force is any influence which changes a body's velocity. A body's net force is proportional to its acceleration, and that constant of proportionality is its mass. Individual forces can be summed vectorally (Serway, 1986).

2.3.2.6 Free Body Diagram

A free body diagram is a simplified picture of a complex situation where all the forces acing on one object are analyzed and vectorally summed (Serway, 1986).

2.3.2.7 Work

Work is the transfer of energy from one body to another, the system and the surroundings. The unit of work is the force applied times the distance traveled. The SI standard unit of work is the Joule and the US customary unit is the kilocalorie (Serway, 1986).

2.3.2.8 Energy

Energy is defined by having the potential to do work and not being created or being destroyed. Energy is measured in the same units as work. Energy can either be active energy, like kinetic energy, or stored energy, like potential energy due to gravity (Serway, 1986).

2.3.2.9 Lenz's Law

Lenz's Law states that a change in magnetic flux produces an induced current through a metal conductor. Magnetic flux is a measurement of how many magnetic field force lines are moving through a surface area (Olenick, 1986).

2.3.3 Electricity and Magnetism

Newton's second law can be applied to electricity and magnetism as well. Charged particles go through changes when they pass through electric fields producing a force upon that charged particle. Depending on the charge, negative or positive, the electric field and the force produced can have different quantitative values. For example, a negative charge particle will have a negative force in the opposite direction as it passes through the electric field and vice versa. An equation can be expressed for this property as:

$$F=qE$$

2.3.4 Regenerative Braking

Regenerative braking is a technology in modern hybrid cars. It is a method used to recapture energy that would have been lost as heat in the braking phase of driving. Regenerative braking works when the brakes of a vehicle are applied. Kinetic energy from braking is transformed into electric energy to be stored within the car battery for use at a later time (Cibulka, 2009). A brushless DC motor is the equipment on the wheel hub of cars that is used for the regenerative braking. They are easy to build and are highly efficient. The down-side is that the magnet material required for the motor to work is expensive (Westbrook 2005).

2.3.5 Science Museum Exhibits

Several science museums have displays on Newton's three laws of motion.

2.3.5.1 American Museum of Natural History

The American Museum of Natural History in the New York City Central Park displays an exhibit on Newton's laws pertaining to meteorology and space. The exhibit is located in the Arthur Ross Hall of Meteorites. The title name for this exhibit is: *Newton's Law of Motion and Gravity Applied to Meteorites-for Physical Science Students*. The lab, catering to physical science students, is designed to help teach students Newton's Laws as well as identifying examples of the laws that exist in this solar system. Students are separated in pairs or small groups in the beginning of the lab. They are instructed to cite examples of each of the three laws from the meteorite exhibit and present their findings to the class. An example of Newton's Law of Gravity found in the exhibit is the accumulation of minute particles found in the early solar nebula. This example shows how every single body in the universe attracts each other (American Museum of Natural History, 2012).

2.3.5.2 The Museum of Science and Industry in Chicago

The Museum of Science and Industry in Chicago contains a Newton's laws workshop for fourth to eighth grade students. The lab is for a class size of about thirty students. The objective of the workshop is designed to teach students about Newton's second law by experimenting on how mass effects acceleration on a system. Students graph a model of how force and mass effects the distance a car travels, followed by calculating the acceleration of the car. This experiment demonstrates Newton's Second Law: Force equals mass times acceleration (F=ma). There are several key concepts that are introduced in the workshop such as mass, force, acceleration, and the spring scale. The Lab defines mass as the amount of matter contained in an object. Force is defined as a push or pull that causes an object to move, whereas acceleration is the change of direction or speed of an object that is moving. The spring scale is used in the workshop to measure force in Newton's. Another experiment demonstrates the classic egg drop experiment. The purpose of this experiment is to demonstrate Newton's First Law where an object remains in motion, or stays at rest unless the object is acted upon by an outside force. The egg is placed on a plastic sheet above a glass of water where the egg remains at rest. The student is instructed to quickly remove the plastic sheet observing how the egg drops into the glass water. The egg falling into the water shows how the potential energy of the egg is transformed into kinetic energy (Moving with Newton, 2012).

2.3.5.3 Rochester Museum and Science Center

Another museum that host similar exhibits and activities is at the Rochester Museum and Science Center; Newton's Laws of Motion are discussed through a series of lab experiments. The exhibits are designed to think about questions such as, “What are the different variables that affect how the balls start, stop, speed-up, or slow down?” as well as, “How are things like friction, gravity, momentum and inertia related to one another, and how do they affect the ball’s motion?” (Newton’s Law of Motion). The lab exercises define vocabulary such as velocity, acceleration, collide, exert, force, friction, gravity, inertia, law, mass, momentum, motion, variables, and all the definitions of Newton’s Laws. Different exhibits have lab questions to encourage critical thinking about the physics displayed. The Roller-Coaster model delves into energy. The lab’s objective is to understand why the first hill of the roller-coaster is always the largest. The answer is that the first hill needs to produce the largest kinetic energy for the rest of the roller-coaster’s hills because potential energy is being restored backing to the coaster as kinetic energy is being depleted throughout the track. Another model is the Ski Jump where balls roll down different angled ramps. The lab question asks how the speed changes as the ball moves down each ramp. This involves Newton’s Second Law (F=ma) where different accelerations display different forces. Also, ramps have different forces of friction involved to demonstrate how friction affects the total forces. The loop-the-loop experiment demonstrates how the ball must experience a force greater than gravity to perform a whole vertical loop (Rochester, 2012).

2.3.6 Styles of Learning

Different people learn in different ways. A common misconception about learning styles is that people can fall into one of three categories: visual, audio, or physical learners. A study for psychological Science in the Public Interest found that there is little valid evidence for this theory of learning (Pashler, 2008). The director of the royal institute in England says that the idea of three learning styles is a problem and is wasting valuable resources (Henry, 2007).

2.3.7 California State Standards

The California State’s Standards Test for physics involves a section of Newton’s Laws of Motion. Key concepts of Newton’s Laws were adopted in set criteria by the State Board of Education in 2002. The definitions of the Newton’s Three Laws of Motion should be understood. By understanding the first law students should be able to notice that if there is no acceleration, then the forces are balanced. Physics students should be able to solve one dimensional problems using the second law (F=ma). Furthermore, the knowledge of the third law should enable students to realize that there for every action there is an equal and opposite reaction. Newton’s Laws are not exact, but are approximations of reality unless the object of question is near light speed or is so small that quantum mechanics are involved (State of California, 2002)

2.3.8 Physics Experiments and Applications

Different workshops provide a variety of physics experiments and their applications.

2.3.8.1 Sonoma State Lab Workshop

In Collaboration with NASA’s SWIFT mission, Sonoma State educators created a workshop with several different lab activities involved that demonstrate Newton’s first law. The student activities worksheet is designed to teach the first law in a fun and interesting way. The lab has features that can be changed according to the level the students are at and can be sorted with students individually, as well as, in groups. Students create a logbook in order to take notes and record their findings. Besides containing several lab activities demonstrating Newton’s first law, the workshop includes a brief historical background of Sir Isaac Newton and his laws of motion.

The first lab activity demonstrates circular motion with a yo-yo. Note that a softer object such as a bagel attached to a string should be used due to safety precautions. The student swings the yo-yo over their head in a circular motion as seen in Figure 2-2. The strings tension is the force holding the yo-yo in place. Once the student releases the yo-yo the projectile motion should be in a tangent straight line from the point of release. This is stated in Newton’s first law where an object in motion remains in motion along a straight line unless acted upon by a counteracting force. The yo-yo remains in a straight projectile motion until acted upon by wind, gravity, or other forces like air resistance.

Figure 2-2: A yoyo being thrown in a circle (Whitlock, 2009)

The next lab activity is entitled, “Inertia-A Body in Motion”. A student holds a tennis ball and runs at different pace towards a target about 10-15 meters from the starting point. The student is instructed to try to drop the ball onto the target. Noticing that the ball must be dropped before reaching the target, the student logs their observations in their logbook while keeping Newton’s first law in mind. The ball is at rest until dropped onto the target where the outside force is gravity illustrated in Figure 2-3. Newton’s first law applies to horizontal motion, thus no horizontal force is acted upon the ball when dropped onto the target. Only the horizontal motion of the runner acts on the ball to change position (Whitlock, 2009).

