CHALLENGES IN PHYSICAL SCIENCE®

Gravity Wheel

Teacher's Guide

A Supplemental Curriculum for Middle School Physical Science

From Project DESIGNS:
Doable Engineering Science
Investigations Geared for Non-science Students

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Sponsored by the
Harvard-Smithsonian Center for Astrophysics
with funding from the
National Science Foundation and
additional support from the
Smithsonian Institution

KENDALL/HUNT PUBLISHING COMPANY
4050 Westmark Drive Dubuque, Iowa 52002

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ISBN 0-7872-6460-1

This material is based upon work supported by the National Science Foundation under Grant No. ESI-9452767. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

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To the Teacher

"Wow, it works! I can't believe it works!" Expressions of stunned astonishment at the accomplishment of building a working electric motor draw fellow classmates to this minute mechanical marvel. Wobbling and anemic, the motor struggles, straining to make each turn. Assembled from nails and wire, this was the first working device that this middle-schooler had ever built. Soon her classmates followed with their own successes. Over the next few weeks, their motors improved through students' innovations, discovering along the way: imbalance and balance, friction and lubrication, short circuits and insulation, and how to strengthen invisible magnetic fields. Students competed and cooperated, dissected motors from toys and shared their findings. Science was slowly mastered and skills strengthened. Journals filled with data and drawings. Soon motors whirred at 6,000 rpm and beyond, matching the performance of those in their tape recorders and toy cars. The progression of the class—from first copying a poorly performing prototype through successive improvements that revealed the underlying science—marked the birth of the DESIGNS (Doable Engineering Science Investigations Geared for Non-science Students) philosophy in my classroom twenty years ago. Building and improving devices formed the core of a technology and science course for youngsters who were still learning about their own interests and abilities.

Inspired by the MIT undergraduate engineering competitions, challenges that are suitable to teach the elements of science and technology at the middle school level are not easy to find. Most students are unfamiliar with even the simplest of hand tools. The innards of common devices they use each day are hidden from view. It takes support and encouragement to explore the unknown. Recreating the youthful experiences reported by adults enticed into scientific and technological careers has been our aim. Such projects are too often out-of-school events, supported by a knowledgeable adult, and are rare in families without technological expertise. Uncovering the path to exciting and lucrative careers that are too often untrod by girls and other underserved groups, DESIGNS challenges provide an exciting entry into these fields.

This set of challenges is the output of an extraordinary group of teachers, educators, and scientists. With the support of the National Science Foundation and the Smithsonian Institution we have brainstormed, tested, written, drawn, invented, and struggled. We have failed more often than succeeded, but the result of our three-year effort has been worth it. This collection of activities is fun, contains much science, and is thoroughly tested in a variety of classrooms. They capture students' imaginations and energy. They are not simple to master, but the built-in rapid iteration process tends to test students' ideas rather than their spirits. Failures are frequent but small, each a learning experience that can be absorbed and used. The challenges are designed so that successful strategies are often counter-intuitive, reflecting what we have learned about children's ideas and how they change. Students exhibit little difficulty generating ideas for improvement. But only when their ideas fail do they see a need to pay attention to others' success and restructure their own thinking.

This project has been the beneficiary of many previous development efforts, both our own and those of others. We have attempted to credit all those who helped directly, but we also wish to thank those who remain nameless, teachers with a great suggestion at a workshop, a clever idea from an article, a scientist's solution to a difficult problem, and most of all the thousand or so middle school students who contributed their time and passion as we worked out the bugs in our design of DESIGNS.

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Introduction

About CHALLENGES IN PHYSICAL SCIENCE

CHALLENGES IN PHYSICAL SCIENCE Goals that Cross All Modules

Each of the six CHALLENGES IN PHYSICAL SCIENCE modules contains three or more challenges. Embedded within each challenge are three important goals. They are as follows:

1. **Support learning through clear student goals.** Each student goal is presented as a clearly defined challenge in physical science. These challenges are invitations to students to improve the performance of a simply designed device commonly found in their world.
2. **Empower students as problem-solvers.** Students are encouraged to use their prior knowledge to develop strategies to make progress in each challenge. Students discover and utilize physical science concepts as they achieve the goal characterized by the challenge.
3. **Encourage students to be critical creators of knowledge.** Students propose, test, and eventually defend their ideas. Teachers probe student strategies and interpretations, and encourage students to assess their own and others' evidence.

Students quickly recognize the goal that is posed as a challenge. For example, if the challenge is to improve a working model of a windmill, students easily visualize what is expected and what constitutes a successful outcome. The student who encounters the poorly designed windmill interacts with the basic model, decides what might be changed, makes those changes, and evaluates the results.

CHALLENGES IN PHYSICAL SCIENCE makes two important assumptions about students who accept the challenge: 1) they understand the goal, and 2) they accept the goal as their own. Students who accept ownership of the goal are more likely to be motivated to complete the work they begin. Students also appreciate the link between each challenge and its real-world application. Student interaction with science is often through the technology that results from scientists' work. Each challenge offers students an interesting task centered on the theme of improving an existing design (e.g., a windmill, a battery, or an electromagnet).

All of the challenges were crafted so that students could easily recognize the goal, quickly obtain feedback from their work, and effectively act on that feedback. This strategy is intended to invite students to act, and to empower and support their learning once they accept the invitation. Students who accept the challenge soon find that the problem becomes very compelling. They are motivated for several reasons. The iterative nature of the activity provides timely feedback. The feedback provided by nature is always available, always impartial, and typically unambiguous. Students can quickly determine if their ideas and actions are bringing them closer to the goal they recognized in the challenge. The interaction between the challenge, the supportive teacher, and the problem-solving student is critical in helping students to be self-directed, critical creators of knowledge.

CHALLENGES IN PHYSICAL SCIENCE challenges/goals are also intended to encourage teachers to continually assess whether the classroom setting supports student work in meeting the module goals. From this perspective, teachers focus on encouraging students to follow their own convictions. As a result, students are less dependent on the instructor for the "right answers." Instead, they seek to improve the strategies they use in meeting the design challenge. Often great progress is made when students discover that their beliefs are not supported in nature. Students who learn to question nature directly learn to increasingly value their experiments and become more interested in their results. Students who are motivated to accept the challenge need less assistance from the teacher to proceed. Students uncomfortable with this freedom may still seek the teacher's help. However, teachers who let the challenges guide the students help build students' confidence in their problem-solving ability. Teachers ultimately act to support student understanding of how science proceeds instead of what science has produced.

CHALLENGES IN PHYSICAL SCIENCE vs. National Standards

CHALLENGES IN PHYSICAL SCIENCE goals agree philosophically with the following goals for school science as articulated in the *National Science Education Standards* (p. 13):

- Experience the richness and excitement of knowing about and understanding the natural world.
- Use appropriate scientific processes and principles in making personal decisions.
- Engage intelligently in public discourse and debate about matters of scientific and technological concern.

However, in an attempt to go beyond philosophical agreement with these goals, CHALLENGES IN PHYSICAL SCIENCE strives to create guiding principles that help direct the work of students and teachers. To this end, CHALLENGES IN PHYSICAL SCIENCE goals support the grades 5–8 Content Standards in the *National Science Education Standards* for Science as Inquiry which include (p. 143):

- Abilities to do scientific inquiry.
- Understanding about scientific inquiry.

Furthermore, CHALLENGES IN PHYSICAL SCIENCE's goals directly support the grades 5–8 Science and Technology requirements in the *National Science Education Standards*. In particular, CHALLENGES IN PHYSICAL SCIENCE seeks to create opportunities for children so that, "as a result of activities in grades 5–8, all students should develop abilities of technological design" (p. 161). The underlying objective is that students will be able to perform the following (pp. 165–166):

- Identify appropriate problems for technological design.
- Design a solution or product.
- Implement a proposed design.
- Evaluate completed technological designs or products.
- Communicate the process of technological design.

All CHALLENGES IN PHYSICAL SCIENCE goals provide a framework to support scientific inquiry and technological design. This framework is the foundation on which students distinguish the difference between science and technology. Students work towards recognizing that the goal of science is to create knowledge, while the goal of technology is to apply that knowledge into developing the tools people use to solve problems. To support experimenting as well as the building of tools, CHALLENGES IN PHYSICAL SCIENCE uses materials that are inexpensive, readily available and easily recognized by students as common items that constitute a part of their everyday world.

Skills that Cross All Modules

Science is a unique tool for understanding nature. It assumes that systems (such as the devices in a module) can be understood by first breaking them down into parts that can be later modified. Students learn by making changes to the variables they identify within a design (e.g., increasing the number of wire wrappings in an electromagnet). Students are encouraged to experiment, generate ideas, formulate conclusions, and support their ideas and conclusions with explanations. At the end of the project the students should be able to perform the design process and fabricate their best designs. As a result, they formulate and articulate theories about how each design works. Whether their theories are naive or sophisticated, students test their beliefs through each of their design modifications.

An important outcome of the module goals is that students develop both manipulative and cognitive skills in science. Three skills in particular are realized through student work:

1. **Articulating and testing prior notions** about how a design works. In many ways this skill represents the traditional view of what scientists do: asking questions, forming hypotheses, testing those hypotheses, etc. Students can easily identify the parts of the devices with which they are working. These "parts" represent the design variables that students can control as a scientist or engineer might. Students want to know what will happen to their designs when they choose to modify, add, or remove variables. Their questions become the guiding principles behind how they test their ideas.

2. **Judging the impact or magnitude of a change.** When a student wonders how a change might impact the original design, the student is posing the question directly to nature. Once the change has been implemented, nature provides the answer. Students judge the impact of their own ideas. They see that not all changes result in the same effect or even have any effect. Because the teacher is outside the question-answer cycle, students concentrate on looking to nature to find answers to their questions.

3. **Making convincing arguments** that a change has resulted in a meaningful improvement to the design. Students are expected to evaluate the impact of changes as well as judge the magnitude of change. They are encouraged to employ tools (such as graphs, tables, and charts) to support claims that some changes had a greater impact than others, or that a change had no impact at all.

To the extent that these skills are practiced in the module, CHALLENGES IN PHYSICAL SCIENCE supports the broadest standard in the *National Science Education Standards*. "As a result of activities in grades K–12 all students should develop understanding and abilities aligned with the following concepts and processes" (p. 117–118):

- **Evidence, models, and explanation:** Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- **Constancy, change, and measurement:** Energy can be transferred and matter can be changed. . . . Changes can be quantified . . . . Different systems of measurement are used for different purposes.

Introduction to the Gravity Wheel Module

Descriptions of the Gravity Wheel Challenges

Challenge 1: Maximum Speed

Challenge Objective

Design a gravity-powered wheel that will cover a given distance in the shortest time. The variables that can be altered are the weight applied for momentum, the length of the lever arm, and the angle of the lever arm.

Challenge Scenario

The owner of a major rock quarry needs a device that will haul loads of cement from the mixer to the building site. Since power sources are not always available, she prefers to use a gravity driven car and has asked you to develop the wheels of the car. Since the cement dries very quickly, the car must move as fast as possible. Your challenge is to create a model of the car's wheel that will travel six feet (or two meters) in as little time as possible.

Challenge 2: Maximum Distance

Challenge Objective

Design a gravity-powered wheel that will travel the farthest carrying the heaviest load. The variables that can be altered are the total mass of the wheel (i.e., the weight of the load), the length of the lever arm, and the angle of the lever arm.

Scenario Change

The rock quarry owner needs another device that will haul as much gravel as possible as far as possible. Since these loads will be very heavy, she prefers to use gravity as a power source rather than something more expensive (such as electricity or gasoline). Your challenge is create a model of the car's wheel that will travel the greatest distance carrying the heaviest load.

