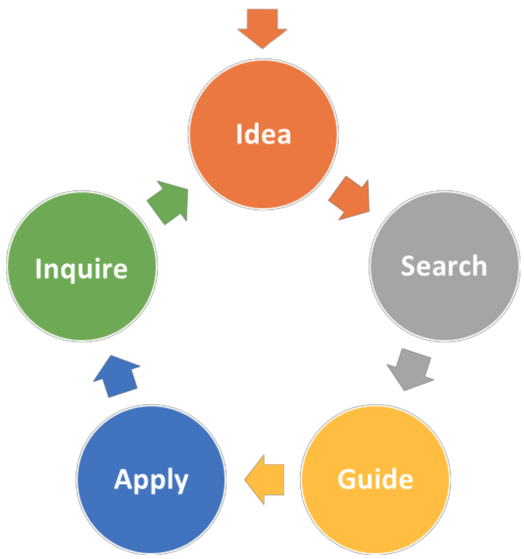
Conceptual Physics
Beyond the Laboratory Manual

A Cyclic Guided Inquiry Approach Using Everyday Materials



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Introduction

MISSION STATEMENT

Thank you for your interest in this “Beyond the Laboratory Manual”. With this manual you are stepping outside the traditional academic laboratory with the understanding that the world itself is one big playground. Within this natural environment, and with a bit of innovation, we can learn about the rules of nature using everyday household materials. You will find this to be an enjoyable adventure. But as with any adventure, there will be challenges. However, you will find these challenges to be well-placed. In tackling these challenges, you will be rewarded with a deeper understanding of how things work. Ultimately, this adventure will nurture your innate love-of-learning while also helping you to grow as an individual.

This adventure path is full of mechanical skills you will need to master. These include:
• Following reporting procedures used by scientists. This includes writing in the third person with an academic author voice.
• Being able to identify independent, dependent, and controlled variables.
• Writing appropriate If/Then hypotheses that may include mathematical relationships.
• Articulating how each activity relates to daily living and is connected to the concepts presented in the textbook. You should be able to do this in both verbal and written forms.
• Creating data tables and graphs, as well as using your cell phone to import images and other media into a text document.
• Formulating a conclusion to each investigation and suggesting ways to create similar experiments with different variables.

By following this manual you will
• Use “every-day” items, kitchen supplies, office supplies, and toys readily available through local stores. You will see the marriage between mathematics and the physics concepts of your daily life.
• See that physics is all around us, impossible to avoid but also easy to enjoy. It is not just something that happens within the confines of a classroom.
• Be engaged by simple but effective “hands on activities” many of which you will be building from scratch.

Students these days seem to be infatuated with “cell phones and selfies”, so there is plenty of opportunity for students to learn to use their personal devices as learning tools and not just communication devices. Background information can be looked up, graphs made, photographs imported and reports written all with the use of a cell phone if one chose to do so with these investigations..

ACKNOWLEDGEMENTS

Brooklynn Engel, Jonah Blake, Jacob Blake, Donald Bolick, Margaret Bolick, Meghan Sweckard, Kevin Sweckard, Jennifer Snyder, Michelle Wytik, Mike Brown, Tom Tomasi, Georgianna Saunders, Janice Greene, David Johnston, Pam Hankins, Pam Hedgpeth, Jason Michel, Sheila Wynn, Pat Quick, Alma Pettinger, Kathy McGrane, Kathy Gross, Jay Miller, Becky Baker, Bryan Breyfogle, David Cornelison, David Andereck, Charlie Armstrong, Denise Vinton, Rich Vinton, Miriam Watson, Chance Wistrom, Judy Brunner, Tiffany Caywood Brunner, Cindy Wilson, Jennifer Reneger, Annie Wallenmeyer, Paul Durham, Jared Durden, Morgan Presley, Amelia Horras, Allen Reed, Cheryl Hall, Myra Dickensheet, Cheryl Brown, Dennis Page, Sharon Page, Denise Fredrick, Justin Herrell, Melissa Hoffmeister, John Thompson, Gloria Gammel, Michael House, David Miller, Stephanie Jacobs, Kathy Hodge, Loren Vigil, Rachel Kenning, Ryan Savage, Jourdain Johns, Darlena Jones, Ryan Lackson, Justine Lines, Charlie Mace, Melissa Mace, Melissa McCandless, Lori Naramore, Layla Piland, Rob Powers, Colby Fronterhouse, Jennifer Rector, Natalie Rector, Nathan Rector, Dale Rector, Melissa Thompson, Rhett Robberson, Rob Speer, Chris Stein, Byron Strohm, John Mansfield, Daniel Molloy, Corey Robinson, Tia Caesar, Charla Hampton, Tyler Tahtinen, Josh Vanhorn, Jacob Smith, Kelly McHenry, Victoria Frizell, Kiara Buck, Crystal Stine, Dana Sherman, John Fishback, Clint Nurnberg, David Stone, Sandy Pierce, G'Raavi Junkere, every presenter at the National Science Teacher Association Conventions, and every student who ever sat through a physics class.

