ROLLER COASTER

A simulation solving a scientific mystery while learning about the science of motion

BONNIE PETTIFOR VREEMAN, the author of ROLLER COASTER, received her B.A. in English and M.A. in Education from Washington University, St. Louis, Missouri. A former elementary teacher in both American and overseas public and private schools, currently she is a freelance writer and editor residing in Illinois. For Interact she also wrote NEW ATLANTIS, a simulation of scientific teams wisely using the Ocean Planet's inner space habitats, INSECT ISLAND and FUDGE FACTORY, two other titles in the Science Mystery Series for Intermediate Students.

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Interact
10200 Jefferson Boulevard
P.O. Box 802
Culver City, CA 90232-0802
800-359-0961
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PURPOSE

Your students become true scientists as they work to solve a scientific mystery. After working to solve the mystery, students become better prepared to conduct and understand scientific investigations. Through using the scientific method during the simulation, they learn to hypothesize, observe, draw conclusions from factual information, and carefully record their endeavors in a science journal—just as scientists do. Specifically, your students will gain the following:

Knowledge
1. Understanding of Newton's three Laws of Motion and how they influence our world
2. Understanding of related physics concepts and terms (inertia, friction, gravity, kinetic and potential energy)
3. Learning or reviewing the steps of the scientific method
4. Learning importance of proper experimental design
5. Learning about related historical highlights and how science knowledge in this area developed
6. Learning how these physics principles affect our daily lives, including our safety

Skills
1. Working as a team with classmates
2. Conducting experiments according to the scientific method
3. Enhancing language arts and problem-solving skills through accurately collecting and recording scientific data, observations, and questions in a journal
4. Reading for information and discerning helpful data

Feelings and Attitudes
1. Developing and valuing a sense of teamwork
2. Increasing confidence in applying the scientific method
3. Respecting how Newton's Laws of Motion and other related concepts affect our daily lives, especially in the realm of safety
4. Appreciating accurate record keeping

OVERVIEW

Most students are fascinated by mysteries because they are able to take pieces of information and see how they fit together as they attempt to solve a problem. Unfortunately, some students are under the impression that all mysteries are connected with murder and suffering because that's what they see on television and in the movies. Students need to recognize that real people investigate and solve mysteries daily in science, history, health, engineering and many other disciplines. ROLLER COASTER is a simulation that exposes your students to a scientific mystery. As they use the scientific method during this simulation, they have the opportunity to work as scientists do to solve a real mystery. This simulation will engage, excite and challenge students as they actively increase their understanding of the scientific process. Students are motivated and excited as they uncover clues and gain information, much like a detective does. ROLLER COASTER is part of Interact's Science Mysteries series, stressing the scientific method and discovery. The author also contributed INSECT ISLAND to this series and wishes to thank Beth Arner who began the series with PETERSON'S POND and MYSTERIOUS MACHINE.

ROLLER COASTER consists of three distinct phases.

- **Phase 1** covers the basics of the laws of motion and related concepts through brief written histories and basic science experiments and activities.
- **Phase 2** explores more details and offers further examples of the laws of motion and related concepts as students work to solve the mystery.
- **Phase 3** provides several options for extending this simulation, including ideas for culminating events and challenging independent study projects.

PHASE 1: MOMENTOUS HISTORY (OPTIONAL)

Students learn about the major historical people and moments related to discoveries in the field of motion and gravity. Then they conduct experiments to illustrate these discoveries using the scientific method.

1. **Eureka! Moments**
   These brief histories provide teachable opportunities to explore the following:
   - Aristotle and Galileo and freely falling objects; controlling experimental design
   - Galileo and Newton's First Law of Motion
   - Huygens and Newton's Second Law of Motion
   - Newton's Third Law of Motion
   - Newton's Law of Universal Gravitation
2. **Eureka! Activities**
   These activities re-enact and illustrate the moments in scientific history discussed in the Eureka! Moments, demonstrating the principles discovered and showing how Newton expanded upon and corrected the earlier work of Aristotle and Galileo. These Activities lay the groundwork for the scientific study in the Phase 2.

3. **Phase 1 is optional**
   If your students are already familiar with the scientific method and the concepts underlying the laws of motion and gravitation, you may simply have them read and discuss the contents of the Student Guide: Phase 1, then proceed to Phase 2.

PHASE 2: ROLLER COASTER WORLD

TEACHING TIP

The Phase 2 explorations expand students' knowledge about the scientific process and the importance of carefully recording observations and experimental notes.

This phase, the main portion of the simulation, guides students through a scientific mystery set in an amusement park where the rides are not working reliably. Divided into teams, students explore Roller Coaster World with "Ms. Roundenround," the amusement park's owner, searching for clues and participating in a variety of laboratory explorations. Students apply what they have learned about the laws of motion and gravitation to solve the mystery.

1. **T.E.A.M. Activities**
   Each day, students participate in daily group problem solving sessions, called T.E.A.M. Activities (**T**ogether **E**veryone **A**ccomplishes **M**ore), which provide basic and

additional information about and examples of related physics principles to help them solve the mystery.

2. **Clue Searches**
   Students receive information about the problems plaguing the park's five most popular rides in the form of CLUE SEARCH information sheets, written as narratives of student experiences at the amusement park.

3. **Design Tests**
   Students explore the questions raised by the CLUE SEARCH information and gain additional practice in use of the scientific method as they complete five DESIGN TEST activities. Students then "program" a simulator with their design corrections for the roller coaster in question and enjoy a scripted *virtual ride*.