Challenge 3: Minimum Speed

Challenge Objective

Design a gravity-powered wheel that will travel the slowest carrying a standard load. The variable that can be altered is the distribution of the mass on the wheel. The wheel must travel the same distance regardless of the placement of the mass. This test will be performed on the elevated test track. Place the track between two desks. The axles of the gravity wheels will sit directly on the track while the paper plates will extend outside the track.

Scenario Change

The rock quarry owner needs another device that will haul very fragile sheets of marble from one building to another. Since the marble is very expensive and can break very easily, the car hauling it must travel as slowly as possible, but must always cover the same distance. Your challenge is create a model of the car's wheel that will travel at the slowest speed while carrying the same amount of weight over the same distance.

Module Goals

This module allows students to explore the nature of inertia, motion, and energy transfer by manipulating design elements and construction materials in a simple vehicle powered by gravity.

The goal of the first challenge is to explore and modify a design for a wheel powered by gravity to make it travel the greatest distance in the least time. The second challenge is to design a vehicle to carry the greatest load as far as possible. The third challenge is to design a vehicle that will travel the slowest on a track. Constraints on each challenge focus on several concepts associated with inertia, force, motion and energy transfer.

Content Goals of the Module

1. From the perspective of the *National Science Education Standards* (Physical Science: Content Standard B): "As a result of their activities in grades 5–8, all students should develop an understanding of motions and forces and transfer of energy" (p. 149). The underlying concept objectives that students recognize are:

- The motion of an object can be described by its position, direction of motion, and speed. That motion can be measured and represented on a graph. (p. 154)
- Unbalanced forces will cause changes in the speed or direction of an object's motion. (p. 154)
- Energy is a property of many substances and is associated with heat, light, electricity, *mechanical motion,* sound, nuclei, and the nature of a chemical. Energy is transferred in many ways. (p. 155, emphasis added)

2. From the perspective of CHALLENGES IN PHYSICAL SCIENCE:

The student's goal is to improve a wheel's design so that modifications lead to improvements in how fast or how far the wheel can go. To this end, students encounter the following concepts in order to successfully meet this challenge:

A. Weights that are suspended above the floor can store energy. This energy is called **potential energy**.

   1. Increasing the amount of weight increases the potential energy available to the wheel.
   2. Increasing the weight's height above the floor also increases the potential energy available to the wheel.

B. Falling weights can be used to make a wheel move. If potential energy (or stored energy) is transferred to the wheel, the wheel moves (it goes forward, backward, spins, etc.). The wheel in motion has **kinetic energy** (the energy of motion).

C. The weights on the lever arm can "pull" a wheel.

   1. The wheel can continue moving even though it is no longer being pulled. This property is called **inertia.**

D. Changing the amount of the weight on the lever arm will change both the speed of the wheel and the distance that the wheel travels.

   1. Increasing the amount of potential energy available to the wheel can increase the wheel's moving or kinetic energy.
   2. Increasing the wheel's kinetic energy means that the wheel moves more quickly. If two wheels of different masses are traveling at the same speed, the more massive wheel will have more kinetic energy.
   3. The potential energy of the falling weights can be converted into the kinetic energy of the wheel's motion.

E. The distance between the axle of the wheel and the position of the weights is important. Changing the distance can change how fast or how far the wheel can travel.

   1. Changing the distance between the axle and the weights will change the torque of the wheel. Torque is the turning force defined in part by the distance between the application of the force (the weights) and the rotational axis (the axle). If the torque is too large the wheel may slip on its turning surface. If the torque is too low the wheel might not begin to turn.
   2. Changing the amount of weight also changes the torque. Torque is measured as weight (force) times distance (between the axle and the weights).

$$\text{TORQUE} = \text{WEIGHT} \times \text{DISTANCE}$$

F. The mass of the entire wheel and the distribution of that mass are important. Mass is defined as the amount of matter in an object.

1. More massive wheels generally require more torque than less massive wheels to initiate motion.
2. When the same potential energy is imparted to wheels of differing mass, the heavier one will move more slowly.

Scientific Concepts and Knowledge

Potential Energy and Kinetic Energy

In the Gravity Wheel Module students utilize the concepts of potential and kinetic energy. For this module they are defined as follows:

- **Potential Energy**—the stored energy of an object resulting from its mass and position with respect to other objects.
- **Kinetic Energy**—the energy of motion resulting from the use of some or all of its potential energy.

Since all of the challenges for this module are performed on flat surfaces, potential and kinetic energy are straightforward properties. They are portrayed in the challenges by the following variables:

1. **The number of weights placed in the cup.** This alters the weight applied to the lever arm and thus the potential energy. When the arm swings forward to move the gravity wheel, potential energy is converted to kinetic energy as the weight descends.
2. **The position of the weights on the lever arm.** This alters the distance the weight can descend and thus the potential energy.
3. **The starting position of the lever arm from horizontal.** This alters the height of the weight cup above the ground and thus how far the weight can descend.

Torque

Torque is a rotational quantity affected by the length of the arm of rotation and the amount of force applied to that arm. The angle at which the force is applied to the arm also affects the amount of torque produced. Torque is portrayed in the challenges by the following variables:

1. **The position of the cup on the lever arm.** This alters the length of the arm of rotation and thus increases or decreases the torque.

2. **The position of the lever arm from horizontal.** This alters the total amount of force applied to the arm of rotation and thus the amount of torque produced.

$$\text{TORQUE} = \text{LENGTH OF LEVER ARM} \times \text{FORCE}$$

Newton's Law of Universal Gravitation

This law defines gravity according to total mass. Every mass exerts a gravitational pull on every other mass. The gravitational force of the Earth on the wheel is far greater than the gravitational force of any other object, so we consider only the Earth's gravity in the challenges.

Newton's Laws of Motion

The challenges in this module primarily exemplify the first two of Newton's three laws of motion.

1. Every object continues either in its state of rest or its state of constant speed in a straight line until an outside force acts upon it causing a change in its state. This law is also referred to as the law of inertia.
2. The acceleration of an object is in the same direction as the force applied to it and is proportional to the force applied.
3. When an object exerts a force on another object, the second object exerts an equal and opposite force back upon the first object.

By placing weight in the cup on the gravity wheel's lever arm, then letting the wheel go, we are causing an outside force (the weight) to act on the gravity wheel and are exemplifying Newton's first law. The wheel will then travel in the direction that the weight is applied and attain a maximum speed proportional to the amount of weight applied, an example of Newton's second law. The third law also applies, but is not directly observable in the challenges.

Rotational Inertia

Rotational inertia, also referred to as moment of inertia, is the rotational application of Newton's first law of motion: objects set in motion remain in motion until a force is applied to them causing them to stop. (NOTE: this law is also true for objects at rest. They will remain at rest until a force is applied to them causing them to move.)

Rotational inertia relies upon the distribution of mass about the axis of rotation. When mass is distributed close to the center of the rotating object, the rotational inertia will be reduced. When mass is distributed toward the outer edge, rotational inertia will increase.

In Challenge 3 rotational inertia is altered when the position of the bolts changes with respect to the axis of the wheel. Initially the bolts (the main mass of the wheel) are clustered close to the wheel's center, reducing rotational inertia and increasing the speed of the wheel. The bolts are then moved toward the edge of the wheel, increasing rotational inertia and decreasing the speed of the wheel.

Science Process Skills

Process Goals

- Controlling Variables
- Teamwork
- Recordkeeping
- Multiple Iterations
- Hypothesizing
- Synthesizing
- The 3 Rs: Retreat, Reflect, Redraw (overcoming resistance in order to learn: willingness to scrap designs based on misconceptions and to try again with a design based on new discoveries and a new awareness resulting from the flow of ideas throughout the classroom)
- Relating observed behaviors to actual science concepts
- Recognizing multiple results as equally valid
- Performing multiple trials. (Although time constraints often allow for only one trial in the classroom, students should be aware that scientists perform at least three trials of each variable.) [Note: For information on assessment of process skills, see the Rubrics section at the end of this module.]

Science Technology Society

The following STS connections are intended:

- Competition in industry
- Creative design: innovation, ingenuity
- Utilization of alternative energy sources and energy storage devices
- Roles in the working world
- Presentation skills
- Attribution (acknowledging and crediting originators of ideas)

Assessment

Students' understanding of science concepts will be revealed in their work as they progress through the challenges. Assessment tools are provided for the teacher, but observations of the progress of each student, revealed in class discussions, worksheets, reports, storyboards, and design modifications will portray the complete picture of the student's progress.

History of Gravity as a Power Source

How did humans first begin to understand gravity? Gravity has been used for thousands of years both directly and indirectly to accomplish many different tasks. Let's examine some of these uses to learn how humans began to think about this force of nature.

Aqueducts

One of the earliest direct uses of gravity is the system of transporting water from one location to another using artificial channels called aqueducts. Ancient cultures in India and Mesopotamia used aqueducts to irrigate crops and provide water to villages. Over two thousand years ago Romans developed aqueducts into structures several miles long. The Roman aqueducts included open or closed canals, tunnels, and elevated bridges that carried water for nearly sixty miles (100 km) from the countryside into the city of Rome. Ancient Rome received water from more than ten aqueducts that supplied more than 38 million gallons (144 million liters) of water each day.[1]

How do these aqueducts work? They simply use the force of gravity to pull the water from a higher area to a lower area. Imagine pouring water on the top of a slide. The water travels down the slide until it reaches the bottom. This is exactly how aqueducts work except that the canals, tunnels, and bridges do not slope as steeply as a slide. They do slope, however, allowing water to flow in one end and out the other.

[1] *Encarta 98.*

Aqueducts continue to be used throughout history. The Marseilles aqueduct in France was built in 1847 and is sixty miles long (100 km). Aqueducts have also been built in Scotland, Austria, and England. Aqueducts in the United States are extensive. The Delaware aqueduct carries 800 million gallons (3 billion liters) of water daily from the Catskill Mountains to New York City and is 85 miles (137 km) long. It is the longest continuous tunnel in the world. The Colorado River aqueduct, which helps supply water to southern California, is 242 miles (390 km) long and carries more than 1 billion gallons (3.8 billion liters) of water a day. However, this aqueduct is assisted by power sources other than gravity.[2]

Clocks

Gravity has long been used as a power source to help people tell time. The hour glass, a device that allows sand to flow from a top chamber into a bottom chamber, has been used for many thousands of years. A similar device known as a clepsydra allowed water rather than sand to drip from a higher container into a lower one. Both devices utilize gravity to pull the sand or the water down at a steady rate.

In the 14th century the first mechanical clocks were made. A heavy weight attached to a geared clock hand was pulled down by the constant force of gravity. These clocks were large and difficult to manage. They were often kept in high towers which allowed their weights to drop greater distances. The original term for a time-measuring device was "horologium" or "hour teller." During the late Middle Ages mechanical clocks were most often kept in bell towers, so they were referred to by the term for "bell" which was "clock."[3]

In the late 16th century an Italian scientist named Galileo Galilei (normally referred to simply as "Galileo") studied the properties of weights falling, rolling down inclined planes, and swinging through the air. He realized that a constant force was pulling on the weight each time. This understanding of how gravity pulls on a weight allowed clockmakers to develop the pendulum clock. This regular pull makes each pendulum swing almost identical, slowing the falling weight.

In the 15th century, springs were also being used in timekeeping devices. Other non-gravity driven mechanisms have been developed in recent years that allow for more accurate timing. However, some of the

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[2] *Encarta 98.*

[3] The Middle English spelling is "clokke" while the Old French spelling is "cloke." Both are derived from the Latin "clocca." [Source: *American Heritage Dictionary,* Houghton Mifflin Co., Boston 1985.]

original gravity driven clock devices are still used today. You may see a small hour glass in your kitchen, often used to time the boiling of "three minute" eggs. You may also find a tall pendulum clock in your home, sometimes called a "grandfather clock."