DEDICATION

This manual is dedicated to every young person on the planet. May you never stop asking "why?" and to my favorite inquisitor of all time, Jonah Blake. You inspire me daily.

ABOUT THE AUTHOR

Stephanie A. Blake taught Physics, Anatomy and Physiology, and Chemistry in an urban high school in the Midwest for fourteen years, with twelve of those teaching dual enrollment Physics for Missouri State University, and six of them as a science department head before moving to Ozarks Technical Community College, in Springfield, Missouri as a science instructor full time in 2014. Her original undergraduate degree was a major in Biology with a minor in chemistry and a minor in physics. She obtained teaching certificates in all four content areas of middle school and high school science (Biology, Chemistry, Physics, and Earth Science) as well as in Mathematics. However, once in the classroom she quickly fell in love with the teaching of physics in particular. She went on to obtain Advanced Placement Certification in Algebra Based Newtonian Mechanics, Algebra Based Electricity and Magnetism, Calculus Based Newtonian Mechanics, and Calculus Based Electricity and Magnetism. She also obtained National Board Certification in Physics. In addition to multiple Master's Degrees in the science content areas, she also has a Master's Degree in Educational Administration and a Specialists Degree in Leadership. As a result, she is also a certified secondary principal and superintendent. Her awards include two time Teacher of the Year Finalist for Springfield Public Schools, USA Today National Teacher of the Year Honorable Mention and Site Team Teacher of the Year for Parkview High School. She has presented at several National and Regional Conventions (including the National Science Teachers Association) on the topics of Elementary Physics Laboratory Exercises, Presentation of Bioethics in the Classroom, and Classroom Walkthroughs as a Professional Development Tool. Ms. Blake has served on Science Safety Committees, Curriculum Adoption Committees, Professional Development Committees and Accreditation Committees at the Site, District and State Level.

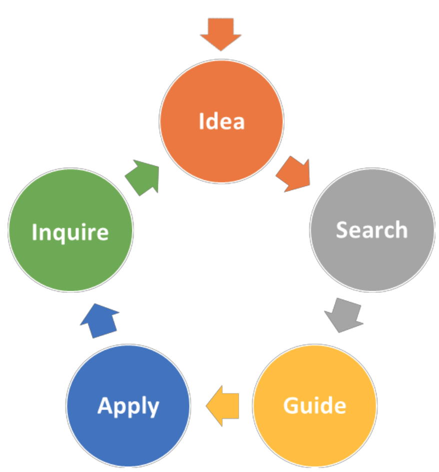
CYCLIC GUIDED INQUIRY

"Free inquiry" is a method of learning where the students are provided no direction—they are free to make discoveries on their own. But should we expect every student to derive Newton's law of universal gravitation on their own? Of course not. The frontiers of science have accelerated forward over the past couple centuries primarily because scientists have learned to work together and to make use of what is already known. Science is very much a community endeavor.

Opposite from free inquiry is that traditional cookbook experiment. Add "A" to "B" and sure enough you'll get "C". Just do it and you'll see it's true. The advantage here is that there's a strong guarantee for "success". However, if the experiment fails then that means you did something wrong, not that something was wrong with the experiment. This is hardly in the spirit of exploration.

In the middle ground between these two extremes is what we call "guided inquiry". This is where just enough information is given to the student to provide the excitement of free inquiry while also keeping the student on track so that learning is efficient. This manual covers this full spectrum, moving from full free inquiry to cookbook as appropriate, but with an overall emphasis on the middle ground of guided inquiry.

Further, this guided inquiry is presented in a "cyclic" approach. Each experiment begins with the student researching a specific **idea** as presented in the accompanying Conceptual Physics textbook and also through online resources. After summarizing the main ideas of this **search** in writing or aloud, the student is then **guided** through a hands-on activity in which the physics is explored. To show the **application** of this physics, the student draws or downloads an image, which is also described in writing or aloud. To complete the cycle, the student takes the next and most creative step of devising a related experiment in the spirit of an approach closer to free **inquiry**.



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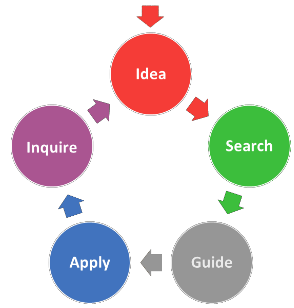
Introductory Information

MATERIALS LIST

You will be performing investigations that have been created using household items. You will need to purchase the following supplies for your labs in this course. I have tried to require items that can all be purchased at Walmart, for one stop lab shopping. My hope is that you will already have many of these items around your home.