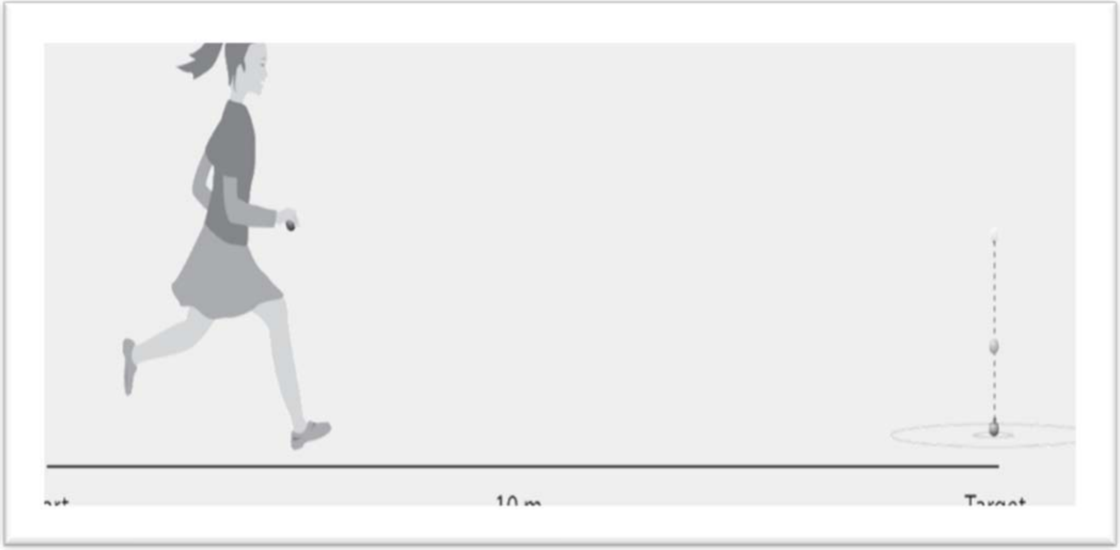


Figure 2-3: Inertia, a body in motion (Whitlock, 2009)

The last activity is called; "And They Are Off!" where two jars are raced alongside each other starting on separate inclined binders. One jar is filled with sand and the other with lead pellets. The student lets go of the jars and records the distance the jars have traveled. Different surfaces should be used for the runway such as a wooden floor, carpet, linoleum, tile, and any other surfaces available. The student compares the different distances recorded for the runway and observes why they may be different distances illustrated in Figure 2-4. Friction is the force that cause the jar to eventually slow down, thus the first law is upheld where the jar rolls in a straight line until a force, friction, acts upon it. The student should conclude that smoother surfaces enable the jars to travel farther, and the force that upholds the first law is friction (Whitlock, 2009).

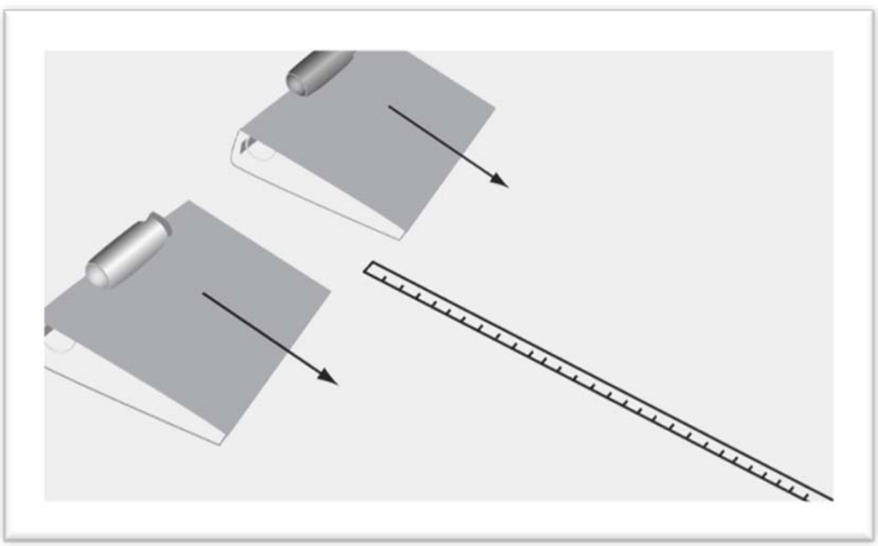


Figure 2-4: A race to the bottom (Whitlock, 2009)

2.3.8.2 Newton's Laws of Motion and Inertia demos

The demonstrations will cover Newton's first, second, and third Laws of Motion. These are successful demonstrations that have been performed. For the second law, the demonstration is to drop two different weighted rocks or other objects of similar shape into a bucket of sand to determine which object creates more force based on the size and depth of the hole created, and roll a large and small marble down an incline and see which sized marble pushed the other to the end the fastest (HomeScienceTools, 2012). This explains the equation F=MA where the amount of force created equals how much mass an object has and how much acceleration it creates. For the 1^{st} law, the demonstration is to place a pile of books onto a towel or poster board and proceed to quickly pull the towel or paper while the books move (Becker, 2010). The demonstration demonstrates that an object at rest stays at rest and an object moving will stay moving unless acted upon by an unbalanced force. A demonstration of Newton's third law is to use a rope and force gages at each end to determine who is using more force in a game of tug-of-war. This explains that for every action, there is an equal and opposite reaction (Mellenstei, 2008).

2.3.8.3 Magnets and Copper Pipes

When a magnet is dropped through a copper tube, the magnetic flux through the tube is changing, forcing eddy currents to run through the tube (Olenick, 1986). The eddy currents are composed of magnetic forces created by the magnet (Partovi, 2006).

Professor Feldman at George Washington University who demonstrates Newton's third law of motion using a magnet falling down a copper tube. He says the demonstration makes people see Newton's laws as less of an abstract idea (Feldman, 2007).

2.3.9 Low-cost materials

The intent of the Laurel Tree project is to use recycled materials if possible or just low-cost materials because of a limited budget. A good source for free stuff is Freecycle where people in a local area post listings at Freecycle.com about items that they give away for free to whoever wants the stuff. Freecycle is meant to keep stuff that can be reused out of landfills (Freecycle, 2010). Another useful place is The Koop located in Arcata that sells various electronics, motors, metals, and other items. For wood there is Old Growth Timbers which is located in Arcata and sells used wood boards and planks for $1.50/BF (board foot) (Evenson, 2012).

3 Search for Alternative Solutions

3.1 Introduction

Section 3 addresses the alternative solutions for the Newton's Laws of motion apparatuses. In this section, brainstorming sessions are discussed which led to the generation of these alternative solutions. These solutions will try to fulfill the criteria described in Section 2.

3.2 Brainstorming

GREENtree brainstormed several times, filling a large whiteboard with ideas and concepts. These brainstorming sections are documented in Appendix A. After the ideas were generated, GREENtree combined several of the ideas together. At least one criterion incorporated into each solution. After brainstorming new ideas, we further brainstormed by drawing pseudo schematics of some of our ideas, which are also in Appendix A.

3.3 Alternative Solutions

Using the literature review and brainstorming sessions, alternative solutions were generated for the Newton's laws of motion apparatuses. Sections 3.3.1 to 3.3.10 describe individual experiments that can be analyzed by either one or multiple laws of motion. From these solutions, three are to be used to complete the project, as desired by the client.

- Rotating Hammer
- Mass Pendulum
- Inclined Planes
- Tablecloth Magic
- Centripetal Acceleration and Tangential Velocity Roller Coaster
- Loop de Loop Rollercoaster
- Demolition Derby
- Hammer and Air Pump
- Magnet in a Copper Tube
- Balloon Rocket Model

3.3.1 Rotating Hammer

The Rotating Hammer is a hammer attached to a fixed rotating point which will allow students to hit toy cars of different masses with the hammer illustrated in Figure 3-1. Analyzing the force from the hammer based on how far it traveled and its mass, and the distance the car traveled will determine the coefficient of friction of the surface the car traveled on. Cars could have pads attached to them so that the hammer does not break them. In a physics laboratory experiment, students could calculate how far the car will be pushed by the hammer through analyzing the situation using all of Newton's three laws of motion.

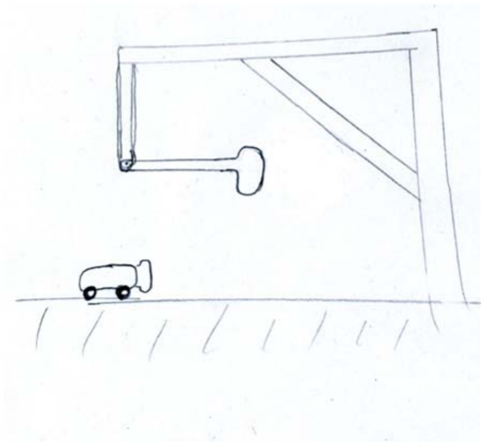


Figure 3-1: Rotating hammer apparatus (2012, J. Quick)

3.3.2 Mass Pendulum

The Mass Pendulum apparatus is a pendulum that has interchangeable masses. Students observe a given mass collide with a row of similar masses, causing the last mass to gain an angle and a height. Students can measure and make several calculations to determine different variables from kinetic energy to the initial force applied. Different media, like wood, metal and magnets, can be used to demonstrate the same concept of this experiment. All of the laws of motion can be applied to this apparatus. Refer to the Appendix A for more of the apparatus' renderings.

3.3.3 Inclined Planes

The Inclined Planes demonstrate Newton's First Law by analyzing different friction forces. The law states that an object at rest remains at rest, or an object in motion remains in motion unless acted upon by an unbalanced force. In the case of the Incline Planes model, friction is the opposing force that slows down the object of choice in motion. Two objects of choice are allowed to slide down the incline and the winner of the "race" is observed. The lab contains two inclined planes that can be adjustable at different angles for comparative results. On the inclined planes' surfaces there are adjustable plane cut-outs that are designed to show different friction forces acting on upon the object. Examples of the friction forces include cutouts of carpet, wood, tile, linoleum, or any other surface of choice. These different friction surfaces can be swapped on any of the two inclined planes. The students shall then test and compare the different friction surfaces by racing two objects down the inclined plane that contain different friction surface cut-outs. Measurements of the speed and distance traveled can be calculated for comparison reasons. Furthermore, higher level students can create a free body diagram of the forces that are on the object, such as the figure3-2.