Sir Isaac Newton

During the middle of the 17th century, an English mathematician and physicist named Sir Isaac Newton developed the law of universal gravitation. This law states that all bodies in space and on the Earth are affected in the same way by the force called gravity. Everything that has mass exerts a gravitational pull on every other mass. Although a very weak one, even the pencil on your desk exerts a gravitational pull on the desk. The Earth is a much larger mass and exerts a much greater gravitational pull on the desk. We feel the effects of the Earth's gravity whereas we cannot feel the effects of the gravity of objects around us because they are far too small.

Newton also developed three additional laws which we now call Newton's Laws of Motion. The first law simply states that objects put into straight line motion will stay in motion at a constant speed indefinitely until a force causes them to stop. This law also applies to objects that have stopped: if an object is at rest, it will continue to sit still until a force causes it to move. This property of objects is called inertia. The second law states that if a force is applied to an object, the object will move in the direction of the force. This law also states that the greater the mass of the object, the greater the force necessary to move it. The third law states that whenever one object exerts a force on another object, the second object will exert an equal force opposite to that of the first object on the first object.[4]

What do these laws mean to us? We see Newton's laws in operation every day. If you kick a ball on the ground, the ball continues to roll even though you do not continue kicking it. This is an example of Newton's first law of motion. When you kick the ball, it moves in the direction that you kicked. If the ball is very large, you must kick it harder to make it move. That is Newton's second law. When you kick the ball, the ball exerts the same amount of force back at your foot, and could hurt your toe. That is Newton's third law. These laws operate with or without gravity.

Newton did not invent gravity, but he was one of the first people to model it and to explain it to others. He published his studies in 1687

[4] *Conceptual Physics,* Paul G. Hewitt, Scott Foresman Co., Glenview, Illinois, 1990.

in a book called *Philosophiae Naturalis Principia Mathematica*. Most scientists refer to it simply as the *Principia*.

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Gravity Railway

During the 19th century, before steam engines were developed, engineers sought a way of moving heavy loads up and down hillsides easily and cheaply. One solution was the gravity railway. This design involved two sets of tracks running side by side. Cars sitting on each track were attached to chains or ropes, which attached to each other at the top and bottom of the track. As one car went up the track, the other went down. Then the two were reversed. This system required only gravity and a very strong brake mechanism to make it work properly.

The first commercial railway in the United States was the Granite Railway Company of Quincy, Massachusetts, constructed in 1826. It was established to haul heavy loads of granite from the quarry down to ships which would transport it throughout the area of Boston, Massachusetts. The Granite Railway Company utilized a gravity railway as part of its system. The following passage describes this system:

> Mr. Gridley Bryant . . . built the Incline to bring stone down eighty-four feet on an inclined plane to the railway level. Mr. Bryant was very proud of this ingenious mechanical device. The cars that carried stone from the quarry were attached at the head of the Incline to [a closed loop of] chain which lowered the loaded cars and raised the empty ones.[5]

Gravity Today

Today scientists and engineers are still studying and using the effects of gravity. Engineers use gravity indirectly to help perform many tasks from driving giant water turbines that create electricity to pulling down the little rubber ball in your computer's mouse so that it will come in contact with the mouse pad.

We use gravity so often that we hardly consider it. However, engineers developing equipment for use in outer space must think about gravity all the time. The devices used by astronauts to perform every single task, from running experiments to cooking, must operate without the benefit of gravity. We take gravity for granted, but perhaps in the future we may experience a new world without it.

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[5] "The Granite Railway," H. Hobart Holly. *Quincy History*. Quincy Massachusetts. No. 26 Fall 1991.

Class Preparation and Set-Up

Module Materials

Materials for Gravity Wheel

- Heavy duty paper lunch plates, 8 3/4 inches (22.2 cm) in diameter (two per gravity wheel for standard design, additional plates required for Challenge 2)[1]
- Wooden dowel, 3/16 inch (5 mm) diameter, 8 inches (20.3 cm) long (one per gravity wheel)
- Rubber faucet washers: beveled 5/8 inch (1.6 cm)—13/16 OD (four per gravity wheel)[2]
- Corrugated cardboard cut into 2 × 2 inch (5 × 5 cm) squares (four per gravity wheel)
- Plastic drinking straw (one per gravity wheel)
- Heavy duty cold drink paper cups, 7 ounce (207 ml) size (two per gravity wheel)
- Bolts: 1/4–20 1/2 inch (1.3 cm) flat-head, slotted (24 per gravity wheel for Challenge 3)
- Nuts: 1/4–20 (24 per gravity wheel)
- Hole punch, 1/8 inch (3 mm) size (or small nail)
- Scissors
- Pencils
- Hand-held pencil sharpener
- Data Sheets for each challenge
- Design Sheets for each challenge
- Protractor
- Compass
- Pen or marker
- Center finding device
- Plate hole template
- Ruler or meterstick
- Tape

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[1]Chinet™ brand is recommended.

[2]True Value Hardware Master Plumber IBM #584458 is recommended.

Materials for Testing Station

- Masking tape
- Stop watch
- Yard stick or tape measure
- Shelf standards, 6 feet (2 meters) long
- Wooden blocks, 3.5 inches (8.9 cm) square and 3/4 inch (2 cm) thick
- Screws or elastic bands
- Level
- Protractor

Materials for Center Finding Device and Plate Hole Template

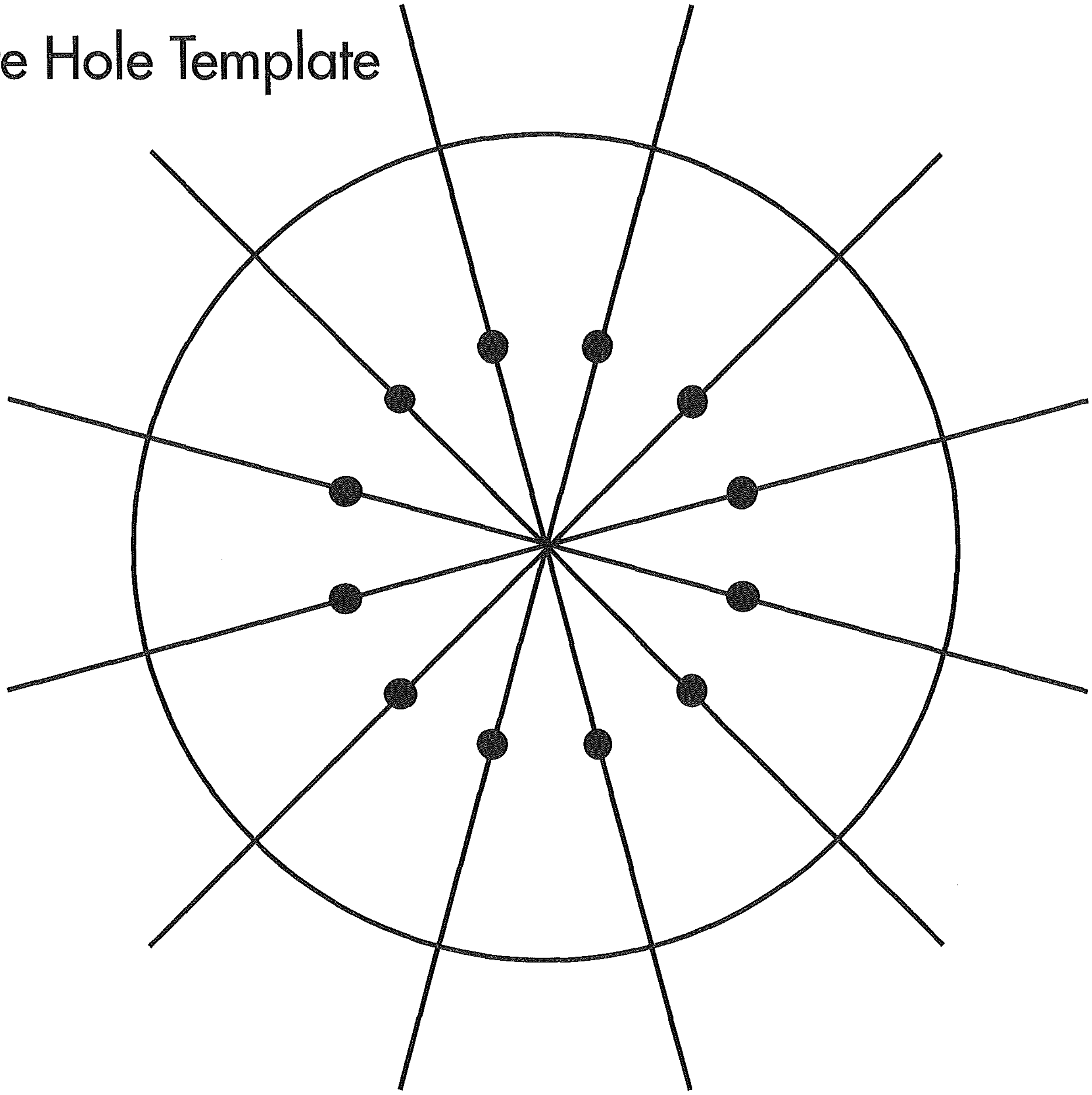
- String, 18 inches (45.7 cm) long
- Protractor
- Glue stick
- Ball point pen
- Small nail
- Plate hole template
- Table or desk with a 90° angle corner
- Tape
- Index cards
- Pencil
- Compass
- Ruler

Construction

Creating the Center Finding Device

1. Locate a table or desk with a 90° angle corner.
2. Using the protractor, divide the table corner into two halves. Each half will be 45°.
3. Draw a line or use a piece of tape to mark the 45° angle. The line should be 12 inches (30.5 cm) long.
4. Tape one end of the piece of string to the table corner at the 45° line.
5. Using two index cards, tape one to each side of the table corner. These cards will form the sides of a 90° angle "V" with the string at the "V" base.

Plate Hole Template



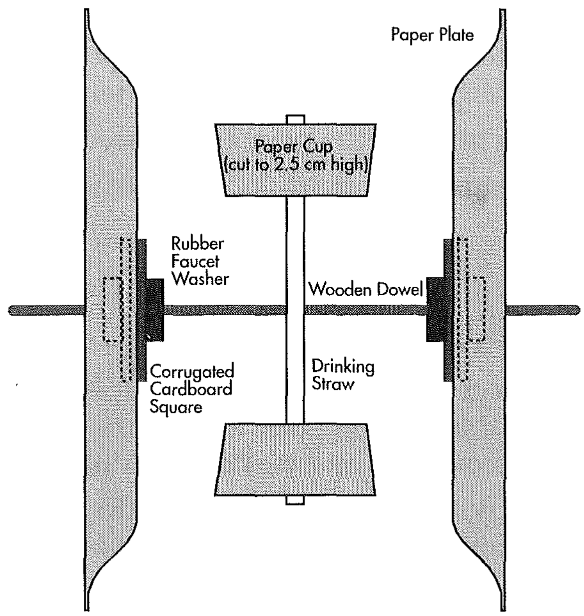
Using the Center Finding Device and Creating a Plate Template

1. Place a paper plate bottom side up against the index cards. Make sure that the plate's edge touches both cards at the same time.
2. Holding the plate in place with one hand, pull the string tightly over the plate. Hold the other end of the string on the 45° line.
3. Using a pen, draw a line along the string on the plate.
4. Rotate the plate 90° and repeat steps 1–3.
5. The intersection of the lines that you marked on the plate is the center of the plate.
6. Cut out the plate hole template.

7. Center the template on the center point of the paper plate and glue it in place with glue stick. (An easy way to center the template is to poke a nail through the center point of the plate, then place the center of the template over the nail.)
8. Using a nail, poke small holes at all of the points indicated on the template.
9. Students may now use this template to mark locations of holes on their gravity wheels using a pen.