1) 1 small can of play dough or clay
2) 1 small skein of yarn or string
3) 1 ruler with centimeters
4) 1 box of jumbo paperclips
5) 20 popsicle sticks
6) 1 roll of masking tape
7) 1 rubber balloons
8) 1 small box of drinking straws
9) 1 plastic spoon or soda bottle top
10) 1 roll of aluminum foil
11) 1 protractor
12) scissors
13) 1 roll of paper towels
14) 1/2 bag of sugar
15) 1/2 bag of flour
16) container of salt
17) 1 roll of transparent tape
18) 1 2-Liter bottle of soda
19) 4 coffee stirrers
20) 100 pennies
21) 1 small bag of rubber bands
22) 10 different spheres (e.g. baseball, golf ball, basketball, bouncy ball, whiffle ball, etc.);
23) 1 small bag of marbles
24) 1 large bottle of rubbing alcohol
25) 1 set of dice (or computer simulation)
26) 1 pair of polarized sunglasses
27) 1 bottle of agave syrup
28) 1 bottle of maple syrup
29) 1 box of jumbo washers
30) 1 large safety pin
31) 2 small magnets
32) 1 AA battery
33) 1 30 cm stretch of insulated stereo wire
34) 2 wine glasses
35) 1 pair of pliers
36) 1 pair of safety goggles

LAB REPORT HELPFUL HINTS



EXPERIMENT

IDEA

CHAPTER:

Purpose:

SEARCH

Background Information/Literature Review: Fill in the appropriate information from the textbook or online sources that applies to this investigation. Make sure to cite the sources using proper formatting. Include more than just definitions. For this experiment the following concepts could be considered for inclusion:

Because of the technological world we live in, students can find information in an instant at their fingertips. It is important for students to learn to discern between primary sources and secondary sources, peer reviewed articles and non-peer reviewed articles, journal articles and magazine articles, reliable sources and unreliable sources, fact and opinion. In so doing, it will be important for students to being to learn to cite their sources, including photographs in this section. This helps students analyze the reliability and validity of the information they are processing from their textbook, library or online sources. In this section students should feel free to include pictures, diagrams, equations, concepts, and links, not just definitions of vocabulary words. Like a scientific literature review, students should take the information and put it into their own language, not just copy and paste.

Background Information / Literature Review / Pictures / Equations (continued):

Like a scientific literature review, students should take the information and put it into their own language, not just copy and paste. If students have the opportunity to share background information with other participants and add to their writing that is even better. After all, science is about sharing results and ideas and adding to the body of knowledge through an infinite testing, learning and reporting cycle.

Citations (including pictures):

While the style of citations (bibliography) information does not need to be mandated (i.e. APA versus MLA), it is important for students to include more than just a url address as a form of citing This helps students to examine the potential validity of the source, including Wikipedia, textbooks, internet information, diagrams, and pictures.

GUIDE

Hypothesis:

Materials:

Procedure:

Picture/Labelled Diagram: Insert pictures of yourself performing the experiment.

Students love taking selfies and capturing their experiment performance is no exception. However, to take it to the next level, be sure to have the student give the picture an appropriate title and caption as well as copyright notations, just like a real scientific journal article.

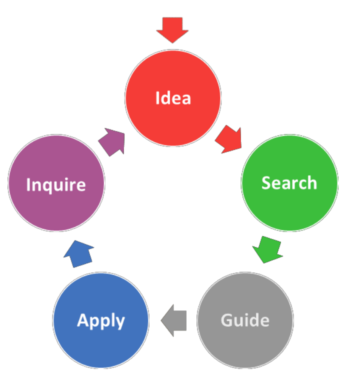
Data Table: **Be sure to include a title (including units), and headings (including units). It is customary for the independent variable (x-axis on the graph) to go on the left and the dependent variable (y-axis on the graph) to go on the right. Be sure to include units here as well. Students need to take measurements that are as precise as possible, carrying out as many digits after the decimal as their measuring device will allow. You will need to decide if you want to use the rules of significant digits when performing calculations.**

1	
2	
3	
4	
5	

Data Analysis: What kind of mathematical relationship appears to exist between the sphere's mass and time to complete the track?

In this section students will need to discern what kind of graph appears to be present (i.e. linear, parabolic, exponential, inverse, etc.) You might also consider expressing the equation of the line or curve as well as the slope (and its proper units) if applicable. Explain the importance of this relationship between the two variables. This is also the section where students should show their work if any calculations are necessary to complete the data table.

Graph: Make a line graph of relative sphere mass versus time to complete track. You may substitute a computer made graph using Microsoft Excel or some other software if you prefer. **You should know that the best graph has a title, makes use of almost all the available space, and the X and Y axes are properly labeled with units. Be sure to make a curve or line of BEST FIT, do not simply connect the data points like a constellation.**

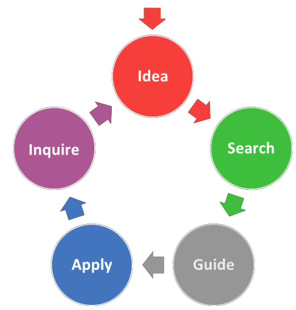


Conclusion: Use the following questions as a guide to write a conclusion. Use formal academic language, which means sticking to third person pronouns whenever possible.