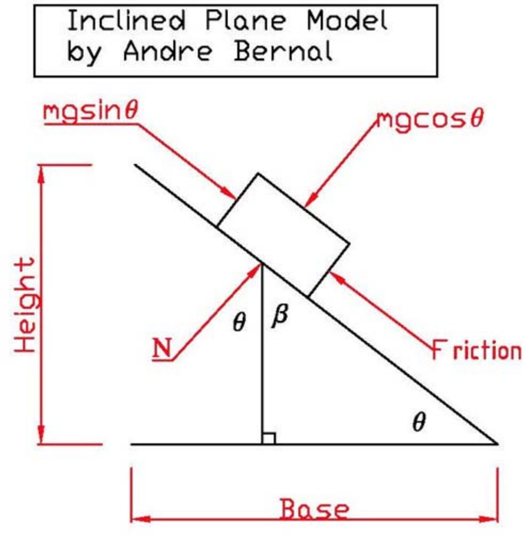


Figure 3-2: Object on an inclined plane (2012, A. Bernal)

3.3.4 **Tablecloth Magic Trick**

The Tablecloth Magic trick is similar to what has been seen in movies and shows. It requires having a tablecloth with plates, silverware, napkins, etc on it. Then the tablecloth is quickly yanked from the table while all the items on the tablecloth are left intact close to where they were placed. This can also be done with a big piece of paper that is thick like poster board where a heavy object is put on it and the paper is yanked leaving the object where it was. It is not magic, but allows students to observe Newton's first law of motion.

3.3.5 **Centripetal acceleration and tangential velocity roller coaster**

A cylindrical roller coaster with a tangential ramp will launch a ball a distance in this apparatus for students. Students can measure and observe to get an understanding of centripetal acceleration and tangential velocities. Students will measure heights, radii and lengths that are needed. Using some basic algebra and the distance the ball jumps, the initial velocity can be calculated and assumed to be the tangential velocity of the coaster. Several variables can be changed to create numerous experiments for students, like the mass of the ball and the inclination of the ramp. A challenge can be created by calculating the height the ball will need to get through a hoop and then checking if observation matches prediction shown in Figure 3-3.

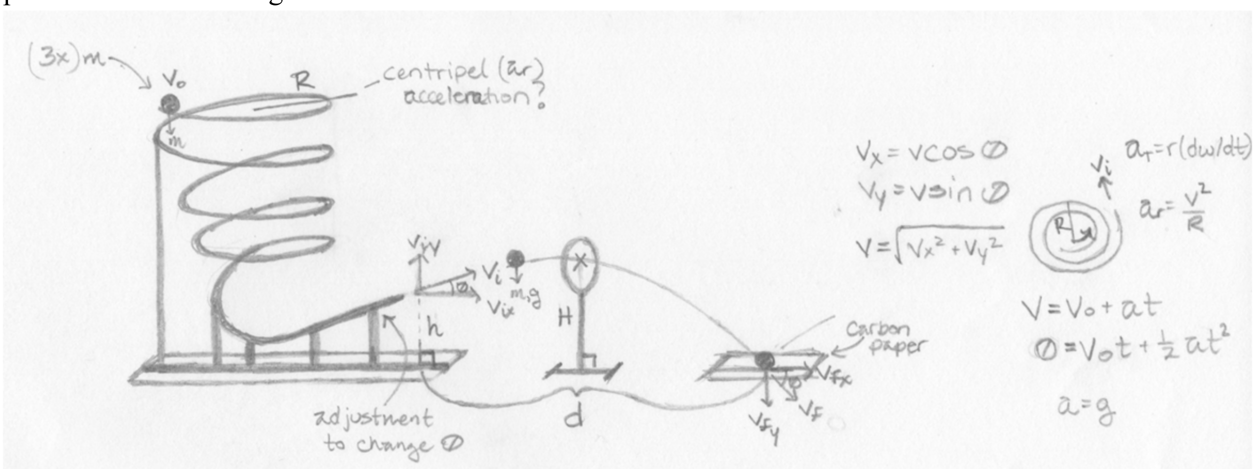


Figure 3-3: Centripetal and tangential roller coaster apparatus (2012, C. Alston)

3.3.6 **Loop de Loop Rollercoaster**

The Loop de Loop Rollercoaster apparatus is a fun and simple demonstration of Newton's second law. There is a marble track that students can shape. Students can make their own rollercoaster using marbles and track. The masses of the marbles are known. Students set up a loop de loop ramp. The goal is to create as big a loop as possible without the marble falling out of the loop shown in Figure 3-4. Students first try to calculate an optimal height, and then test their calculations with experiment. To calculate the optimal height of the loop, students will equate the centripetal acceleration of the marble with the acceleration due to gravity, and be told to lower their loop a little to account for friction. This will be a fun hands on demonstration of finding the net force of an object and using F=ma to solve a practical problem.

To calculate the force needed to overcome gravity, students will be given the information that in rotational acceleration, acceleration is equal to the velocity squared divided by the radius of rotation. This acceleration has to be at least equal to the force of gravity so that the marble does not fall off the track.

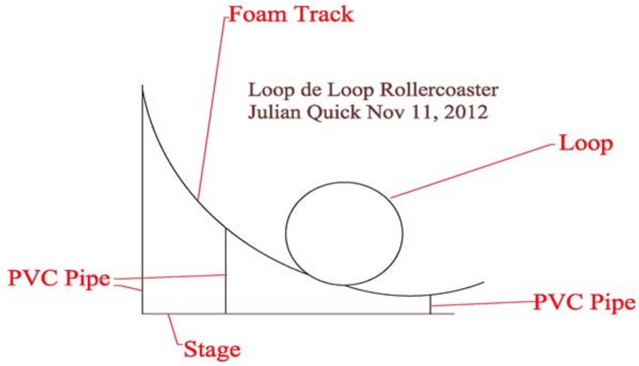


Figure 3-4: loop de loop concept (J. Quick, 2012)

3.3.7 Demolition Derby

The demolition derby requires two equally weighted toys cars like Matchbox or Hot Wheels and a tape measure. It involves launching one of the cars at the other from the same distance each time and using variable amounts of force to launch the car and then record the distance the car being hit goes. This gives a general idea of how much force is generated by having one of the cars launched at variable speeds but keeping a constant mass. This demonstration is used to show Newton's Second Law of Motion, F=ma, where the mass is constant and the acceleration is variable for even record keeping.

3.3.8 Hammer and Air Pump

This experiment will allow students to observe and measure several variables as kinetic energy is converted into potential energy. This transfer of force from the hammer to the air pump will be determined by the students. Several different variables can be interchange like the hammer head, the ball's mass and the amount of potential energy stored in the hammer lever. Other variables will have to be given like gravitational acceleration. In the experiment, students will observe the hammer delivering a blow that pushes air into a chamber causing a ball to gain elevation and a height illustrated in Figure 3-5. With the data collected, students can calculate the force transferred by the hammer and the acceleration of the hammer as it collides with the air pump.

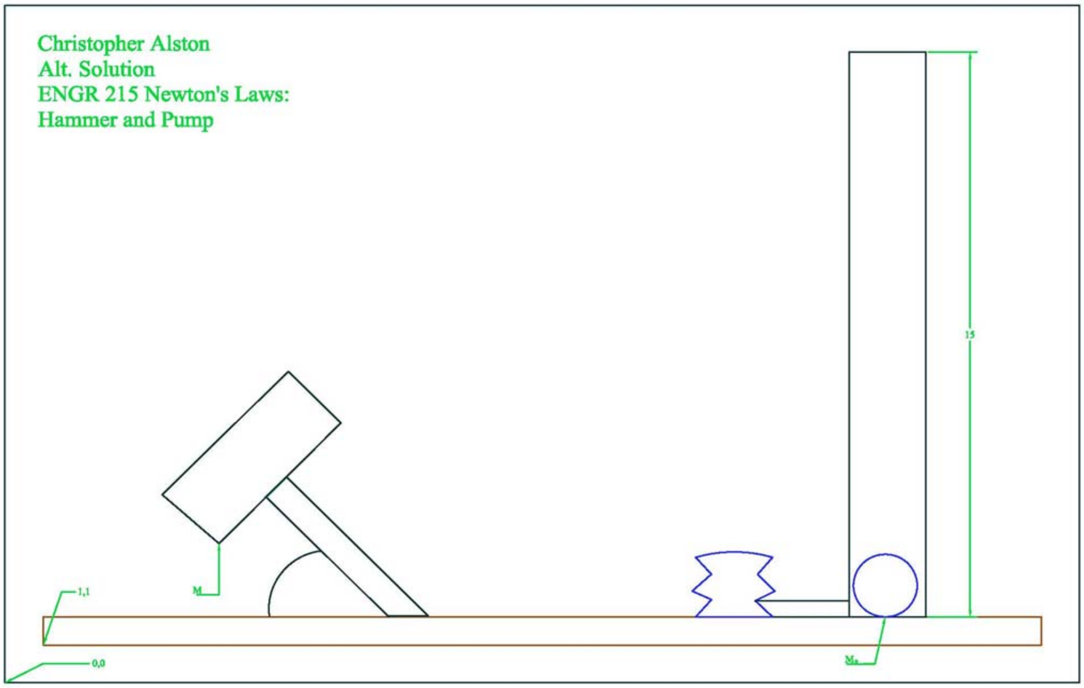


Figure 3-5: Hammer and air pump apparatus rendering (2012, C. Alston)

3.3.9 Magnet in a Copper Tube

There is a magnet and a 1 foot long copper tube. The magnet is dropped down the copper tube. As the magnet falls through the tube, the magnet forces eddy currents of electricity to flow through the copper tube. Because of Newton's third law of motion, there is an equal and opposite force that pushes back on the magnet, slowing it down until it reaches terminal velocity in the downwards direction. This apparatus would be fun for kids of all ages because it's such an out of this world experience. Students could measure how fast the magnet falls and deduce how much force the magnet forces. A magnet and a copper tube would be an unforgettable learning experience. Seeing this application of Newton's law of motion in action will make Newton's laws of motion seem less abstract and more concrete (Feldman, 2007).