Initial Standard Design for the Gravity Wheel

1. Cut an 8 inch length of 3/16 inch (5 mm) diameter dowel. Measure in 1 inch (2.5 cm) from each end and mark with a pencil. Locate the middle of the dowel by measuring in 4 inches from one end and mark with a pencil.
2. Taper the dowel ends slightly with a pencil sharpener. **Do not make them too sharp, or injury may occur to students during construction!**
3. Cut corrugated cardboard into 2 inch (5 cm) squares. Each gravity wheel will need four squares. Locate the center of the cardboard squares by drawing lines on them that connect opposite corners. Poke a hole in the center of each piece using a small nail. These pieces of cardboard become the braces that keep wheel wobble to a minimum.
4. Cut a plastic drinking straw to a length of 7 1/2 inches (19 cm). Using the 1/8 inch (3 mm) paper punch make a hole in the middle. Using a permanent marker, draw lines on the straw at the following increments from the hole: 3 inches (7.6 cm), 2.5 inches (6.4 cm), 2 inches (5 cm), 1.5 inches (3.8 cm). Take two paper cups and cut the sides down to a height of 1 inch above the cup's bottom. Estimate the center of each cup and punch a hole with a nail.
5. Slide the dowel through the 1/8 inch (3 mm) hole in the straw to the mark at the middle of the dowel. (Tape in place if it slips.) The dowel is the axle of the gravity wheel while the straw is the lever arm.
6. Slide the rubber faucet washers over the dowel with the tapered sides toward the middle until the outer face lines up with the 1 inch mark. Place another mark on the dowel where the washer ends. Slide the 2 inch (5 cm) cardboard braces over the dowel and against the faucet washers on each end. Place a paper plate with the template markings, bottom side in, over the axle. Slide the remaining 2 inch (5 cm) cardboard braces on each end of the axle, followed by the remaining two faucet washers.
7. Slide the paper cups over each end of the straw, bottom sides in, to the 3 inch (7.6 cm) mark on the lever arm.



General Notes

- To facilitate storage, each gravity wheel can be disassembled. All loose parts can be placed between the paper plates and the unit can be secured with tape or a rubber band. This will enable students to take their gravity wheels home if they should wish to do so.

Testing the Gravity Wheel

1. Place a nut in the paper cup attached to the lever arm.
2. Hold the gravity wheel with the lever arm perpendicular to the ground.
3. Release the gravity wheel without pushing it forward. The weight of the nut will pull the gravity wheel forward until the nut falls to the floor. The momentum of the gravity wheel will continue to carry it forward. The gravity wheel should move smoothly across the floor.
4. If the gravity wheel appears to wobble or if the lever arm is not effective, reassemble the gravity wheel and test it again. If the holes in the plate are too large, remove the plate and start over with a new one.

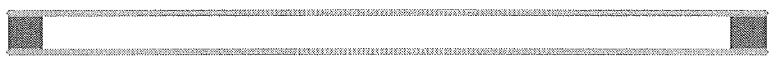
Testing Station for Challenges 1 and 2

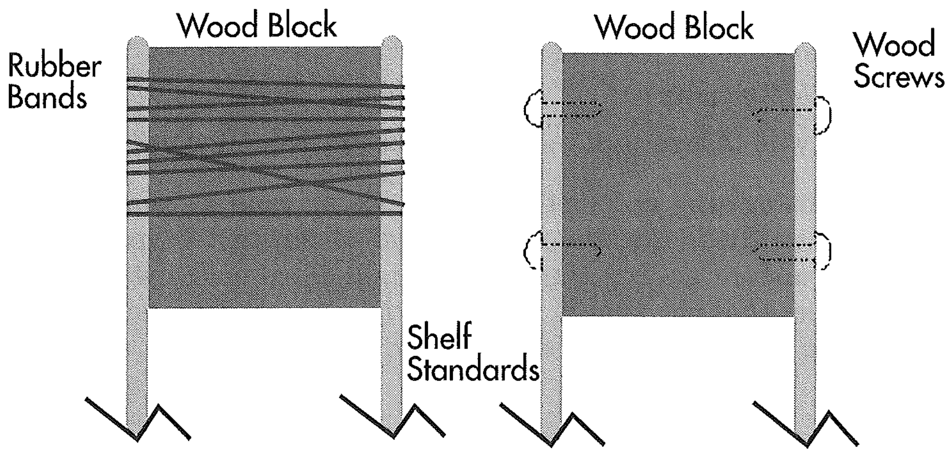
Locate a level space at least 6 feet (1.8 m) long on a smooth floor. Using masking tape, mark off the distance in feet and inches or meters and centimeters.

Testing Station for Challenge 3

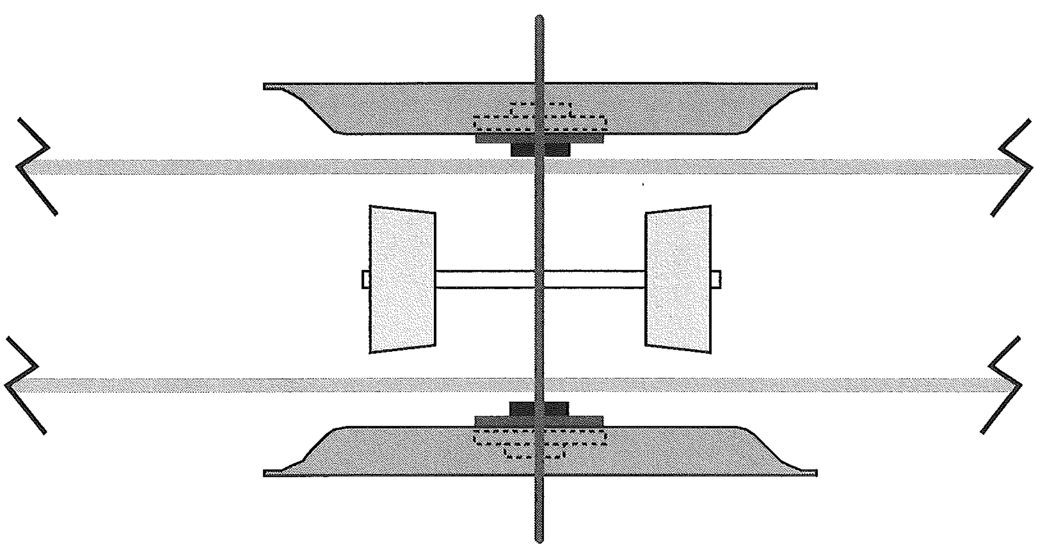
Construct a 6 foot (1.8 m) test track using two metal shelving standards. Align the standards parallel to each other and four inches apart. Place the wooden blocks between the standards and attach the standards at each end to them using screws or rubber bands. Elevate the track between two tables, using a level to make sure that it is parallel to the floor. Mark off a distance of 1 yard or 1 meter along the center of the track using a marking pen or masking tape (NOTE: do not let the tape touch the top of the track). This is the test distance. The axles of the gravity wheels will sit directly on the track while the paper plates will extend outside the track.

Assembled Test Track





End Assembly
(Two methods)



Pretest

Before constructing the standard design, administer the Pretest to determine students' thoughts about gravity.

Brainstorming Questions

Lead a class discussion by asking students the following questions:

- What do you think gravity is?
- What can gravity do for us? How does it affect our everyday life?
- How do we use gravity?
- Can we "stop" gravity?
- Can gravity do things that motors and batteries do for us?

The goal of brainstorming is for students to use or consult their experiences when dealing with these questions. This kind of support helps develop the expectation that understanding begins with challenging one's own experiences. If students suspect that the goal is to guess what the teachers want, then students are missing a necessary experience to advance their understanding.

Challenge 1
Maximum Speed

Challenge Objective

Design a gravity-powered wheel that will cover a given distance in the shortest time. The variables that can be altered are the weight applied for momentum, the length of the lever arm, and the angle of the lever arm.

Challenge Scenario

The owner of a major rock quarry needs a device that will haul loads of cement from the mixer to the building site. Since power sources are not always available, she prefers to use a gravity driven car and has asked you to develop the wheels of the car. Since the cement dries very quickly, the car must move as fast as possible. Your challenge is to create a model of the car's wheel that will travel six feet (or two meters) in as little time as possible.

Materials

- Heavy duty paper lunch plates, 8 3/4 inches (22.2 cm) in diameter (Chinet™ brand works well) (two per gravity wheel)
- Wooden dowel, 3/16 inch (5 mm) diameter, 8 inches (20.3 cm) long (one per gravity wheel)
- Rubber faucet washers: beveled 5/8 inch (1.6 cm)—13/16 OD (True Value Hardware Master Plumber IBM #584458 works well with the 3/16 inch dowel) (four per gravity wheel)
- Corrugated cardboard cut into 2 × 2 inch (5 × 5 cm) squares (four per gravity wheel)
- Plastic drinking straw (one per gravity wheel)
- Heavy duty cold drink paper cups, 7 ounce (207 ml) size (two per gravity wheel)
- Nuts: 1/4–20 (24 per gravity wheel)
- Hole punch, 1/8 inch (3 mm) size (or small nail)
- Hand-held pencil sharpener
- Data Sheet (one per team)
- Design Sheet (one per team)
- Stopwatch or timer
- Protractor (to measure angle of lever arm)
- Tape
- Plate hole template
- Compass
- Center finding device
- Pen or marker
- Scissors
- Pencils

Gravity Wheel Construction

1. Cut an 8 inch (20.3 cm) length of 3/16 inch (5 mm) diameter dowel. Measure in 1 inch (2.5 cm) from each end and mark with a pencil. Locate the middle of the dowel by measuring in 4 inches (10.2 cm) from one end and mark with a pencil.

2. Taper the dowel ends slightly with a pencil sharpener. **Do not make them too sharp or injury may occur!**

3. Cut corrugated cardboard into 2 inch (5 cm) squares. Each gravity wheel will need four squares. Locate the center of the cardboard squares by drawing lines on them that connect opposite corners. Poke a hole in the center of each piece using a small nail. These pieces of cardboard become the braces that keep wheel wobble to a minimum.

4. Cut a plastic drinking straw to a length of 7 1/2 inches (19 cm). Using the 1/8 inch (3 mm) paper punch make a hole in the middle. Using a permanent marker, draw lines on both ends of the straw at the following increments: 3 inches (7.6 cm), 2.5 inches (6.4 cm), 2 inches (5 cm), 1.5 inches (3.8 cm). Take two paper cups and cut the sides down to a height of 1 inch (2.5 cm) above each cup's bottom. Estimate the center of each cup and punch a hole with the nail.

5. Slide the dowel through the 1/8 inch (3 mm) hole to the mark at the middle of the axle. (Tape it in place if it slips.) The dowel is the axle of the gravity wheel while the straw is the lever arm.

6. Slide the rubber faucet washers over the dowel with the tapered sides toward the middle until the outer face lines up with the 1 inch (2.5 cm) mark. Place another mark on the dowel where the washer ends. Slide the 2 inch (5 cm) cardboard braces over the dowel and against the faucet washers on each end. Place a paper plate with the template markings, bottom side in, over the axle. Slide the remaining 2 inch (5 cm) cardboard braces on each end of the axle, followed by the remaining two faucet washers.

7. Slide the paper cups over each end of the straw, bottom sides in, to the 3 inch (7.6 cm) mark on the lever arm.

Troubleshooting Tips

- Centering the plates properly on the axle is critical to the success of the challenge. It is helpful for the teacher to provide a template for students by punching a hole in a paper plate rather than requiring students to use the centering device.
- Tape the lever arm (straw) to the axle to avoid slipping.
- Distribute the nuts evenly in the cup rather than dropping them all on one side.
- If the floor is uneven the test can be run on the test track. Distance and speed will be reduced significantly, however.
- The faucet washers should fit tightly and prevent the plates from slipping. If they do not fit tightly, remove the axle and soak it in water for an hour. This will cause the wood to swell and will create a tighter fit.
- A nail can be used in place of the 1/8 inch (3 mm) hole punch.