• What was the independent variable?
• What was the dependent variable?
• What were the controlled variables?
• Did you achieve your purpose?
• What was the relationship between variables?
• How accurate was your hypothesis?
• Why was the hypothesis correct/incorrect?
• What events in the experiment were expected?
• What events in the experiment were not expected?
• What human error occurred (i.e. measurement errors, significant digit errors, mathematics errors, etc.)?
• What equipment error occurred (i.e. friction, air resistance, improper calibration, broken equipment, etc.)?
• How could the lab be improved?
• How could this lab apply to physics in the real world?
• What similar experiment could be done next to further study this phenomenon?

The above questions are suggestions, some more appropiate than others for a particular experiment. Not all of them need to be answered. Further, do not simply answer the questions outlined above, but rather turn an answer into paragraph form and practice using proper academic third person language.

EXAMPLE LAB REPORT



EXPERIMENT 1

IDEA

ROLLING BOULDERS

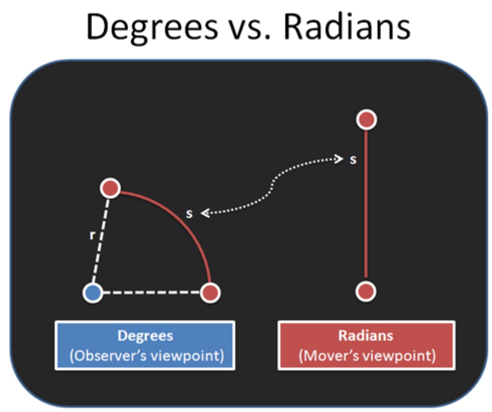
CHAPTER 2: INERTIA

Purpose: To determine how the mass of several different spheres affects the inertia of the objects (or relative maneuverability) while the object is being manipulated around a track on a flat surface.

SEARCH

Background Information/Literature Review: Fill in the appropriate information from the textbook or online sources that applies to this investigation. Make sure to cite the sources. For this experiment the following concepts could be considered for inclusion: rotational motion, radian, angular displacement, angular speed, angular acceleration, tangential speed, tangential acceleration, centripetal acceleration, gravitational force, etc.

Rotational motion is the rotation of a body about its center mass. Such as when a dancer is performing, her body is the center of mass and her appendages are her rotational motion.



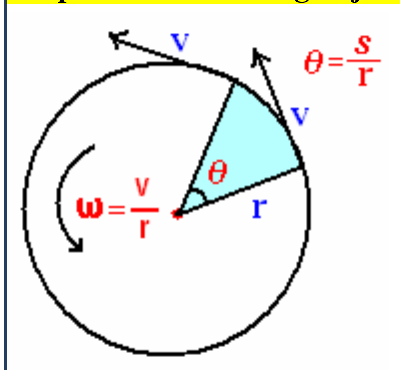
Radian is a unit of angle, equal to an angle at the center of a circle whose arc is equal in length to the radius. To the right is an example as to how degrees translates into radians.

$$Radian = \frac{distance \quad traveled}{radius}$$

$$\theta = \frac{s}{r}$$

The angular displacement is defined as the angle through which an object moves on a circular path. It is the angle, in radians, between the initial and final positions. (θf - θi) = angular displacement. θ = s/r.

Displacement also shows the covered distance but it shows the complete change in the position of moving objects.



For θ angle and the radius of curved path is r. The linear displacement is related to the angular displacement.

Angular Speed, is the rate at which an object changes its angle (measured) in radians, in a given time period. Angular speed has a magnitude (a value) only. Angular speed = (final angle) - (initial angle) / time = change in position/time. ω = θ /t. ω = angular speed in radians/sec.

An object travels a distance of 35 ft in 2.7 seconds as it moves along a circle of radius 2 ft. Find its linear and angular speed over that time period.

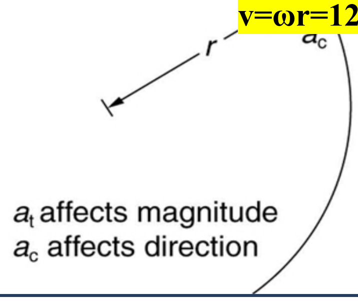
Solution: Here we have t = 2.7 sec, r = 2 ft.,

And s = 35 ft. So the linear speed v is

v=s/t = 35feet/2.7sec ⇒ ***12.96ft/sec***,

And thus the angular speed ω is given by

v=ωr=12.96ft/sec = ω(2ft) ⇒ ***ω=6.48rad/sec***



Angular acceleration, also called rotational acceleration, is a quantitative expression of the change in angular velocity that a spinning object undergoes per unit time. It is a vector quantity, consisting of a magnitude component and either of

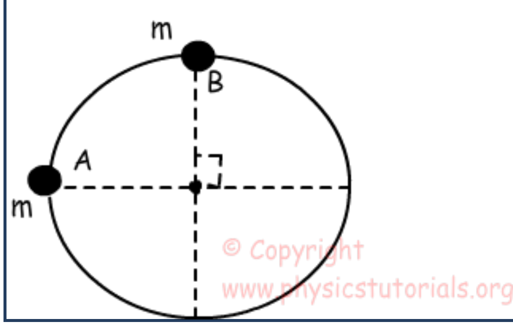
two defined directions or senses. The magnitude, or length, of the angular acceleration vector is directly proportional to the rate of change of angular velocity, and is measured in [radian]s per second squared. The angular acceleration magnitude can be expressed in degrees per second squared (deg/s^2 or deg · s^{-2}). The direction of the angular acceleration vector is perpendicular to the plane in which the rotation takes place. If the increase in angular velocity appears clockwise with respect to an observer, then the angular acceleration vector points away from the observer. If the increase in angular velocity appears counterclockwise, then the angular acceleration vector points toward the observer.