3.3.10 Balloon Rocket Model

The Balloon Rocket Model demonstrates Newton's third law of motion. Students observe and collect data on the propulsion of the balloon. The data includes per trial the total distance and time duration. The experiment includes a balloon attached to a straw/pipe on a fishing line that is held tight by two poles. The propulsion of the balloon forward is caused by the opposite force of the air being released from the balloon. The rocket propels the air mass in the opposite direction of the movement of the balloon at an intense velocity. Figure 3-6 displays this demonstration after the student releases the balloon. The forces acting on the straw rocket are shown pushing on the balloon. The reaction of the exhaust on the straw rocket is shown acting due to the air inside the balloon forcing the massed particles outwards. Furthermore the tension of the string and straw is shown acting on the balloon. Since the rocket is accelerating there is a net force change, and the forces acting on the rocket are not equal and opposite. Different exercise questions can be asked at the end of the lab to assess the students' comprehension of

Newton's Third Law such as: How does the balloon rocket demonstrate the Third Law of Motion? What is accelerating? What forces are acting on the balloon rocket? For advanced students, they could be instructed to construct a free body diagram of the forces acting in the system internally and externally of the balloon rocket.

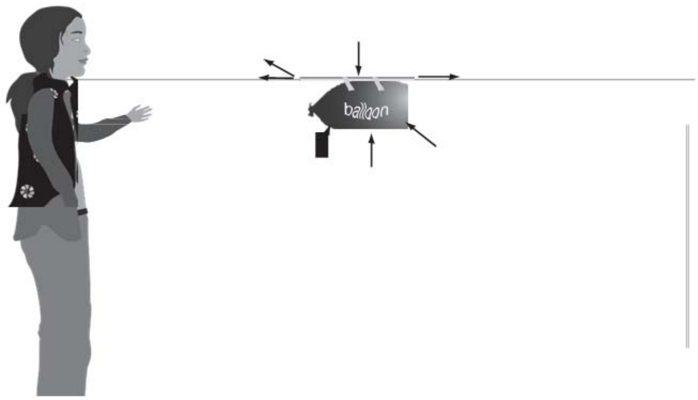


Figure 3-6: A pic of the balloon forces after release and list of forces showing action and reaction (Whitlock, 2009)

4 Decision Phase

4.1 Introduction

Section 4 describes the final decision for this project that determines what the team will construct based on the alternative solutions in Section 3.3. The criteria definitions and alternative solutions are also discussed. All of the proposed solutions are analyzed using the defined criteria in a Delphi matrix and the highest scoring solutions are considered. The final solution is to design three separate demonstrations of Newton's laws of motion that either demonstrate just one of the laws or demonstrate a multitude of the laws.

4.2 Criteria Definitions

The criteria introduced in Section 2.2.3 is defined below:

Durability: Measures the lifespan of the apparatus and how easily replaceable the parts are.
Mysteriousness: The level that students will be able to see Newton's laws of motion in a surprising way
Safety: A gauge of how much an apparatus is in accordance with the schools code of safety regulations and meets instructor's approval when in use.
Educational Value: A value that gauges the teaching of Newton's fundamentals laws of motion with observation and experimentation
Measurability: A gauge of how many variables in the apparatus can be measured and analyzed

Accuracy and Precision: A quantitative value that correlates to each apparatus matching the theoretical values with a small deviation of error.
Inexpensive: A numerical value representing the cost of the production of the apparatus or its low cost in upkeep.
Storability: A gauge of the minimum volume the experiment will occupy when stored away in a closet.
Sustainability: The measure of eco-friendly, low environmental impact, and low embedded energy in the material of the apparatus..

4.3 List of Alternative Solutions

The following solutions from Section 3.3 are analyzed in a Delphi Decision Matrix in Section 4.4.

- Rotating Hammer
- Mass Pendulum
- Inclined Planes
- Tablecloth Magic Trick
- Centripetal Acceleration and Tangential Velocity Rollercoaster
- Loop de Loop Rollercoaster
- Demolition Derby
- Hammer and Air Pump
- Magnet in a Copper tube
- Balloon Rocket Model

4.4 Decision Process

GREENtree has made the final decision for this project using the Delphi Decision Matrix shown in Table 4-1 by using the criteria listed above. To begin the decision-making process, GREENtree analyzed how well each solution meets each criterion on a scale of 1 to 50, where 1 means not meeting the criterion at all and 50 means completely meeting the criterion. Every value was assigned by the team and discussed in detail by averaging or by consensus.

The client submitted numerical weights describing the importance of each criterion on a scale of 1 to 10, where 10 is the most important. GREENtree used the client's weights describing each criterion's importance in a Delphi decision matrix.

For every alternative solution, the scores of how the solution meets each criterion are multiplied by the weight of the importance of the respective criteria. The products are summed, yielding the final value of the solution. The three solutions with the highest values are selected to be built.

Table 4-1: Delphi Decision Matrix

Criteria		Alternative Solutions									
List	Weight	Rotating Hammer	Mass Pendulum	Inclined Planes	Tablecloth magic	Rollercoaster	Loop de Loop	Demolition Derby	Hammer Air Pump	Magnet + Copper	Balloon Rocket
Sustainability	5	40 / 200	35 / 175	40 / 200	45 / 225	35 / 175	40 / 200	30 / 150	35 / 175	35 / 175	50 / 250
Educational Value	7	32 / 224	40 / 280	45 / 315	30 / 210	44 / 308	43 / 301	41 / 287	40 / 280	40 / 280	38 / 266
Accuracy and precision	6	15 / 90	35 / 210	40 / 240	25 / 150	37 / 222	40 / 240	35 / 210	30 / 180	15 / 90	33 / 198
Measurability	7	40 / 280	20 / 140	40 / 280	5 / 35	43 / 301	35 / 245	40 / 280	46 / 322	25 / 175	45 / 315
Mystery	9	15 / 135	30 / 270	30 / 270	35 / 315	29 / 261	26 / 234	30 / 270	40 / 360	50 / 450	35 / 315
Safety	2	20 / 40	45 / 90	49 / 98	20 / 40	45 / 90	45 / 90	45 / 90	20 / 40	47 / 94	45 / 90
Durability	9	45 / 405	35 / 315	40 / 360	39 / 351	20 / 180	43 / 387	40 / 360	30 / 270	42 / 378	47 / 423
Cost	6	50 / 300	35 / 210	35 / 210	50 / 300	28 / 168	41 / 246	30 / 180	15 / 90	20 / 120	48 / 288
Compact	5	47 / 235	45 / 225	40 / 200	42 / 210	17 / 85	32 / 160	35 / 175	35 / 175	45 / 225	49 / 245
Total		1909	1915	2173	1836	1790	2103	2002	1892	1987	2390

4.5 Final Decision Justification

The three highest rated alternative solutions in the Delphi Matrix are the Balloon Rocket, the Inclined Planes, and the Loop de Loop Rollercoaster the Loop De Loop Rollercoaster will be combined with another solution, the Centripetal Acceleration and Tangential Velocity Rollercoaster, to create a hybrid rollercoaster because the Loop De Loop experiment was lacking mysteriousness and measurability attributes. When combined together, the new Loop De Loop experiment sends a ball flying through a loop and landing on carbon paper with a final velocity. From the high scoring solutions, the team has decided to build the Incline Planes experiment, Balloon Rocket experiment, and the new Loop de Loop experiment to be used to measure and conceptualize Newton's fundamental laws of motion for Laurel Tree.

5 Specifications

5.1 Introduction

In this section, specifications and the details of each final solution are addressed. The specifications for each solution include the solutions' description, cost analysis, implementation and prototype performance. The solution descriptions describe what each apparatus is and why they are suitable for this client. Cost analysis covers the design, implementation, and maintenance costs. The materials list covers all of the materials used, their retail price, and what GREENtree paid for them. Performance results inform how the solutions perform during testing or as tests are done on them.

5.2 Solution Descriptions

The three final apparatuses, Inclined Planes, Loop de Loop Rollercoaster, and Balloon Rocket, are described in detail from key features to materials used to construct. Each segment explains the idea and fundamentals, of said apparatus, to justify its significance to Laurel Tree Charter School.