Procedures

Set-Up

Construct and display a gravity wheel so that students can observe its design and performance.

Demonstration

Show students the standard design and demonstrate how the gravity wheel operates by dumping weights from the weight cup onto the floor.

Class Discussion

Ask students to explain how they think the standard design works. Ask them to speculate on how to alter its performance through design changes.

Cooperative Learning Groups

Challenge student teams to design a gravity wheel that will travel the fastest.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Maximum Speed

TEAM NAME: **DATE:**

Design A Vary the amount of weight used for momentum.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	**3**	**6**	**9**	**12**
Distance of cup from axle	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)
Angle from horizontal	90°	90°	90°	90°
Time				
Speed (distance traveled/time)				

Design B Vary the location of the weight on the lever arm.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	3	3	3	3
Distance of cup from axle	**3 inches (7.6 cm)**	**2.5 inches (6.4 cm)**	**2 inches (5 cm)**	**1.5 inches (3.8 cm)**
Angle from horizontal	90°	90°	90°	90°
Time				
Speed (distance traveled/time)				

Design C Vary the angle of the lever arm.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	3	3	3	3
Distance of cup from axle	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)
Angle from horizontal	**90°**	**60°**	**30°**	**0°**
Time				
Speed (distance traveled/time)				

1. Which variables caused the wheel to travel the fastest?

____

2. Why do you think these variables made the wheel travel faster?

____

____

____

3. Select two variables that you would like to change *at the same time*. This will allow you to create your final design.

Variable 1 _______________

Variable 2 _______________

Design D Vary the angle of the lever arm.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts				
Distance of cup from axle (in inches or centimeters)				
Angle from horizontal (in degrees)				
Time				
Speed: distance traveled ÷ time (in inches or centimeters per second)				

Maximum Speed

TEAM NAME: **DATE:**
DESIGN # **TIME:**

Now that you have tested several variables, create a final design that will be submitted to the quarry owner. Your design will compete with the designs of the other teams on the test track. The fastest wheel will win!

Rules for Challenge 1 Design Competition

1. Using the results of your previous tests, design a wheel that will travel the distance of the test track in the shortest time possible.
2. Your team must complete the Design Sheet before taking it to the test station.
3. All tests are public.
4. In case of a dispute, the teacher will be the final judge.
5. Be prepared to report on your team's progress. Keep neat and accurate records.

Description and drawing of new design (include measurements):

Final Time in Design Competition: ________________

Final Speed in Design Competition: ________________

Challenge 1 Wrap-Up

Questions for Class Discussion

- Which design changes did you find to be the most useful?
- Why do you think they worked so well?
- What design elements do the most successful gravity wheels have in common?
- What combinations of design changes seemed to work best?

Performance Variables

- Amount of weight used for momentum (number of nuts)

  Increasing this variable alters the amount of torque. This will enable the wheel to travel more quickly.
- Location of the weight on the lever arm

  As the weight moves toward the axle, the amount of torque decreases. This will cause the wheel to travel more slowly.
- Angle of the lever arm

  As the angle of release decreases from the vertical position, the amount of torque decreases. This will cause the wheel to travel more slowly.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it traveled the entire test distance in a sufficiently short period of time. Additionally, students should be evaluated based on the results that they have recorded on their Design Sheets as well as the organization and neatness of their Data Sheets.

Challenge 2
Maximum Distance

Challenge Objective

Design a gravity-powered wheel that will travel the farthest carrying the heaviest load. The variables that can be altered are the total mass of the wheel (i.e., the weight of the load), the length of the lever arm, and the angle of the lever arm.

Scenario Change

The rock quarry owner needs another device that will haul as much gravel as possible as far as possible. Since these loads will be very heavy, she prefers to use gravity as a power source rather than something more expensive (such as electricity or gasoline). Your challenge is create a model of the car's wheel that will travel the greatest distance carrying the heaviest load.

Materials

- Heavy duty paper lunch plates, 8 3/4 inches (22.2 cm) in diameter (eight per gravity wheel)
- Wooden dowel, 3/16 inch (5 mm) diameter, 8 inches (20.3 cm) long (one per gravity wheel)
- Rubber faucet washers: beveled 5/8 inch (1.6 cm)—13/16 OD (four per gravity wheel)
- Corrugated cardboard cut into 2 × 2 inch (5 × 5 cm) squares (four per gravity wheel)
- Plastic drinking straw (one per gravity wheel)
- Heavy duty cold drink paper cups, 7 ounce (207 ml) size (two per gravity wheel)
- Nuts: 1/4–20 (24 per gravity wheel)
- Hole punch, 1/8 inch (3 mm) size (or small nail)
- Hand-held pencil sharpener
- Data Sheet (one per team)
- Design Sheet (one per team)
- Stopwatch or timer
- Tape
- Protractor
- Plate hole template

Gravity Wheel Construction

1. Use the same gravity wheel that you made for Challenge 1.
2. Poke holes at the center of each additional paper plate using a nail and the plate hole template provided by your teacher.

Troubleshooting Tips

- Centering the plates properly on the axle is critical to the success of the challenge. It is helpful for the teacher to provide a template for students by punching a hole in a paper plate rather than requiring students to use the centering device.
- Tape the lever arm (straw) to the axle to avoid slipping.
- Distribute the nuts evenly in the cup rather than dropping them all on one side.
- If the floor is uneven the test can be run on the test track. Distance and speed will be reduced significantly, however.
- The faucet washers should fit tightly and prevent the plates from slipping. If they do not fit tightly, remove the axle and soak it in water for an hour. This will cause the wood to swell and will create a tighter fit.
- A nail can be used in place of the 1/8 inch hole punch.

Procedures

Set-Up

Construct and display a gravity wheel on the test track so that students can observe its design and performance.

Demonstration

Show students the standard design and demonstrate how the gravity wheel operates on the elevated track by dumping weights from the weight cup onto the floor.

Class Discussion

Ask students to explain how they think the standard design works on the new track. Ask them to speculate on how to alter the design's performance through design changes.

Cooperative Learning Groups

Challenge student teams to design a gravity wheel that will travel the farthest and carry the heaviest load, up to a given maximum.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Challenge 2: Data Sheet

Maximum Distance

TEAM NAME: **DATE:**

Design A Vary the amount of mass.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	3	3	3	3
Total number of paper plates	**2**	**4**	**8**	**16**
Distance of cup from axle	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)
Angle from horizontal	90°	90°	90°	90°
Distance traveled				

Design B Select the number of plates that worked the best in Design A and hold that constant for Design B. Vary the location of the weight on the lever arm.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	3	3	3	3
Total number of paper plates (the number that worked best in Design A)				
Distance of cup from axle	**3 inches (7.6 cm)**	**2.5 inches (6.4 cm)**	**2 inches (5 cm)**	**1.5 inches (3.8 cm)**
Angle from horizontal	90°	90°	90°	90°
Distance traveled				

Design C Select the distance of the cup from the axle that worked the best in Design B and hold that constant for Design C. Vary the angle of the lever arm.

	Trial 1	Trial 2	Trial 3	Trial 4
Number of nuts	3	3	3	3
Total number of paper plates (the number that worked best in Design A)				
Distance of cup from axle (the distance that worked best in Design B)				
Angle from horizontal	**90°**	**60°**	**30°**	**0°**
Distance traveled				

Test Results

1. Which variables caused the wheel to travel the farthest?

___

2. Why do you think these variables made the wheel travel farther?

___

___

___

3. Did doubling any of the variables result in doubling the distance traveled?

___

___

___

Challenge 2: Design Sheet

Maximum Distance

TEAM NAME: **DATE:**

DESIGN # **TIME:**

Now that you have tested several variables, create a final design that will be submitted to the quarry owner. Your design will compete with the designs of the other teams. The wheel that travels the farthest while carrying the most weight will win!

Rules for Challenge 2 Design Competition

1. Using the results of your previous tests, design a wheel that will travel the farthest distance while carrying the most weight.
2. Your team must complete the Design Sheet **before** taking it to the test station.
3. All tests are public.
4. In case of a dispute, the teacher will be the final judge.
5. Be prepared to report on your team's progress. Keep neat and accurate records.

Description and drawing of new design (include measurements):

Final Number of Plates in Design Competition: ____________________

Final Distance in Design Competition: ____________________

Challenge 2 Wrap-Up

Questions for Class Discussion

- Which design changes did you find to be the most useful?
- Why do you think they worked so well?
- What design elements do the most successful gravity wheels have in common?
- What combinations of design changes seemed to work best?

Performance Variables

- Amount of mass of the gravity wheel

  An increase in the gravity wheel's total mass will enable it to travel farther.
- Location of the weight on the lever arm

  As the weight moves toward the axle, the amount of torque decreases. This change will decrease the distance that the wheel can travel.
- Angle of the lever arm

  As the angle of release decreases from the vertical position, the amount of torque decreases. This change will decrease the distance that the wheel can travel.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it traveled a sufficiently long distance on the test track with the maximum number of paper plates added. Additionally, students should be evaluated based on the results that they have recorded on their Design Sheets as well as the organization and neatness of their Data Sheets.

Challenge 3
Minimum Speed

Challenge Objective

Design a gravity-powered wheel that will travel the slowest while carrying a standard load. The variable that can be altered is the distribution of the mass on the wheel. The wheel must travel the same distance regardless of the placement of the mass. This test will be performed on the elevated test track. Place the track between two desks. The axles of the gravity wheels will sit directly on the track while the paper plates will extend outside the track.

Scenario Change

The rock quarry owner needs another device that will haul very fragile sheets of marble from one building to another. Since the marble is very expensive and can break very easily, the car hauling it must travel as slowly as possible, but must always cover the same distance. Your challenge is to create a model of the car's wheel that will travel at the slowest speed while carrying the same amount of weight over the same distance.

Materials

- Heavy duty paper lunch plates, 8 3/4 inches (22.2 cm) in diameter (use the same number as needed for the best design in Challenge 2)
- Wooden dowel, 3/16 inch (5 mm) diameter, 8 inches (20.3 cm) long (one per gravity wheel)
- Rubber faucet washers: beveled 5/8 inch (1.6 cm)—13/16 OD (four per gravity wheel)
- Corrugated cardboard cut into 2 × 2 inch (5 × 5 cm) squares (four per gravity wheel)
- Plastic drinking straw (one per gravity wheel)
- Heavy duty cold drink paper cups, 7 ounce (207 ml) size (two per gravity wheel)
- Bolts: 1/4–20 1/2 inch (1.3 cm) flat-head, slotted (24 per gravity wheel)
- Nuts: 1/4–20 (24 per gravity wheel)
- Hole punch, 1/8 inch (3 mm) size (or small nail)
- Hand-held pencil sharpener
- Data Sheet (one per team)
- Design Sheet (one per team)
- Compass
- Ruler or meterstick
- Plate hole template

Gravity Wheel Construction

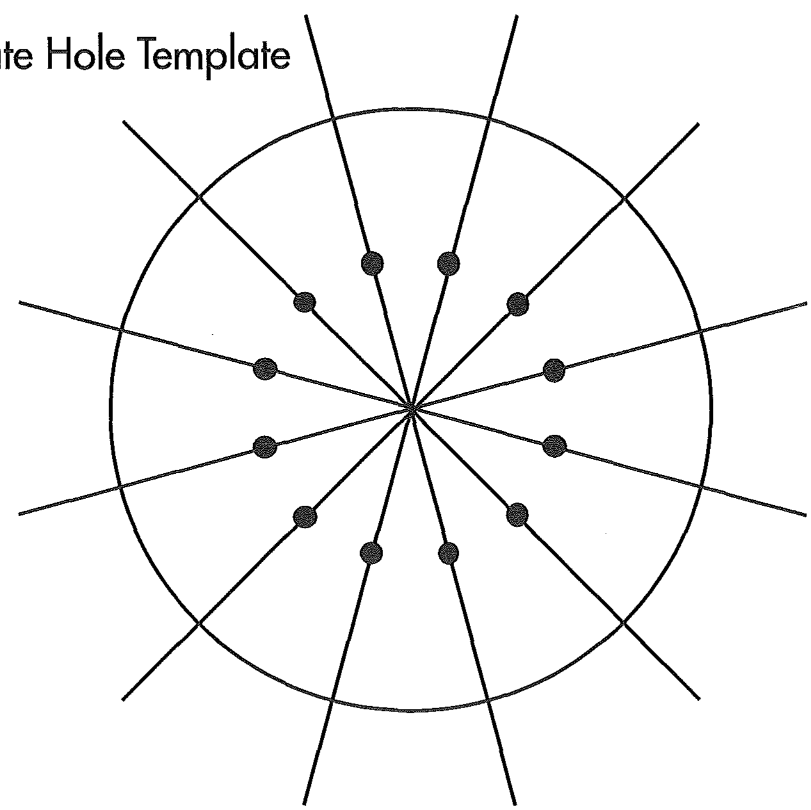
1. Using the results from your previous tests, choose the design from Challenge 2 that traveled the farthest distance.
2. Using a compass, draw concentric circles at 2 inches (5 cm), 3 inches (7.6 cm), and 4 inches (10.2 cm) from the center of the plates.
3. Draw straight lines radiating out from the center of the plates using a ruler. These lines should look exactly like the ones shown on the plate hole template.
4. Punch holes in the plate using a small nail where each of the lines intersects with the circles.