Linear speed and tangential speed gives the same meaning for circular motion. In one dimension motion we define speed as the distance taken in a unit of time. In this case we use again same definition. However, in this case the direction of motion is always tangent to the path of the object. Thus, it can also be called as tangential speed, distance taken in a given time. Look at the given picture and try to sequence the velocities of the points larger to smaller.

Period: Time passing for one revolution is called *period*. The unit of period is second. T is the representation of period.

Frequency: Number of revolutions per one second. The unit of frequency is 1/second. We show frequency with letter f.
The relation of f and T is: f=1/T

Tangential speed of the object is linearly proportional to the distance from the center. Increase in the distance results in the increase in the amount of speed. As we move to the center speed decreases, and at the center speed becomes zero. We use the same unit for tangential speed as linear motion which is "m/s".
Example A particle having mass m travels from point A to B in a circular path having radius R in 4 seconds. Find the period of this particle.



Particle travels one fourth of the circle in 4 seconds. Period is the time necessary for one revolution. So,
T/4=4s
T=16s.

Citations:

"SAT Prep: Physics." *SparkNotes*. SparkNotes, Retrieved 22 May 2017.
Azad, Kalid. "Intuitive Guide to Angles, Degrees and Radians." *BetterExplained*. Retrieved 22 May 2017. -**Includes 1st image**
"Angular Displacement Formula." *Math*. Retrieved 22 May 2017. "Angular Displacement." *Angular Displacement, Angular Displacement Formula | Physics@TutorVista.com*. Retrieved 22 May 2017. -**2nd image**
"Angular Speed Formula." *Math*. Retrieved 22 May 2017.
"Circular Motion: Linear and Angular Speed." *Circular Motion: Linear and Angular Speed*. Retreived. 22 May 2017.
"What Is Angular Acceleration (rotational Acceleration)? - Definition from WhatIs.com."*WhatIs.com*. Retrieved 22 May 2017. - **3rd image**
Administrator. "Tangential Speed/Velocity." *Introduction*. Retrieved 22 May 2017.

GUIDE

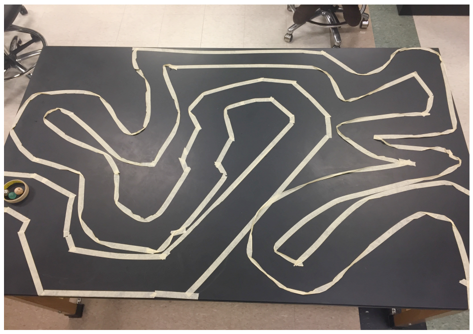
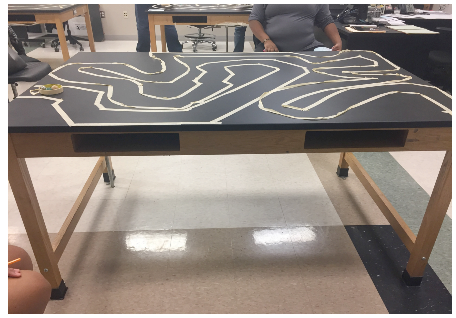
Hypothesis: If the relative mass of each sphere increases, then the time it takes to maneuver the ball around a flat track will decrease (increase, decrease, or stay the same)

Materials: Five different spheres (i.e. marble, basketball, golf ball, tennis ball); masking tape; two writing utensils (pens or pencils); stop watch (cell phone, tablet, computer, etc.)

Procedure:

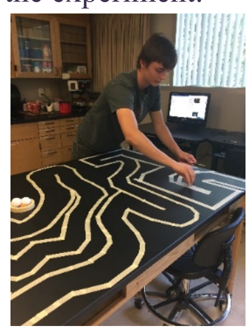
1) Using your masking tape, create a race track on a flat surface (like a table, counter top, or sidewalk). The race track should be approximately six inches across and should have as many curves and twists as possible. Use the masking tape to create the "edges" of the race track. Your race track should be approximately 10 feet long. Make a starting line and a finish line.
2) Find five different spheres of different sizes. Using your hand to "feel" the relative weight, line the spheres up from lightest to heaviest.
3) Put the lightest sphere at the start line. Prepare your timing device nearby. After you press "start" on your timing device, you will move the sphere through your maze by only TAPPING it with the two pencils (or pens), one in each hand. You must also ALTERNATE tapping the sphere with the right hand pencil, then the left hand pencil, then the right, and so on and so forth until the sphere has crossed the finish line.
4) If the sphere goes over one of the tape lines, you must start back over at the "start" line and try again. Record the time it takes for you to maneuver the sphere from start to finish.