5.2.1 **Inclined Planes**

The Inclined Planes experiment, shown in Figure 5-1, is designed to slide objects down an angular surface with different friction force cutouts such as, a metal slate, a carpet ruminant, and a rectangle of wood. These friction cutouts can be attached to the base of the plane by four Velcro® pieces both attached to the stencils and to the base of the inclined planes. The angle of the plane is adjustable with the construction of an adjustable wooden lever. The inclined planes have attached hinges to enable angular change that can be attached on the inclined plane as well as the platform.

Figure 5-1: Inclined Planes apparatus in use. (2012, C. Alston)

5.2.1.1 Solving For the Coefficient of Static Friction

In the Inclined Planes experiment students are instructed to find the maximum angle of the object on the inclined plane up until the object starts to slide down. At this point the maximum static friction force can be calculated using the friction force equation: friction force equals the coefficient of static friction times the normal force on the object ($F = \mu N$). Different objects can be used such as wood and aluminum. Using the free body diagram as seen in Figure 5-2, students can then find the static coefficient of friction at the point of the maximum static friction using the following steps:

- Assume $F= \mu N$
- $F= mg\sin(\theta)$
- $N= mg\cos(\theta)$
- using substitution in the equation $F= \mu N$, $mg\sin(\theta)= \mu mg\cos(\theta)$
- So, $\mu= \tan(\theta)$

Note that the force of the object due to gravity ($W= mg$) cancels out in the equation and the trigonometry determines the coefficient of static friction. Using the different friction plane cutouts, students can use various combinations of the objects and planes to find different static coefficients of friction of the different materials.

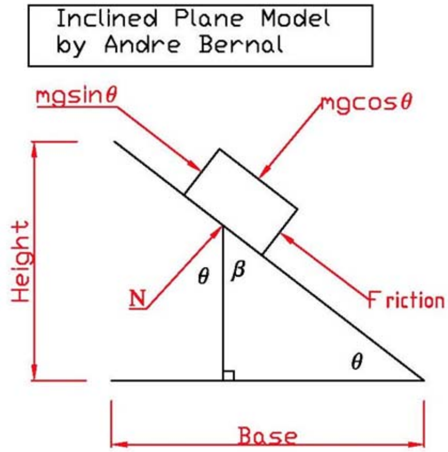


Figure 5-2: Free body diagram of the Inclined Planes (2012, A. Bernal).

Furthermore, students can race objects down the two inclined planes for a conceptual view of the different kinetic friction forces acting on different materials. For example, an aluminum object on the aluminum friction cutout surface can be raced against a wood object on the wood friction cutouts surface. A different combination of objects and the friction cutouts gives different results.

5.2.1.2 Adjustable Angles

The Inclined Planes apparatus are supported by an adjustable stand that is attached to the inclined plane as well as the base platform. This can be seen in Figure 5-3 where the adjustable angular components can be viewed. The adjustable stand is attached to the inclined plane by a pair of hinges, and is attached to the base platform by another set of paired hinges. The angle of the plane is adjusted by students manually raising the inclined planes.

Figure 5-3: Adjustable angles allow students to change the planes. (2012, C. Alston)

5.2.1.3 Friction Force Cutouts

The friction force cutouts are of the same dimensions as the inclined plane. The different friction cutouts include a metal slate, a wood slate, and a carpet slate as seen in Figure 5-4. Velcro® is attached to the inclined plane and each of the friction cutouts so that the cutouts can be exchanged during the experiments.

Figure 5-4: Friction force cutouts. (2012, C. Alston)

5.2.1.4 Sliding Objects

The objects used in the inclined planes, as seen in Figure 5-5, include aluminum mini vents, wooden plugs, and steel washers. These objects all have known calculated coefficients of friction specifically with the wood and aluminum friction cutouts. Furthermore any object that can slide can be used in this experiment.

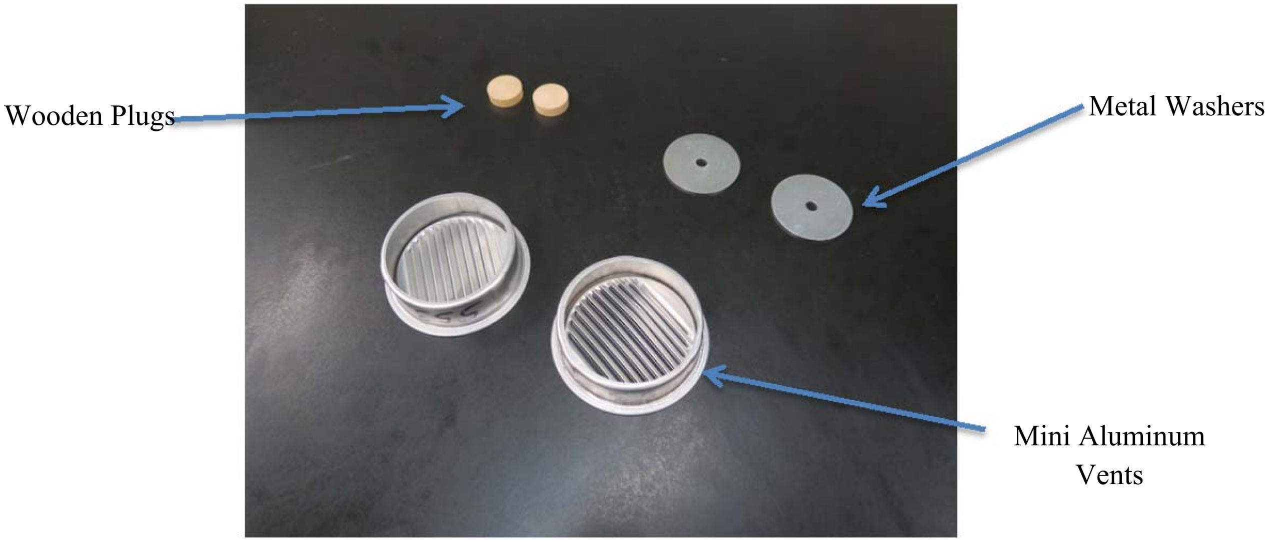


Figure 5-5: Objects used for the Inclined Planes Apparatus. (2012, C. Alston)

5.2.1.5 Materials List

The list of materials for the Inclined Planes apparatus is shown below in Table 5-1. It includes the retail cost of each material and the actual cost the spent.

Table 5-1: Inclined Planes' Material and Cost Data

Inclined Planes			
Material	Quantity	Actual Cost	Retail Cost
Pinewood 6" by 30" (planes)	2	$ 9.10	$ 9.10
Plywood 4' by 4' (platform)	1	donated	$ 16.37
Hinges	4	$ 17.98	$ 17.98
Metal slate 6" by 30"	1	donated	$ 21.98
Carpeted section 6" by 30"	1	donated	$ 5.79
Plywood stands	4	donated	$ 15.49
Bag of nails and hardware	1	$ 1.99	$ 1.99
Mini aluminum vents	2	$ 3.58	$ 3.58
Wooden plugs	4	$ 0.40	$ 0.40
Metal washers	2	$ 0.60	$ 0.60
Wood glue	1	$ 3.49	$ 3.49
Velcro®	8	$ 3.99	$ 3.99
Subtotal		**$ 32.03**	**$ 100.76**

5.2.2 Balloon Rocket

The Balloon Rocket is used by releasing a balloon filled with air attached on a string track and measuring the distance traveled, as well as the time it took to travel that measured distance. The balloon is pushed by the air it expels until there is no more air in the balloon, or the balloon reaches the end of the track. This demonstrates Newton's third law because there is a force of the balloon on the air and an equal and opposite force of the air on the balloon. The Balloon Rocket is made of two parts; the make shift balloon apparatus and the track that it will travel on. GREENtree hung the PVP pipes in a tree and sat them in buckets semi filled with concert to create the base for this apparatus as shown in construction in Figure 5-6.

Figure 5-6: The construction of the Balloon Rocket experiment. From left to right, Zipursky, Bernal, and Quick, are shown in this figure. (2012, C. Alston)

5.2.2.1 Balloon

The balloon apparatus consists of a party balloon being adhesively attached to a straw guide that keeps the balloon in a straight line on the track. The straw should be attached near the end of the balloon where the air is expelled, demonstrated in Figure 5-7.

Figure 5-7: How the balloon is attached to the string (2012, C. Alston)

5.2.2.2 Track

The track is made of two 4’ tall PVC pipes positioned into two buckets that are filled with cement to hold the PVC pipes in place. The track that the balloon will travel on will be a low friction string that can be sized to various distances, shown in Figure 5-8.