5. Place 12 nuts and bolts in the plate holes on each side of the gravity wheel (24 nuts and bolts total per gravity wheel).

Troubleshooting Tips

- Distributing the weight evenly on the wheel is very important because it ensures that the wheel will travel smoothly. A template is provided with this challenge. The teacher should glue the template to a plate, punch the holes in it where indicated, then provide it to the class so that students may use it as a stencil for their wheels. Students should remove the paper plates from their gravity wheels, place the template plate on them, and mark the locations of the holes with a pen. (Multiple templates may be needed for larger classes.) Students should use a compass to draw concentric circles at 2, 3, and 4 inches (5, 7.6, and 10.2 cm) from the center of the plate. Using a ruler, the template lines can be extended until they intersect with the circles. Students can then punch holes at all of the points where the lines intersect the circles.
- The faucet washers should fit tightly and prevent the plates from slipping. If they do not fit tightly, remove the axle and soak it in water for an hour. This will cause the wood to swell and will create a tighter fit.
- A nail can be used in placed of the hole punch.
- A cardboard box can be placed under the start of the test track to catch nuts as they fall.

Plate Hole Template



Procedures

Set-Up

Construct and display a gravity wheel on the test track so that students can observe its design and performance.

Demonstration

Show students the standard design and demonstrate how the gravity wheel operates on the elevated track by dumping weights from the weight cup onto the floor.

Class Discussion

Ask students to explain how they think the standard design works on the track. Ask them to speculate on how to alter the design's performance through design changes.

Cooperative Learning Groups

Challenge student teams to design a gravity wheel that will travel the slowest without changing the amount of load carried.

Instructions to Students

All teams must document and publish their progress. After running each test, teams post their results on a graph or chart for public viewing.

Challenge 3: Data Sheet

Minimum Speed

TEAM NAME: **DATE:**

Design A Vary the distribution of mass.

	Trial 1	Trial 2	Trial 3
Distance of bolts from center	**2 inches** (5 cm)	**3 inches** (7.6 cm)	**4 inches** (10.2 cm)
Number of nuts	3	3	3
Distance of cup from axle	3 inches (7.6 cm)	3 inches (7.6 cm)	3 inches (7.6 cm)
Angle from horizontal	90°	90°	90°
Distance traveled (inches or centimeters)			
Time			
Speed: distance 4 time (inches or cm./second)			
Number of plates (best design from Challenge 2)			

Test Results

1. Which location of the bolts caused the wheel to travel the slowest?

___

2. Why do you think changing the bolts location made the wheel travel more slowly?

___

___

___

Minimum Speed

TEAM NAME: **DATE:**
DESIGN # **TIME:**

Now that you have tested the variables, create a final design that will be submitted to the quarry owner. Your design will compete with the designs of the other teams on the elevated test track. The wheel that travels the slowest will win!

Rules for Challenge 3 Design Competition

1. Using the results of all your previous tests, design a wheel that will travel the slowest on the elevated test track. Your design must include all of the bolts, but you may attach them to the plate in any way that you choose.
2. Your team must complete the Design Sheet before taking it to the test station.
3. All tests are public.
4. In case of a dispute, the teacher will be the final judge.
5. Be prepared to report on your team's progress. Keep neat and accurate records.

Description and drawing of new design (include measurements):

Final Speed in Design Competition: ______________________________

Challenge 3 Wrap-Up

Questions for Class Discussion

- Which location for the bolts did you find to be the most useful?
- Why do you think that that bolt pattern worked so well?
- What design elements do the most successful gravity wheels have in common?
- What combinations of design changes do you think would work best?

Performance Variables

- Mass distribution of the gravity wheel:

  Changing the distribution of the mass (without changing the amount of mass) on the wheel affects the wheel's rotational inertia. Clustering the mass close to the center causes the wheel to rotate more quickly. Spreading the mass farther out causes the wheel to rotate more slowly. Note, however that NEITHER of these variables affect the overall DISTANCE covered, only the speed at which the distance is covered.

Competence & Performance Criteria

Each student's design should be evaluated to determine if it traveled a set distance on the elevated test track in a sufficiently long amount of time. Additionally, students should be evaluated based on the results that they have recorded on their Design Sheets as well as the organization and neatness of their Data Sheets.

Wrap-Up Activities

Class Discussion Questions

Use any of the following questions to initiate student discussion about ideas explored during the design challenges:

- Did you ever think about gravity before doing these challenges? What were your thoughts?
- How are the challenges that you encountered here different from what an engineer would have to deal with when designing a gravity wheel in the "real world"? What other factors might the engineer consider?
- What would you do to explain how a gravity wheel works to a young child?
- In what other situations would your understanding of gravity, torque, and rotational inertia be useful?
- In what other situations could you use your design skills or your experience building and testing models?
- Create an analogy comparing gravity wheels to some other device.

Report Topics

The following topics are suggested for student reports, presentations, or journal entries:

- Write the history of how you developed your design for one of the challenges. What were the successes and failures? Why did you make your design changes?
- Describe how your ideas changed during the design process from one challenge to the next.
- Write a creative story featuring a gravity wheel. Use the story to explain the concepts of gravity, torque, and rotational inertia.
- Now that you have completed the Gravity Wheel Module, list any questions that you still have about designing gravity wheels. Include ideas for how you might find answers to your questions through research and/or experimentation.

Storyboard Frame Design

Students obtain significant amounts of data while working on the challenges; some of these data are recorded on the data sheets. These data, as well as other information, can also be used to create a narrative poster, or storyboard.

A storyboard is a formal poster which is built during the design challenges. A large sheet of cardboard or poster board can be used. Divide the sheet into several large sections. After each design iteration, ask students to record their designs on the storyboard. The storyboards can be displayed in the classroom as "works in progress."

The following items should be included in the storyboard frames:

- Drawing of the Design
- Number of nuts in the cup
- Distance of the cup from the axle
- Angle of the lever arm
- Number of paper plates used (Challenge 2 and Challenge 3)
- Location of bolts attached to the paper plates (Challenge 3)
- The changes made from the previous design
- The changes that you would make to a future design

In-Class Assignments or Homework Assignments

Teacher's Note

Throughout the module, you may wish to assign additional work for students to complete either in class, while waiting between test trials, or at home. These activities support cross-curricular team teaching and can be assigned through other classes. You can also use the assignments as a re-teaching tool, or as part of student assessment.

Vocabulary

The vocabulary sheet provided is a list of terms and concepts encountered during the module. Students should use complete sentences and should write definitions in their own words. They may use dictionaries or science books to assist with definitions, but should not copy directly from these references. Students should display their understanding of the terms by using examples from the challenges that they have completed.

Graphing

Students graph the data from the challenges. Note that Graph D of Challenge 1 may be difficult for students since it involves two variables graphed along the same axis. Explain to students that two sets of units (e.g., distance and angle, or number of nuts and distance) may be put on the same axis, and two lines will be drawn on the same graph.

The History of Gravity

Students answer questions about what they have learned from reading the **History of Gravity**.

Devices that Use Gravity

Students are encouraged to look around them and consider the multitude of uses for gravity, both direct and indirect.

Assessment

Assessing Student Competence

Students have effectively mastered the concepts presented in this module if they have achieved the following:

- Student can use the gravity wheel and other devices to explain the concept of gravity.
- Student has an understanding of the principles behind Newton's three laws of motion.
- Student can use the gravity wheel and other devices to explain rotational inertia.
- Student can calculate speed.
- Student can graph data results.

Criteria

Science Process Skills

The student has learned the correct science process skills if the following criteria have been met:

- The student was able to **define single variables** during the design process and **create experiments** that tested the importance of each variable.
- The student used the results of one experiment to provide information for the next.
- The student used the data sheets effectively to record information about each design.

Concept Knowledge

Evaluate the student's knowledge of concepts by answering the following questions:

- How is the student thinking about potential energy, kinetic energy, torque, and rotational inertia in the context of the gravity wheel design?
- Is the student able to explain torque and rotational inertia using examples from the various designs?

Student Products

Teachers may wish to have students create final products that encapsulate the results of the challenges in a format other than the storyboard. Portfolios, posters, and reports are suggested products for this purpose, and can be used to assess the student's understanding of the module.

Portfolios

Students create a portfolio using copies of their data sheets as well as any written assignments. Ask students to include an introduction explaining what they learned during the module.

Posters

Students design a poster which explains each design challenge using drawings, diagrams, and written explanations.

Reports

Students select or are assigned a report topic from the list shown in the **Wrap-Up Activities** section of this module. Researching and writing reports allows students to analyze a particular challenge or concept more deeply, providing an opportunity for increasing their understanding of the module topic.

Answers for Worksheets

Vocabulary

Use with student pages 31–32

Write definitions to the following terms in complete sentences and in your own words. You may use dictionaries or science books to help you with definitions. Use examples from the challenges that you have completed.

gravity ***The ability of a mass to attract any other mass.***

force ***A push or a pull on an object. The challenges utilize the falling weights as the force that starts the motion of the gravity wheel.***

torque ***The product of force applied to a lever arm, most often in a rotational action. The challenges utilize torque to start the motion of the gravity wheel.***

mass ***The amount of matter in an object. The challenges consider the amount of mass applied to the wheel in terms of its distribution over the wheel.***

inertia ***Newton's first law of motion, stating that objects that are in straight line, constant speed motion will remain in motion and objects that are at rest will remain at rest until an external force is applied to change their initial state. The challenges utilize inertia to maintain the forward motion of the gravity wheels once the weights have dropped.***

weight ***The amount of gravitational pull on an object. The challenges use weight to start the forward motion of the gravity wheels.***

energy ***The ability to cause change. The challenges use the energy of the weights to change the state of the gravity wheel from that of rest to motion.***

kinetic energy ***The energy of motion. The challenges use the weights falling from the cup to provide the gravity wheel with motion.***

potential energy ***Energy that is available for use. The challenges use the potential energy of the weights to move the wheel.***

Graphing

Use with student pages 33–36

Using the data from the challenges, create the following graphs.

Challenge 1: Maximum Speed

A. Number of nuts vs. speed

Graphs will vary according to students' results.