5) Repeat the procedure with the next heaviest sphere and record the time. Continue until times have been taken for all five spheres.
6) Create a bar graph with your spheres in order of mass on the x-axis and time to complete the track on the y-axis.

Picture/Labelled Diagram: Insert pictures of yourself performing the experiment.

Left Picture: Student preparing track with tape on table. Right Picture: Student performing experiment on track with sphere.



Data Table: Sphere Complete Track Data from Class

Type versus Time to (seconds) Real Sample

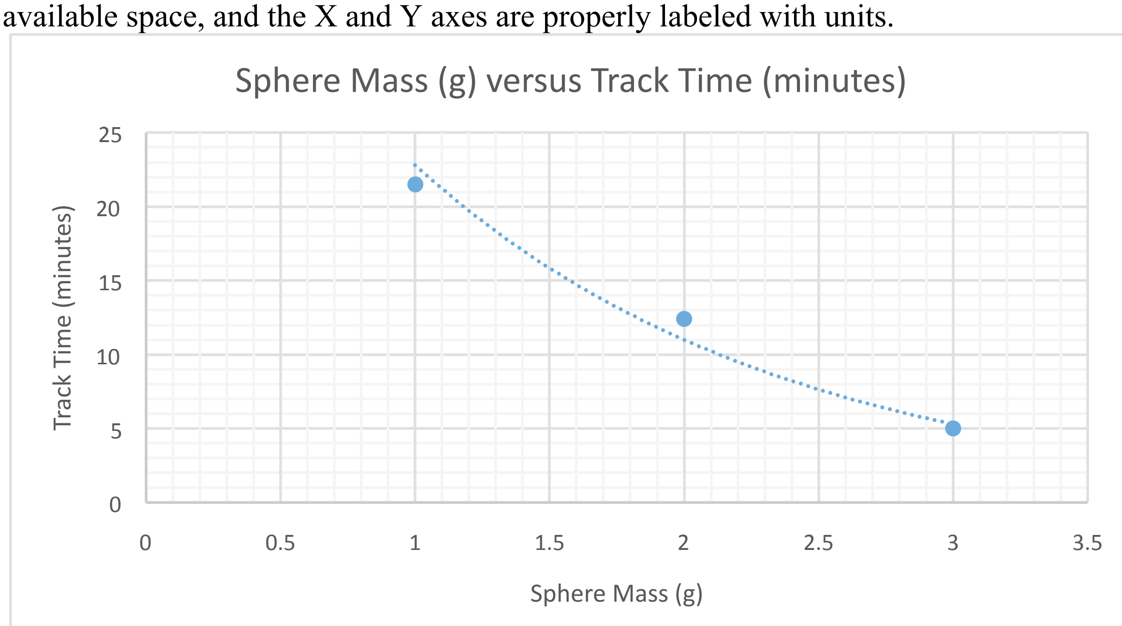
Sphere Description	**Time to Complete Track (min)**
2.203g (white, smooth, almost transparent)	6.21
3.443g (white, divots in the surface)	1.06

3.608g (orange and black mini plastic soccer ball)	1.44
7.421g (orange rubber ball)	.38

Data Analysis: What kind of mathematical relationship appears to exist between the sphere's mass and time to complete the track? Using the concepts such as inertia, momentum, force, acceleration, energy, and Newton's Laws, explain why one sphere was more difficult to control than another (speed up, slow down, and change directions).

The lighter the ball was the longer it took to complete the track, the inertia acting on the ball made it harder to control the ball. With less mass the same amount of force created significantly more acceleration and making it nearly impossible to keep control of the lighter spheres. The larger the sphere, the higher the inertia and the same amount of force exerted from the wrist created much less acceleration making the sphere easier to control. This is supported by the mathematics of Newton's Second Law: F = ma as well as Newton's First Law: the objects stayed in motion because forces were acting on them. It was challenging to control the minute forces applied by

Graph: Make a line graph of sphere mass versus time to complete track. You may substitute a computer made graph using Microsoft Excel or some other software if you prefer. You should know that the best graph has a title, makes use of almost all the available space, and the X and Y axes are properly labeled with units.



Conclusion: Use the following questions as a guide to write a conclusion. Use formal academic language, which means sticking to third person pronouns whenever possible.

• What was the independent variable?
• What was the dependent variable?
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• Did you achieve your purpose?
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• What human error occurred (i.e. measurement errors, significant digit errors, mathematics errors, etc.)?
• What equipment error occurred (i.e. friction, air resistance, improper calibration, broken equipment, etc.)?
• How could the lab be improved?
• How could this lab apply to physics in the real world?
• What similar experiment could be done next to further study this phenomenon?