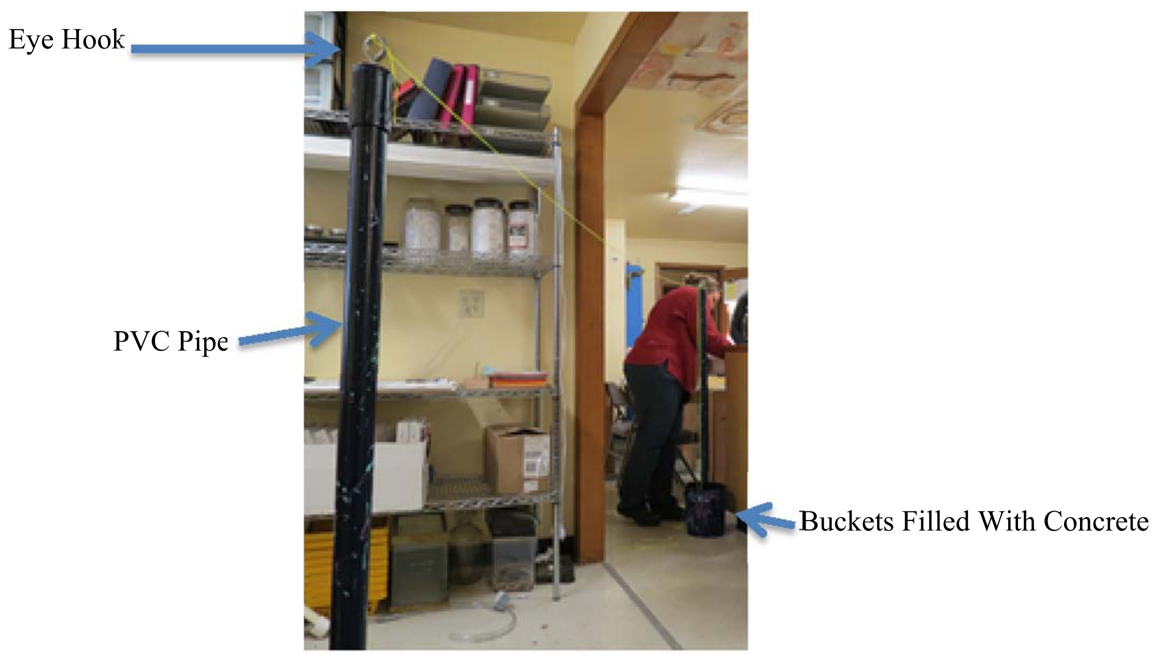


Figure 5-8: Balloon Rocket Track (2012, C. Alston)

5.2.2.3 Materials List

The different components that make up the Balloon Rocket experiment are displaced below in Table 5-2. This table shows the quantity and cost of each part of this apparatus as well as what the actual cost for this part of the project.

Table 5-2: Material and cost data for the Balloon Rocket apparatus

Balloon Rocket			
Material	Quantity	Actual Cost	Retail Cost
4 ft. 1.25" PVC pipe sections	2	$ 5.49	$ 5.49
Buckets (6 gal)	2	$ 13.98	$ 13.98
1.25" PVC coupling	2	$ 2.98	$ 2.98
Eye hook	2	$ 3.98	$ 3.98
1.25" PVC plug	2	$ 2.99	$ 2.99
Spool of chalk string (50 ft)	1	$ 8.99	$ 8.99
Pack of balloons (25 Qt)	1	$ 2.97	$ 2.97
Drinking straws	1	donated	$ 1.99
Washers	4	$ 0.80	$ 0.80
Spray paint	2	$ 9.98	$ 9.98
Bag of concrete (40lbs)	1	$ 5.49	$ 5.49
Subtotal		**$ 57.65**	**$ 59.64**

5.2.3 Loop de Loop Rollercoaster

The Loop De Loop Roller Coaster is a track with negligible friction and a loop de loop that students can roll spherical objects down. The track is made of a foam tube sewn into a loop de loop and is glued to PV supports on a wooden stand. This is a compact apparatus that can be easily transported and stored. This lab demonstrates a practical application of the concepts of centripetal acceleration, conservation of energy, and Newton's second law of motion in roller coaster design.

Students can equate the centripetal acceleration the spherical object feels at the top of the loop with the acceleration due to gravity to solve for what height the marble needs to start at. After the loop, the spherical object flies into the air, giving students the opportunity to calculate how far the marble will travel.

5.2.3.1 Estimating the Initial Height

In order to solve for the initial height for the marble to complete the loop in the Loop De Loop Roller Coaster, students assume that there is no friction in the ramp. Using conservation of energy, it can be shown that potential energy lost is equal to the kinetic energy gained, so the vertical distance between where the spherical object starts and the top of the loop (h) times the marbles mass (m) times acceleration due to gravity (g) should equal half he mass of the marble (m) times the square of its velocity on the top of the loop (v): $mgh = .5\ mv^2$. Solving for velocity, it's true that $v = (2gh)^{1/2}$. Centripetal acceleration is equal to v^2 / R and that must be at least equal to the acceleration caused by gravity. Setting $v^2 / R = g$, one finds that $2gh / R = g$ which implies that $h = R / 2$. So, the ramp must start at least 3 / 2 of the radius up from the ground for the spherical object to go over the loop. Note that this height is independent of the marble's mass.

5.2.3.2 Solving For How Far the Marble Flies

Students can measure the angle the ramp shoots the spherical object into the air. Using conservation of energy to solve for the spherical object's kinetic energy at the last point of contact with the track, students can find the initial velocity of the airborne spherical object. Using the measured angle, students can find the vertical component of the initial velocity of the airborne spherical object. Using the equation d=vi t + ½ a t2, the time the spherical object will be airborne can be deduced. Using the time of flight, students can use the equation distance = velocity x time, because there is no acceleration in the horizontal direction.

5.2.3.3 The Ramp

The original design of the Loop De Loop Roller Coaster was a metal pole cut in half and bent into a loop. Instead of launching the ball after the loop, the original design launched the spherical object into a pocket, so that students only measured the mass of the spherical object, the initial height and whether or not the spherical object went over the loop.

The ramp is a cut piece of black foam pipe insulation. The foam pipe insulation is glued onto the support pipes using E6000 adhesive to allow the foam to be shaped into a loop de loop. Students will be able to place marbles of different masses on the ramp at different heights to see what heights lead to a successful run through the loop de loop, and how mass affects the initial height. After the loop de loop, the ramp shoots the spherical object outwards, and students can calculate how far the spherical object will go. The track is shown is Figure 5-9.

Figure 5-9: The Loop de Loop track. (2012, C. Alston)

5.2.3.4 The Supports

The initial design of the support system was two doweled bars of wood supporting the track, giving the track an adjustable height. Since students will be able to place marbles at different initial heights in a fixed track, a fixed track height was used.

PVC pipe are glued to the foam track to maintain the shape of the apparatus. The bottoms of the PVC pipes are all glued to a baseboard. The top of the PVC pipes are cut into grooves so the track fits snugly inside the grooves, seen in Figure 5-10. Finally, the track is glued to the pipe.

Figure 5-10: The Loop de Loop support system. (2012, C. Alston)

5.2.3.5 Materials List

A list of all the materials used in the Loop de Loop Rollercoaster is provided in Table 5-3. This table shows the quantity, actual cost, and retail cost of each component.

Table 5-3: Material and cost data for the construction of the Loop de Loop Rollercoaster

Loop de Loop Rollercoaster			
Material	Quantity	Actual Cost	Retail Cost
Foam pipe insulation	1	$ 3.98	$ 3.98
1.25 "PVC pipe support segments	6	$ 3.56	$ 3.56
Plywood 2.5' by 1'	2	donated	$ 5.37
E6000 (Adhesive)	1	$ 7.49	$ 7.49
4ft cedar (1" x 1.25") garden stakes	3	$ 1.23	$ 1.23
Sandpaper	2	$ 1.08	$ 1.08
Wood glue	1	donated	$ 3.49
Bag of nails and hardware	1	donated	$ 1.99
Bag of marbles	1	$ 2.99	$ 2.99
Subtotal		**$ 20.33**	**$ 31.18**

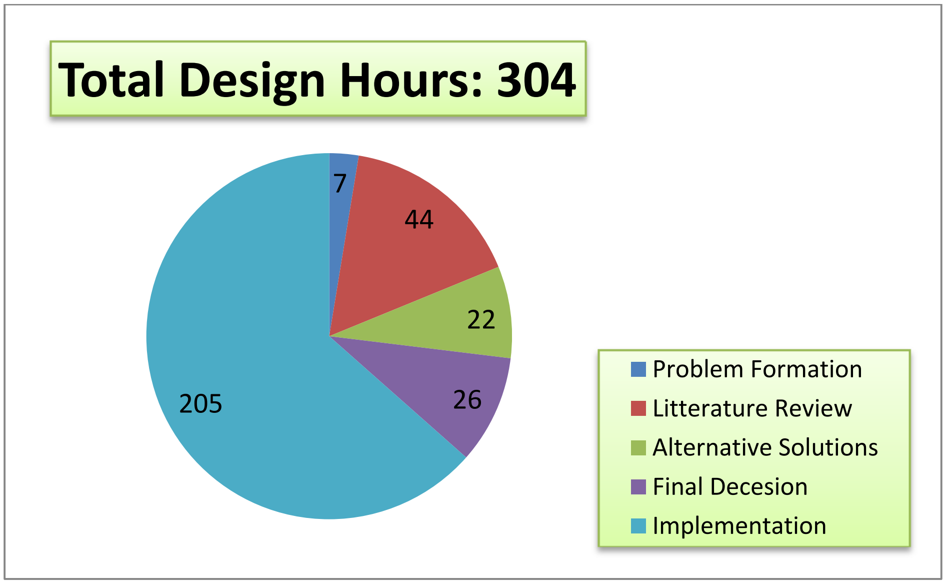
5.3 Cost Analysis

The cost analysis examines different costs to this project which are measured by the design cost, the amount of hours spent on the project, implementation cost, the retail price of project, the maintenance cost, and the cost to replace parts.