B. Distance of cup from axle vs. speed
Graphs will vary according to students' results.

C. Angle of lever arm vs. speed
Graphs will vary according to students' results.

D. The two variables that you selected vs. speed
Graphs will vary according to students' results.

Challenge 2: Maximum Distance

A. Number of paper plates vs. distance traveled
Graphs will vary according to students' results.

B. Distance of cup from axle vs. distance traveled
Graphs will vary according to students' results.

C. Angle of lever arm vs. distance traveled
Graphs will vary according to students' results.

Challenge 3: Minimum Speed

A. Distance of bolts from center of wheel vs. speed
Graphs will vary according to students' results.

The History of Gravity

Use with student pages 37–40

Answer the following questions in complete sentences.

1. How did ancient cultures in India and Mesopotamia use gravity?
These cultures constructed aqueducts that carried water to their villages and fields.

2. How does an aqueduct work?
An aqueduct is sloped from one end to the other to allow gravity to move water from the top to the bottom.

3. Aqueducts consist of what types of structures?
Aqueducts are made up of canals, tunnels, and/or bridges.

4. What are four types of timekeeping devices that use gravity to operate?
Hourglasses, clepsydra, mechanical clocks (utilizing falling weight) and pendulum clocks.

5. What was the original name for timekeeping devices? What does this mean?
The original name was "horologium" which means "hour teller."

6. How did timekeeping devices come to be known as "clocks"?
Mechanical clocks were kept high in bell towers. The Middle English and Old French word for "bell" was "clock," spelled "clokke" and "cloke" respectively. Both are derived from the Latin "clocca."

7. What timekeeping device did Galileo's experiments bring about?

Galileo's experiments brought about the ideas for the pendulum clock.

8. What timekeeping devices that use gravity do you see around you today?

The hourglass and the pendulum clock are still used today.

9. Why do we feel gravity from the Earth but not from a chair?

All objects exert gravity, but it is proportional to each object's mass. The Earth has a far greater mass than a chair.

10. What is Newton's first law of motion?

Newton's first law of motion is the definition of inertia: objects at rest will remain at rest and objects in straight line motion at constant speed will remain in motion until a sufficient force is applied to alter their current state.

11. What is Newton's second law of motion?

The second law states that if a force is applied to an object, the object will move in the direction of the force. This law also states that the greater the mass of the object, the greater the force necessary to move it.

12. What is Newton's third law of motion?

The third law states that whenever one object exerts a force on another object, the second object will exert an equal force opposite to that of the first object on the first object.

13. What is inertia?

Every object continues either in its state of rest or its state of constant speed motion in a straight line until an outside force acts upon it causing a change in its state.

14. What was the name of the first commercial railway in the United States and why was it constructed?

The Granite Railway Company was constructed in 1826. Engineers designed it as a gravity powered railway to haul granite.

15. How do scientists use gravity today when they design devices? Give examples.

Scientists often use gravity to assist with the work of objects that they design. Examples include the giant water turbines that generate hydroelectricity as well as the ink flow in ball-point pens.

16. What special consideration must scientists and engineers give to designing devices that work in outer space?

Items designed for use in outer space must not utilize gravity in order to work. The effect of an object's gravity decreases with distance; spacecraft very far from a planet "feel" little gravity. A spacecraft orbiting a planet is falling which makes it seem as if there is no gravity.

Devices that Use Gravity

Use with student pages 41–42

1. Look around your home and list at least three devices that use gravity directly in order to do a job (example: a paper weight). Explain how each device works.

   Answers will vary but should include devices such as a pencil cup, a paperweight, a telephone cradle, etc. In each case gravity is acting directly upon the object as the primary effort.

2. If the devices were made bigger or smaller, would that change how each works? Explain how it might for each.

   Answers will vary. Larger devices may be more difficult to hold, carry, or maneuver due to an increase in size. They may also exert too much force. Smaller devices may not exert enough force (e.g., a tiny paperweight may not be heavy enough to hold down paper in the wind.)

3. List at least three examples of devices that use gravity indirectly to do a job (example: a faucet placed over a sink. The water is what we use to wash things, but gravity pulls the water down.) Explain how each device works.

   Answers will vary but should include items such as a computer mouse, a ball-point pen, or a compact disk player. Each relies on gravity to pull something down so that it can be used to perform another task.

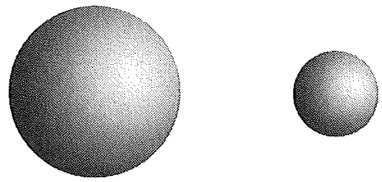
Assessment Answers

Pre/Posttest

Use with student pages 5–6 and 45–46

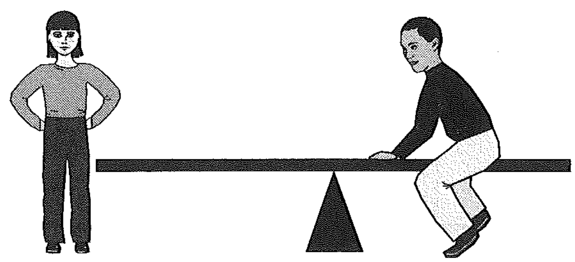
Answer the following questions in complete sentences.

1. Which steel ball would hurt more if it fell on your foot?



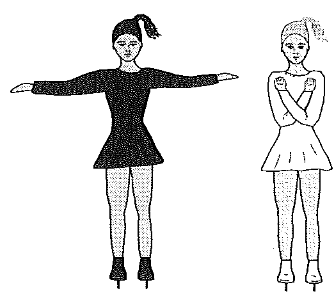
The larger ball has more mass. More gravitational force is exerted on it, so it would be heavier and would hurt more falling on one's foot.

2. Where should lightweight Heather sit to most easily lift big Marcus off the ground? Give reasons for your answer.



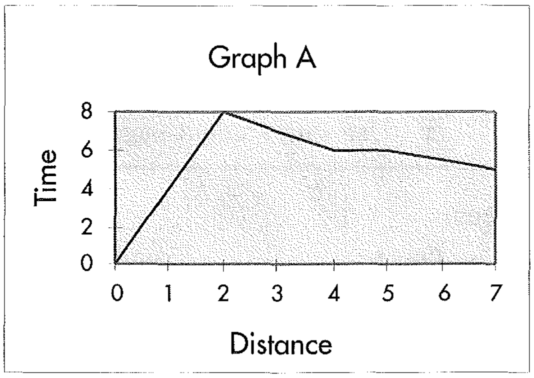
Heather should sit farther out on her side of the see-saw than Marcus is sitting on his side. The torque of each would be equal because the lever arm length is greater on Heather's side.

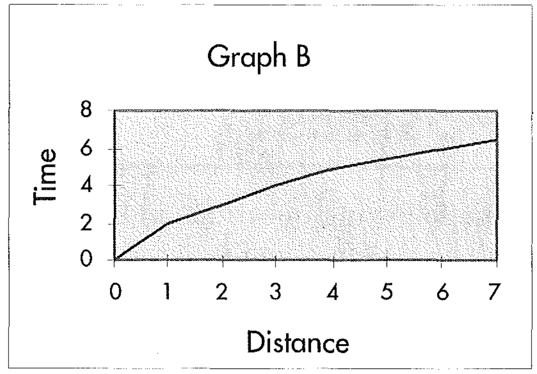
3. Which skater can spin the fastest? Why?



The skater with arms pulled in close to her body will spin faster because this reduces rotational inertia.

4. Which distance-time graph represents a gravity wheel that speeds up quickly and then slowly decreases its speed?





Graph B portrays this effect because it slopes up sharply then begins to level off.

5. In the grocery store your dad asks you to push the grocery cart, so you give a push and then let go. Give a reason for why it keeps going all by itself after you are not touching it anymore.

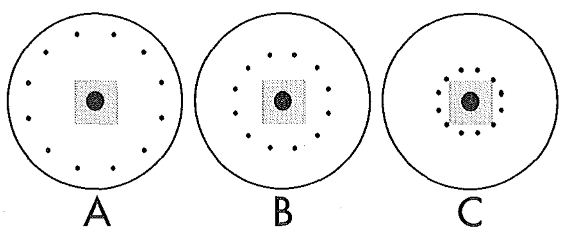
Newton's first law of motion, inertia, describes this behavior: objects put in straight line motion will stay in motion until another force exerted upon them causes them to stop.

Assessment

Use with student pages 47–48

Answer the following questions.

1. All three gravity wheels are tested on the same track using the same amount of falling weight. Which will cover the distance fastest? ***C***

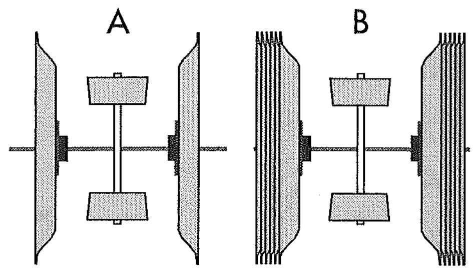


The wheel with weight distributed close to the axis will travel the fastest.

2. One student team made four different gravity wheels. If each of the wheels had the same mass, which wheel had the greatest kinetic energy? The wheel traveling at: ***B***

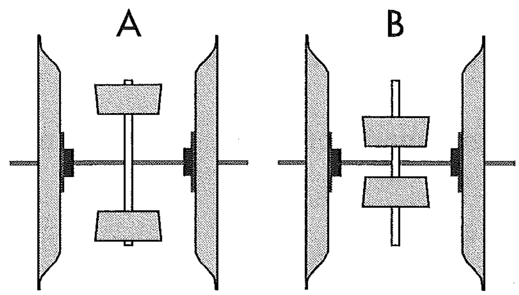
A. 1 m/s **B.** 2 m/s **C.** 1.5 m/s **D.** 0.5 m/s

3. Which gravity wheel will go faster? Why?



The gravity wheel with fewer paper plates on its axle (A) has less mass and will travel faster.

4. Which cup position will cause the wheel to go faster? Why?



The cup placed at the end of the lever arm (A) will result in more torque. This will drive the wheel ahead more quickly.

5. The distance of an object above the ground affects its potential energy.
TRUE

6. Applying weight to the outer edges of a wheel will make it spin faster.
FALSE

7. Sliding the cup containing the weights to the end of the lever arm (far away from the axle) on the gravity wheel will increase torque.
TRUE

8. The gravity wheel will travel more slowly if the rotational inertia is increased.
TRUE

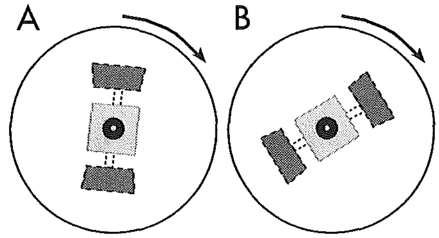
9. Increasing the number of weights dropping from the cup of the gravity wheel causes the speed to decrease.
FALSE

Content/Concept Questions

Use with student pages 49–51

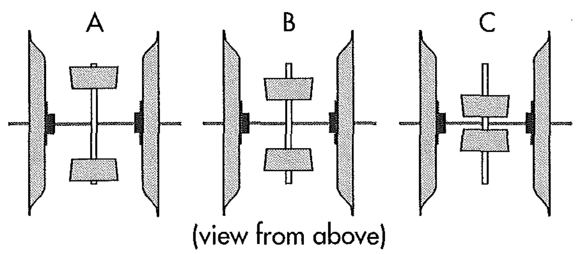
Answer the following questions in complete sentences.

1. Which gravity wheel has more potential energy? Why?



The wheel with the lever arm at a higher angle from horizontal (A) has more potential energy because the distance from the weight to the ground is greater.

2. Which cup position represents more torque for the same number of nuts? Why?



The cup located farther out on the lever arm (A) has more torque.

3. Two gravity wheels are exactly alike except for the number of nuts in the cup: One has three and the other has nine. Which wheel has more potential energy before it is released? Why?