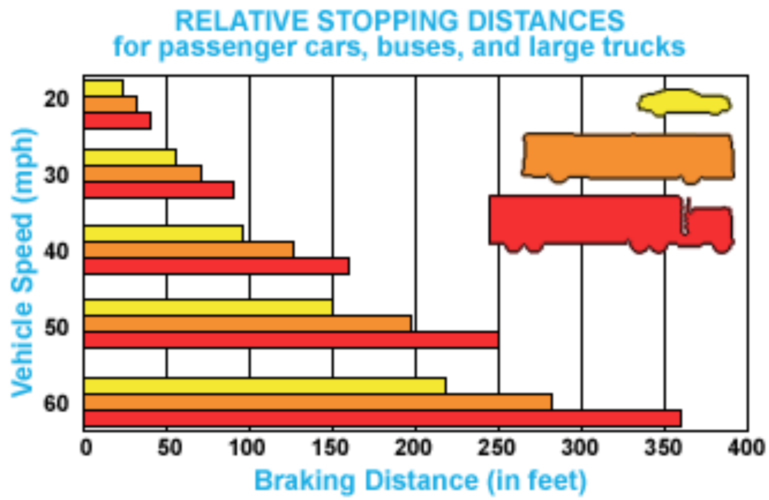
In this experiment, the independent variable was the relative ball mass (inertia), the dependent variable was the amount of time required to complete the track. The controlled variables were that the same person completed the exercise with each sphere and each sphere was used on the same track with every trial. The purpose of studying the effects of force on increasing mass (with respect to inertia) was achieved. According to this set of data, the relationship between increasing mass and time to complete the course appears to be an inverse parabolic relationship, therefore the hypothesis was correct.

Going into the experiment the researcher was not expecting to have such a lack of control over the balls along the track, though it was expected that the task would be challenging. Certainly human errors occurred, since the experiment was based solely on human interaction. It is quite possible that experimental error also occurred in that each of the spheres exhibited different textures and therefore could have had different coefficient of friction values with the table, interfering with the mass only relationship being tested. Therefore, this lab could be improved by finding a way to use the same material of sphere with varying masses.

This lab is directly related to the real world for civil engineers who are charged with setting speed limits down roads, on off ramps and across bridges while accounting for variation in mass and inertia between semi-trucks and smaller personal vehicles. A similar experiment

APPLY

Application – The Physics of Daily Life: Show the real-world application of concepts explored in this experiment through a photo or drawing. Then explain this application in your own words. Consider hauling a pop-up camper. Should it be stuffed heavy?



The more mass the object seems to have the more difficult it is for the vehicle to stop especially at higher

INQUIRE

Your Turn — Inquiry Challenge: Use what you learned from the first round of this experiment to create and perform a related experiment of your own design. For example, what if the table were tilted? Does it matter if all the balls are not of the same circumference?

Title: Sphere Mass versus Rolling Distance

Purpose: To determine how sphere mass effects the distance an object requires to come to a complete stop.

Hypothesis: If the mass of a rolling object is increased, then the stopping distance will decrease in an inverse relationship.

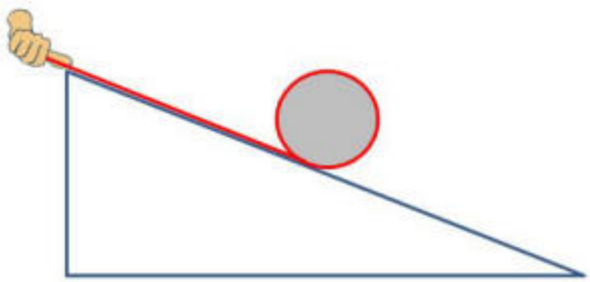
Materials List: List all chemicals, equipment, and supplies you will need.

Bowling ball, soccer ball, basketball, piece of plywood, measuring tape

Procedure: These are the STEP-BY-STEP instructions for your inquiry lab investigation.

1. Angle a piece of plywood by propping it up to make a ramp. Position the ramp in an open flat area such as an unoccupied driveway or parking lot. Keep the ramp at the same angle for all of the trials.
2. Release the bowling ball from rest at the top of the plywood and measure the distance required until the bowling ball comes to a complete stop using the meter tape.
3. Repeat this several times and average the stopping distance.
4. Repeat steps 2 and 3 for the soccer ball and basketball.

Picture/Labelled Diagram: Insert pictures of yourself conducting the experiment into this lab report