5.3.1 Design Cost

GREENtree spent 304 human-hours designing these three apparatuses. 7 human-hours were spent on the problem formation. 44 human-hours were spent in the literature review. 22 human-hours were spent on the alternative solutions. 26 human-hours were spent on the final decision. 205 human-hours were spent on the implementation. This is shown in Table 5-4.

Table 5-4: The human-hours spent on this project



5.3.2 Implementation Cost

The total cost of implementation for each component that makes up the apparatuses is evaluated. The total cost for this project would be $191.58 retail but GREENtree spent $110.01. Each apparatus is made out of durable parts that are inexpensive. The Rocket Balloon is the most inexpensive apparatus to build with a retail value of $57.65. The retail cost of the inclined planes is $32.03, and the retain cost of the Loop de Loop is $20.33. Table 5-5 shows the materials costs for all three apparatuses as well as the total cost.

Table 5-5: The total cost of the final solutions for this project.

Loop de Loop Rollercoaster			
Material	Quantity	Actual Cost	Retail Cost
Foam pipe insulation	1	$ 3.98	$ 3.98
1.25 “PVC pipe support segments	6	$ 3.56	$ 3.56
Plywood 2.5' by 1'	2	donated	$ 5.37
E6000 (Adhesive)	1	$ 7.49	$ 7.49
4ft ceder (1" x 1.25") garden stakes	3	$ 1.23	$ 1.23
Sandpaper	2	$ 1.08	$ 1.08
Wood glue	1	donated	$ 3.49
Bag of nails and hardware	1	donated	$ 1.99
Bag of marbles	1	$ 2.99	$ 2.99
Subtotal		**$ 20.33**	**$ 31.18**
Inclined Planes			
Material	Quantity	Actual Cost	Retail Cost
Pinewood 6" by 30” (planes)	2	$ 9.10	$ 9.10
Plywood 4' by 4' (platform)	1	donated	$ 16.37
Hinges	4	$ 17.98	$ 17.98
Metal slate 6" by 30”	1	donated	$ 21.98
Carpeted section 6" by 30”	1	donated	$ 5.79
Plywood stands	4	donated	$ 15.49
Bag of nails and hardware	1	$ 1.99	$ 1.99
Wood glue	1	$ 3.49	$ 3.49
Mini aluminum vent	2	$ 3.58	$ 3.58
Wooden plugs	4	$ 0.40	$ 0.40
Metal washers	2	$ 0.60	$ 0.60
Velcro®	8	$ 3.99	$ 3.99
Subtotal		**$ 32.03**	**$ 100.76**
Balloon Rocket			
Material	Quantity	Actual Cost	Retail Cost
4 ft. 1.25” PVC pipe sections	2	$ 5.49	$ 5.49
Buckets (6 gal)	2	$ 13.98	$ 13.98
1.25” PVC coupling	2	$ 2.98	$ 2.98
Eye hook	2	$ 3.98	$ 3.98
1.25” PVC plug	2	$ 2.99	$ 2.99
Spool of chalk string (50 ft)	1	$ 8.99	$ 8.99
Pack of balloons (25 Qt)	1	$ 2.97	$ 2.97
Drinking straws	1	donated	$ 1.99
Washers	4	$ 0.80	$ 0.80
Spray paint	2	$ 9.98	$ 9.98
Bag of concrete (40lbs)	1	$ 5.49	$ 5.49
Subtotal		**$ 57.65**	**$ 59.64**
Total		**$ 110.01**	**$ 191.58**

5.3.3 Maintenance Cost

Table 5-6 provides the estimated cost of maintain for all of the apparatuses and the time it might take to complete the task at hand. The Balloon Rocket will need a pack of party Balloons annually. The foam track on the Loop de Loop experiment might need to be replaced after extensive use and the user can always create more fictional cutouts for the Inclined Planes experiment.

Table 5-6: A list of maintenance costs needed to keep these experiments operational

Yearly Maintaince Cost			
Duty or Material Needed for Replacement	Quantity	Average Cost	Hours
Bag of marbles	1	$ 2.99	0
Bag of balloons	1	$ 2.97	0
Package of straws	1	$ 1.99	0
Replacement of foam track	1	$ 3.98	12
Inclinded Planes surfaces (6" by 30")	N/A	$ 15.00	0.2
Velcro®	4	$ 3.99	0
	Total	$ 30.92	12.2

5.4 Testing Results

5.4.1 Inclined Planes

The Inclined Planes prototype includes wood, aluminum metal, and carpet friction cutouts as well as Aluminum mini vents, wooden plugs, and steel washers. Different coefficients of friction were calculated using the wood, aluminum metal, and carpet friction cutouts. The angle at which an object will slide differs with the use of the different friction cutouts resulting in unique measurements of the coefficient of static friction. The aluminum metal coefficient of friction has the biggest measured value followed by the coefficients of the wood and carpet friction cutouts respectively. Objects were raced down the inclined planes in order to show the differences in friction of the wood, aluminum metal, and carpet friction cutouts, seen in Figure 5-11. As predicted by the calculations of the coefficient static friction, the aluminum metal cutout won the race due to its high coefficient of friction. The wood friction cutout came second followed by the carpet.

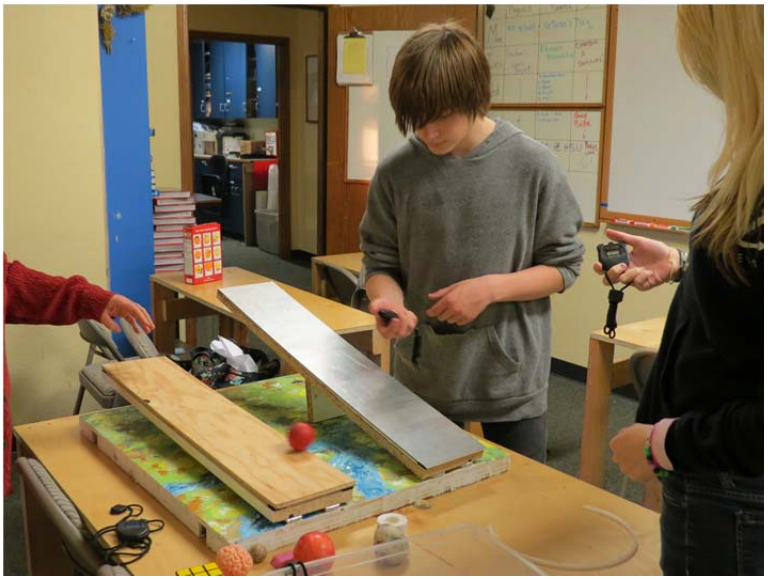


Figure 5-11: The Inclined Planes being tested. (2012, C. Alston)

5.4.2 Balloon Rocket

The Rocket Balloon prototype was functional, but very difficult to successfully use. The balloon was originally attached to the track using a curved piece of plastic tubing. After replacing the plastic tubing with a piece of drinking straw, the Rocket Balloon apparatus was much easier to operate. Beta testers found that the balloon had to be taped to the track so that the axis of the balloon is parallel to the track and that the balloon is taped near the end of the balloon, where the air comes out. The Balloon Rocket apparatus worked well in the classroom of Laurel Charter School where students were able to experiment with the apparatus as shown in Figure 5-12. Students used two different types of balloons: balloon animal balloons and party balloons. It was found that students prefer party balloons while using this apparatus.

Figure 5-12: The Balloon Rocket being tested. (2012, C. Alston)