   The cup with 9 nuts has more potential energy. Nine nuts have more mass than three nuts and thus more weight, increasing the amount of potential energy.

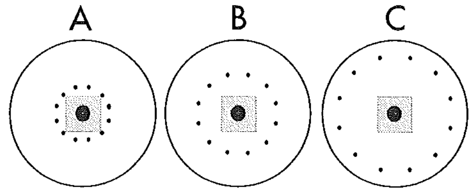
   Which wheel will stop first? Why?

   The wheel with 3 nuts will stop first. This wheel has less kinetic energy and exerts less torque.

4. Two gravity wheels travel the same distance but one moves more slowly than the other. Why could this be?

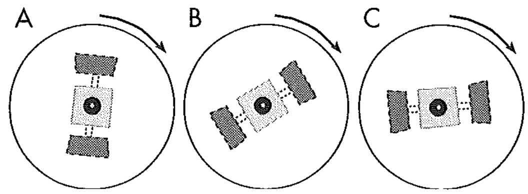
   The wheel moving more slowly has mass distributed toward the outer edge while the wheel that moves more quickly has mass clustered around the axis.

5. Which wheel has more rotational inertia?



The wheel in sketch C will have more rotational inertia because the weights are on the outer edges of the wheel.

6. Which gravity wheel has more torque?



The wheel in sketch A will have greater torque because the lever arm is at a position nearly perpendicular to horizontal.

Open-Ended Questions

Use with student pages 55 and 56

1. You have designed a gravity wheel that travels a distance of one foot in 57 seconds. Your friend has designed a wheel that travels the same distance in 32 seconds. Explain the possible differences between the designs that could result in their traveling the same distance at different speeds.

   Answers will vary but should include a discussion of weight distribution on the wheel and the effects of this on rotational inertia.

2. You have created a gravity wheel that has more kinetic energy than the one your friend made. However, both of you are using the same amount of weight on the lever arm. Explain how your wheel has more kinetic energy. Use drawings to explain the differences between the designs.

   Answers will vary, but should discuss either the weight shifting down the lever arm toward the axle or the lever arm being tilted more toward the horizontal position. Either of these variables will decrease the height of the weight from the floor, decreasing kinetic energy.

3. List all of the variables that affect the speed of a gravity wheel. Discuss how you would combine these variables to create the fastest wheel possible.

   Answers will vary but should include a discussion of the amount of weight used on the lever arm, the position of the cup holding the weight on the lever arm, the angle of the lever arm, the total mass of the wheel, and the mass distribution. Combining the variables to increase speed includes creating the greatest amount of kinetic energy and the least rotational inertia.

Rubrics

Generalized Rubric for Gravity Wheel Challenges

Problem Solving

Problem Solving

4. Identifies creative but plausible solutions to the problem under consideration. The solutions address the central difficulties posed by the scenario, constraint or obstacle.
3. Proposes alternative solutions that appear plausible and that address the most important constraints or obstacles.
2. Presents alternative solutions for dealing with the obstacles or constraints, but the solutions do not address the important difficulties.
1. Presents solutions that fail to address the critical parts of the problem.

Exploring Ideas

4. Demonstrates an extensive knowledge of information resources and commands a wide range of information-gathering techniques. Demonstrates creativity and resourcefulness in collecting ideas and creating original ideas.
3. Demonstrates a knowledge of basic information resources and commands a useful range of information-gathering techniques.
2. Demonstrates a knowledge of some basic information resources but is not aware of all necessary resources, or has command of a limited set of information-gathering techniques.
1. Demonstrates little familiarity with basic information resources or demonstrates a command of only a few basic information-gathering techniques.

Evaluation/Analysis

Observing

4. Notices all detail.
3. Notices most detail.
2. Major errors in observations.
1. Many major inaccuracies.

Choosing a Solution

4. Decides which idea is likely to be the best solution and sets up a way to try and see if it works.
3. Selects what seems to be the best solution and tries it out in a way that will show if it works.
2. Selects what seems to be the best solution but does not try it out in a way to show that it works.
1. Selects what seems to be the best solution but does not try it out.

Evaluating

4. Analyzes the information in detail, accurately and insightfully determining whether it is credible and relevant to the task.
3. Accurately determines whether information is credible and relevant to the task.
2. Makes some significant errors when determining whether information is credible and relevant to the task.
1. Makes little or no attempt to determine whether the information is credible and relevant to the task or totally misjudges the credibility and relevance of the information.

Critical Thinking

4. Consistently translates issues or situations into well articulated tasks that have clearly defined goals and well articulated thinking processes. When appropriate, anticipates difficulties and develops plans to overcome them.
3. Consistently translates issues and situations into tasks that have clearly defined goals and identifiable thinking processes.
2. Sporadically translates issues and situations into tasks that have clearly defined goals and identifiable thinking processes.
1. Rarely, if ever, translates issues or situations into tasks that have clearly defined goals and identifiable thinking processes.

Testing Solutions to Problems

4. Engages in effective, fair, and complete trials of the selected alternative solutions. Trials go beyond those required to solve the problem and show a commitment to an in-depth understanding of the problem.
3. Tests the selected alternatives in trials adequate to determine their utility.
2. Tries out the alternatives, but the trials are incomplete and important elements are omitted or ignored.
1. Does not satisfactorily test the selected alternatives.

Experimental Inquiry

4. Demonstrates an understanding that the selection of manipulated and controlled variables determines whether or not an experiment will produce meaningful results.
3. Understands that the selection of manipulated and controlled variables determines whether or not an experiment will produce meaningful results and usually changes only one variable at a time.

2. Sometimes controls variables and sometimes changes one variable, but does not realize that this has caused a change in another variable that should have been controlled in order to determine which of the two (or both) had caused the new behavior.
1. Ignores the necessity to control variables and thus conclusions made from measurements taken may be invalid.

Effectively Interpreting and Synthesizing Information

4. Interprets the information or data gathered for a task in accurate and highly insightful ways. Provides a highly creative and unique synthesis of the information.
3. Accurately interprets information/data collected for a task and concisely synthesizes it.
2. Makes significant errors in interpreting the information/data determined from the activity or synthesizes the information imprecisely or awkwardly.
1. Grossly misinterprets the information assembled for the task or fails to synthesize it.

Application

Predicting/Hypothesizing

4. Makes predictions that reflect insight into the character of what makes a structure work. Uses facts and concepts of structures to make predictions.
3. Makes predictions that follow from the facts or concepts in structures.
2. Makes predictions which display a misunderstanding of some of the concepts in structures.
1. Makes predictions which display many misunderstandings of the concepts in structures.

Model Building

4. The final process or product goes beyond its intended purpose.
3. The final process or product serves its intended purpose.
2. The final process or product partially serves its intended purpose.
1. The final process or product does not serve its intended purpose.

Concept Knowledge

4. Demonstrates deep understanding of the concept, can give a working definition and use formulas correctly. Student is able to apply the concept to a variety of situations.
3. Can give a working definition of the concept. Makes some errors in measurement and use of formulas. Student attempts to apply the concept in other situations.
2. Can give a working definition of the concept. Makes errors in measurement and use of formulas. There is little attempt to apply concept to other situations.
1. Has a vague notion about the concept and does not see how it relates to real situations.

Reasoning Strategy: Experimental Inquiry

4. Provides an accurate explanation of the phenomenon. The facts, concepts, or principles used for the explanation are appropriate to the phenomenon and accurately applied. The explanation reflects thorough and careful research or understanding.
3. Provides an accurate explanation of the phenomenon. The facts, concepts, or principles used in the explanation are appropriate to the phenomenon and accurately applied with no significant errors.
2. Explains the phenomenon but misapplies or omits some facts, concepts or principles that are important for understanding the phenomenon.
1. Leaves out key facts, concepts, or principles in explaining the phenomenon, or does not use appropriate facts, concepts, or principles to explain the phenomenon.

Expressing Ideas Clearly

4. Clearly and effectively communicates the main idea or theme and provides support that contains rich, vivid, and powerful detail.
3. Clearly communicates the main idea or theme and provides suitable support and detail.
2. Communicates important information but not a clear theme or overall structure.
1. Communicates information as isolated pieces in random fashion.

Documentation

Recordkeeping

4. Demonstrates mastery over record keeping. Keeps complete, accurate records neatly and well laid out.
3. Keeps complete records with occasional minor inaccuracies.
2. Keeps mostly complete records with occasional major inaccuracies.
1. Keeps incomplete records with major inaccuracies in designs, results and thinking.

Collaborative Worker[1]

Working Toward the Achievement of Group Goals

4. Actively identifies the group's goals and works hard to meet them.
3. Is committed to the group's goals and effectively carries out assigned role and tasks.
2. Is committed to the group's goals and tasks but does not carry out assigned roles and tasks.
1. Is not committed to the group's goals and tasks and does not carry out assigned roles or tasks.

[1]Adapted from "Assessing Student Outcomes," *Performance Assessment Using the Dimensions of Learning Model*, Robert J. Marzano, Debra Pickering, Jay McTighe, Association of Supervision and Curriculum Development, Alexandria, VA, 1993.

Performing a Variety of Roles Within the Group

4. Effectively performs several roles within the group.
3. Effectively performs two roles within the group.
2. Attempts to perform more than one role within a group but encounters little success with the secondary role.
1. Resists opportunities or requests to perform more than one role within a group.

Contributing to Group Maintenance

4. Actively helps the group identify changes needed in how the group operates and works toward carrying out those changes.
3. Helps identify changes needed and works toward carrying out those changes.
2. When prompted, helps to identify changes needed in the group and/or is only minimally involved in carrying out those changes.
1. Does not attempt to identify changes needed to make the group work better and does not work toward making changes.

Extensions and Connections

Extensions

Newton's Laws

Ask students to identify Newton's three laws of motion. Have students describe how Newton's Laws, especially the first and second laws, apply to the Gravity Wheel Challenges.

Gravity Wheel Cart

Have students design a cart that will sit on the gravity wheel. Design alterations, such as a wider axle or an additional set of wheels with no lever arm, may be necessary. Have students test their designs carrying different loads.

Inclined Plane

Discuss how an inclined plane can enhance the use of gravity. Have students repeat their tests for the challenges on an inclined plane and compare the results.

Friction

Discuss how friction affects the results of the challenges. Repeat the challenges with high friction substances such as sand paper or rubber attached to the test track beneath the gravity wheels.

Personalize the Gravity Wheel

Gravity wheels can be disassembled and taken home where students can color or paint on the paper plates to personalize their designs.

Cross-Curricular Connections

History

Gravity has been used to tell time for centuries, initially with water clocks, then using pendulums. Later, timekeeping devices that did not rely upon gravity were developed. Assign a research project which compares timekeeping devices throughout history and the importance of each.

Reading

Using the vocabulary words as a guide, select books for student reading that focus on science in the time of Sir Isaac Newton and the understanding of the laws of nature.

English

Assign a creative writing project in which a student describes life in a weightless environment, from the time that they wake up in the morning to the time that they go to sleep at night.

Biology

Have students look up the effects on the human body of living in a weightless environment.

Math

Discuss ways to calculate efficiency, then graph the calculations.

Science

Discuss the differences in gravitational forces on the surfaces of the various planets in our solar system. Ask the students how they would design devices to utilize gravity in these different environments.

Art

Show students various mobiles designed by Alexander Calder and others. Ask students to think about the effects of gravity on these mobiles, then have them design their own.

Resources

World Wide Web Sites

The Energy Fact Sheet, published by the Energy Educators of Ontario, Canada 1993 http://www.iclei.org/efacts/tidal.htm

Numerical Aerospace Simulation (NAS) Facility at NASA—Ames Research Center http://science.nas.nasa.gov/Services/Education/

NASA's education program http://www.hq.nasa.gov/office/codef/education/

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