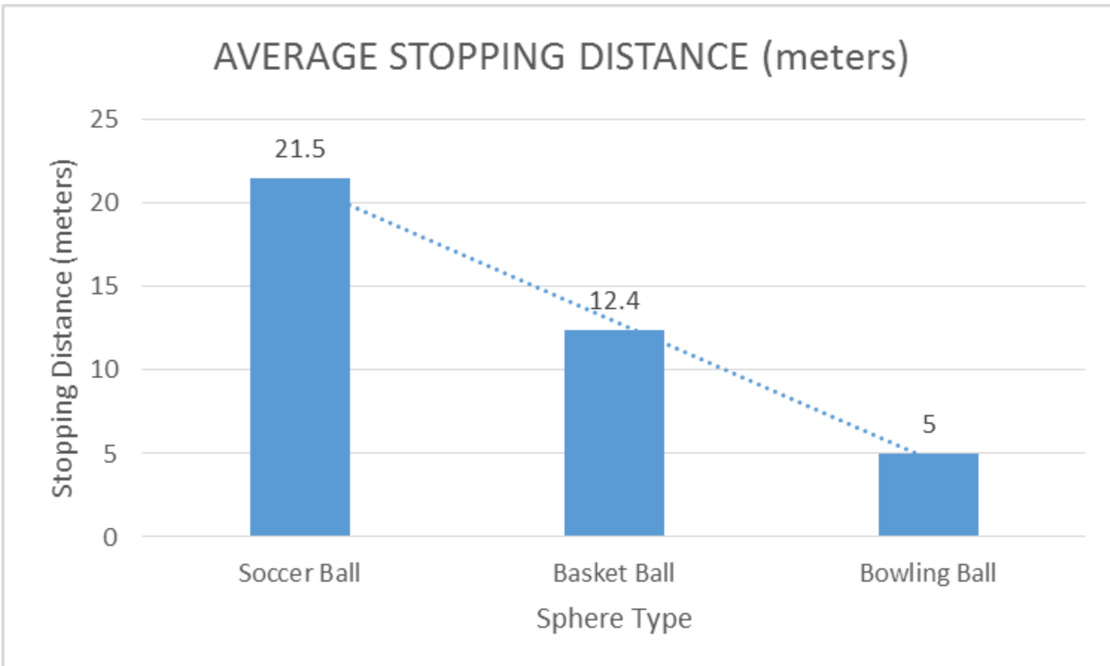
Sphere rolling down ramp.

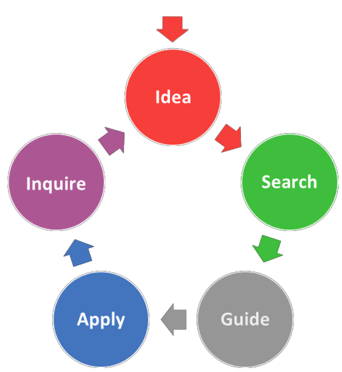
Data Table: Insert your data table here.

Data Table: Sphere Type versus Average Stopping Distance

SPHERE TYPE	TRIAL 1	TRIAL 2	TRIAL 3	TRIAL 4	TRIAL 5	AVERAGE STOPPING DISTANCE
Bowling Ball	5.2 meters	4.8 meters	5.3 meters	4.7 meters	5.0 meters	5.0 meters
Basket Ball	12.7 meters	12.0 meters	12.3 meters	12.4 meters	12.5 meters	12.4 meters
Soccer Ball	20.4 meters	22.5 meters	19.7 meters	21.0 meters	23.7 meters	21.5 meters

Graph: Make a graph of the information found in your data table. If appropriate, make a line or curve of best fit, do NOT connect the dots. Be sure to make use of practially all of the available space within the graph and to title the graph while showing units for the X and Y axes.





Data Analysis: Perform any necessary calculations here.

Bowling Ball

(5.2 + 4.8 + 5.3 + 4.7 + 5.0) /5 = 5.0 meters

Basket Ball

(12.7 + 12.0 + 12.3 + 12.4 + 12/5)/5 = 12.4 meters

Soccer Ball

(20.4 + 22.5 + 19.7 + 21.0 + 23.7)/5 = 21.5 meters

Conclusion: Use the following questions as a guide to write a conclusion. Use formal academic language, which means sticking to third person pronouns whenever possible.

- What was the independent variable?
- What was the dependent variable?
- What were the controlled variables?
- Did you achieve your purpose?
- What was the relationship between variables?
- How accurate was your hypothesis?
- Why was the hypothesis correct/incorrect?
- What events in the experiment were expected?
- What events in the experiment were not expected?
- What human error occurred (i.e. measurement errors, significant digit errors, mathematics errors, etc.)?
- What equipment error occurred (i.e. friction, air resistance, improper calibration, broken equipment, etc.)?
- How could the lab be improved?
- How could this lab apply to physics in the real world?
- What experiments should be conducted to further study this phenomenon?

In this experiment the independent variable was the relative mass of the object and the dependent variable was the stopping distance. The controlled variables were: the angle of the ramp, the surface texture of the asphalt and the approximate diameters of the spheres. The purpose of determining the effect of sphere mass on stopping distance was achieved and indicated the hypothesis was accurate because the graph indicated a potential inverse relationship between the two variables. It was not expected that the soccer ball would travel so far nor that so many trials would have to be done because of the spheres curving off track. In the end the distance traveled had to be approximated with string to account for the curvature of the path of the balls. The measuring tape was capable of measuring two digits after the decimal, but it was difficult to determine where to take the measurement on the balls so only one digit was recorded in the data table. The lab could be improved by using some sort of trough to make the objects go in a straight line. Again, this experiment applies to moving vehicles and their ability to stop in emergency situations. To further study this phenomenon it would be super fun to use real cars on a race track and perform initial velocity versus stopping distance experiments with personal vehicles of various masses.