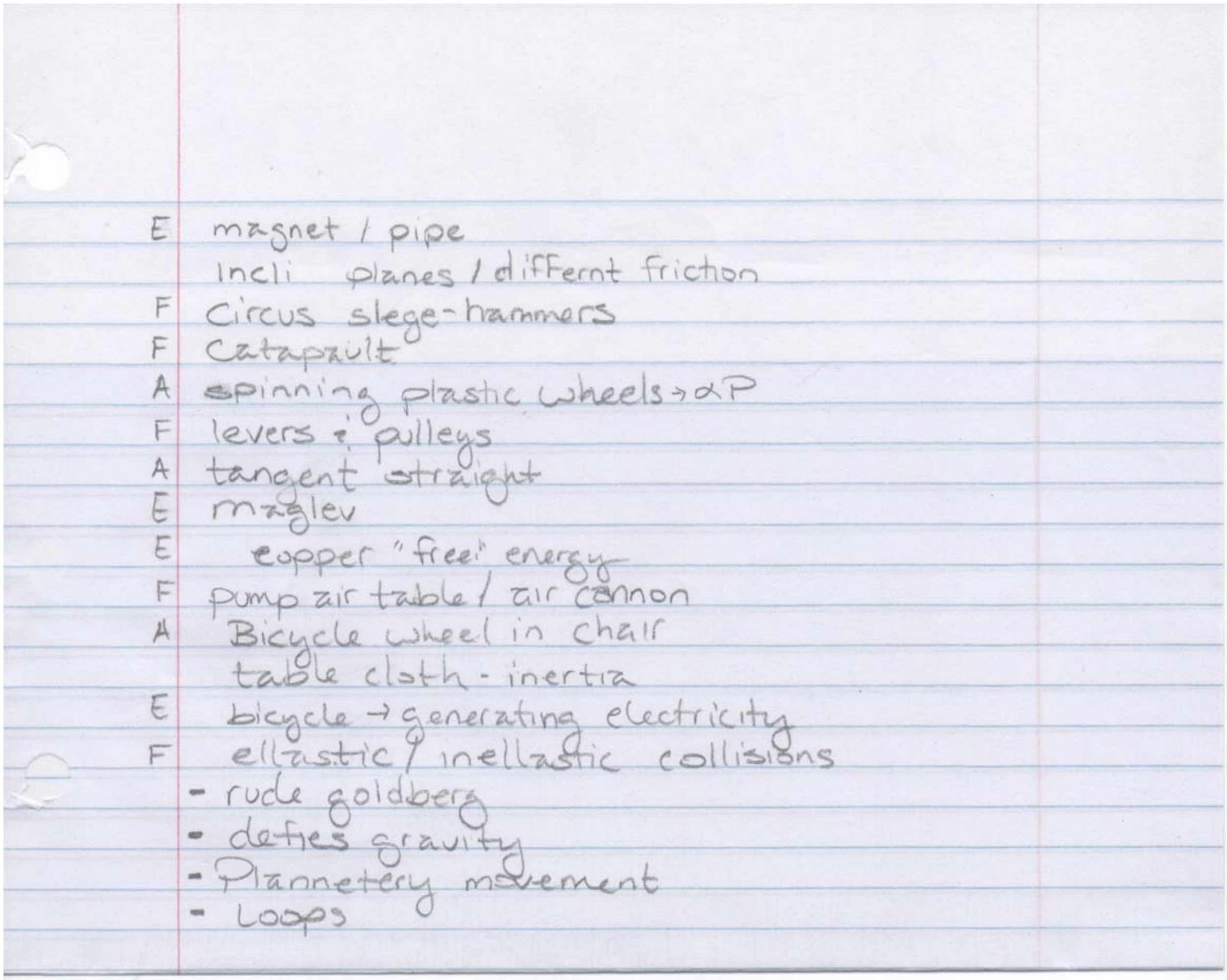
5.4.3 **Loop de Loop Rollercoaster**

The Loop de Loop Rollercoaster seems to have very little kinetic friction. Experimental results matched theoretical results within one significant digit. Engineering students said they enjoyed using the apparatus. Figure 5-13 shows the marble making it around the loop de loop.

Figure 5-13: The Loop de Loop being used. (2012, C. Alston)

Appendices

A. Brainstorming Documentation



E magnet / pipe
Incli planes / differnt friction
F Circus slege-hammers
F Catapault
A spinning plastic wheels → αP
F levers & pulleys
A tangent straight
E maglev
E copper "free" energy
F pump air table / air cannon
A Bicycle wheel in chair
table cloth - inertia
E bicycle → generating electricity
F ellastic / inellastic collisions
- rude goldberg
- defies gravity
- Plannetery movement
- Loops

Figure A-0-1 Brainstorming session ideas

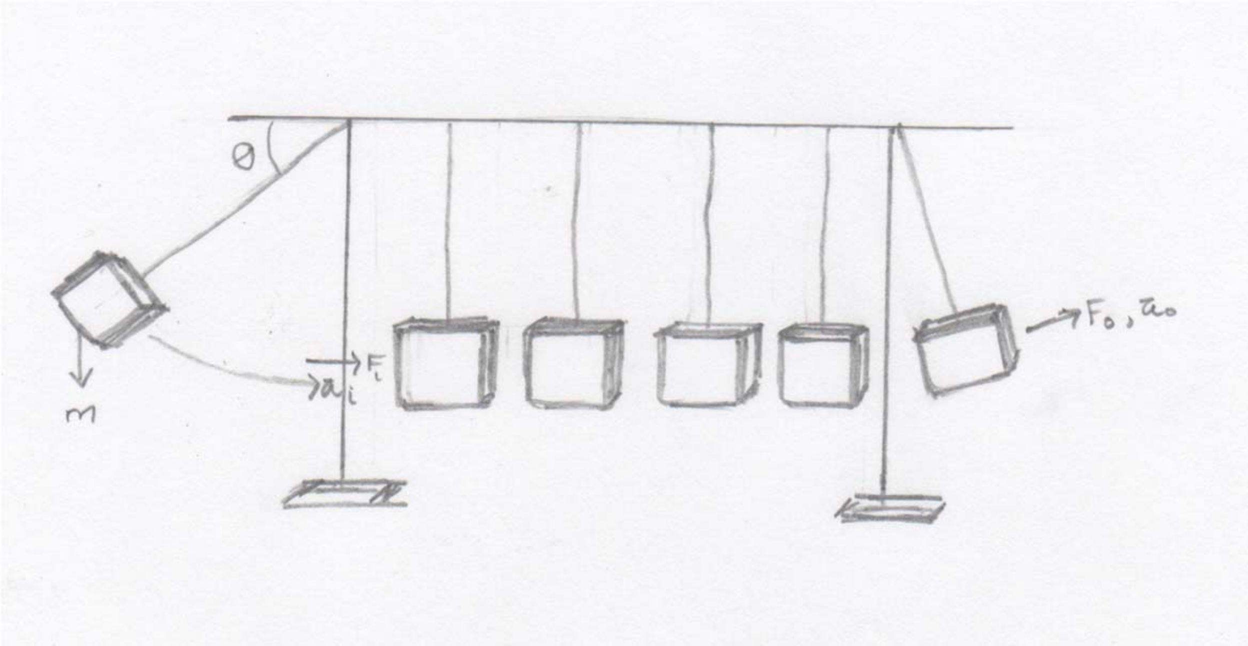


Figure A-0-2: Pendulum brainstorm

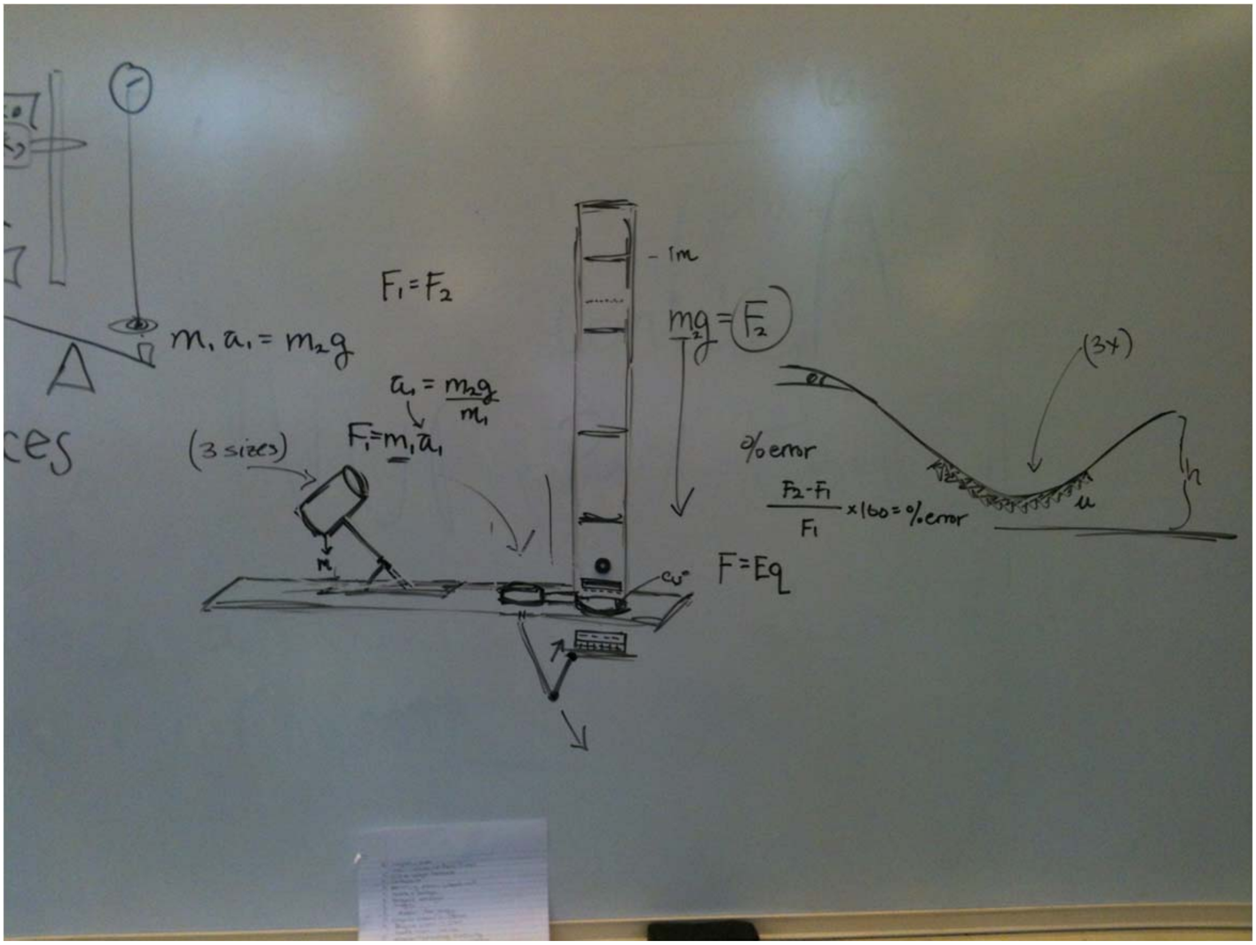


Figure A-0-3: Solutions to ideas from brainstorming

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