4. **Student Debriefing and Recommendations**
   At the end of each day, during a short debriefing session, students discuss what they have learned that day. Ride by ride, students report their recommendations to Ms. Roundenround on a **SCIENTIFIC DETECTIVE RECORD FORM**. After working on the five mystery sessions in Phase 2 and going through a final debriefing session, students are able to make their own judgments about what overall advice to offer to Ms. Roundenround. They then give Ms. Roundenround their recommendations and suggestions (which should be considered reasonable as long as adequate support is given for the arguments chosen).

PHASE 3: EXTENSIONS (OPTIONAL)

Based on the interests and abilities of your students and the time available, decide whether you will extend the learning of the simulation with extension activities.

- Oral presentations of group recommendations to a person acting as Ms. Roundenround.
- Eureka! Moment Re-enactments
- Construction of Marble Coasters
- Challenge Projects
- Audiotape with sound effects of one or more of the roller coaster Virtual Ride scripts.

SETUP DIRECTIONS

1. **Preparation Reading**
   Carefully and thoroughly read this Teacher Guide and both Student Guides *before* beginning this simulation. This will help you plan your time and adjust this simulation to meet your students' needs and abilities.

2. **Science Journals**
   Each student in your class needs a *science journal*. Plan time every day during class (or assign for homework) for students to write their observations and conclusions in their journals. ROLLER COASTER includes a duplicable MY SCIENCE JOURNAL master to use as a cover.
   a. Students make these journals by gluing their copy of MY SCIENCE JOURNAL to:
      - a composition book or notebook
      - folded construction paper (11" x 17")
   b. Each student's science journal should include:
      - the GLOSSARY
      - SCIENTIFIC METHOD
      - at least 10 sheets of lined paper

TEACHING TIP

The GLOSSARY provides an excellent reference for the terminology used throughout this unit. Encourage your students to use this tool!

3. **Schedule**
   The schedule of this simulation is flexible. Study the Unit Time Chart. It is organized by investigations, not by days. If you plan on 45 to 50 minutes for each class period, Phase 1 activities will take approximately five class days to complete. With the same amount of time each day, Phase 2 will take approximately 10 days to complete.
   a. Be sure to look carefully through each phase to determine how you can best use this simulation in your classroom.
   b. If your students need background knowledge regarding Newton's Laws of Motion and related concepts, Phase 1 will prepare them for Phase 2.
   c. Even if your students have some knowledge of Newton's Laws of Motion, consider reading and discussing the Eureka! Moments in the Student Guide: Phase 1.
   d. f you decide to have your students take what they have learned in this simulation one step further, add the time you think they will need to complete the optional Phase 3.

4. **Grouping Students**
   Divide your students into groups of six, to remain together throughout the simulation. If the numbers of students do not divide evenly, some students must be responsible for sharing more than one set of T.E.A.M. ACTIVITY strips during Phase 2.

SETUP DIRECTIONS

5. **Duplication**
   Make copies of the following pages in the quantity indicated in *Italics*. The master pages for you to duplicate begin on page 57.
   Phase 1:
   MY SCIENCE JOURNAL* — *class set*
   YOUR SCIENCE JOURNAL* — *class set*
   SCIENTIFIC METHOD* — *class set*
   EUREKA! ACTIVITY 1: Part 1 — *class set*
   EUREKA! ACTIVITY 1: Part 2 — *class set*
   EUREKA! ACTIVITY 2 — *class set*
   EUREKA! ACTIVITY 3 — *class set*
   EUREKA! ACTIVITY 4 — *class set*
   EUREKA! ACTIVITY 5 — *class set*
   ROLLER COASTER GLOSSARY* — *class set*
   * Needed in Phase 2, even if you opt to not do Phase 1.
   Phase 2:
   CLUE SEARCH 1: The Anaconda — *class set*
   CLUE SEARCH 2: The Phantom Dragon — *class set*
   CLUE SEARCH 3: The Outlaw — *class set*
   CLUE SEARCH 4: The Rattlesnake — *class set*
   CLUE SEARCH 5: The Cobra Spitfire — *class set*
   WHAT ARE T.E.A.M. ACTIVITIES? — *class set*
   T.E.A.M. ACTIVITY 1 — *one set of strips per group*
   T.E.A.M. ACTIVITY 1 RECORD — *one per group*
   T.E.A.M. ACTIVITY 2 — *one set of strips per group*
   T.E.A.M. ACTIVITY 2 RECORD — *one per group*
   T.E.A.M. ACTIVITY 3 — *one set of strips per group*
   T.E.A.M. ACTIVITY 3 RECORD — *one per group*
   T.E.A.M. ACTIVITY 4 — *one set of strips per group*
   T.E.A.M. ACTIVITY 4 RECORD — *one per group*
   DESIGN TEST 1:The Anaconda — *one per group*
   DESIGN TEST 2:The Phantom Dragon — *one per group*
   DESIGN TEST 3:The Outlaw — *one per group*
   DESIGN TEST 4: The Rattlesnake — *one per group*
   DESIGN TEST 5: The Cobra Spitfire — *one per group*
   CLUE TRACKING SHEET — *one per group or as needed*
   SCIENTIFIC DETECTIVE RECORD FORM — *five per group*
   EUREKA! MATH 1 (Optional) — *as needed*
   EUREKA! MATH 2 (Optional) — *as needed*
   EUREKA! MATH 3 (Optional) — *as needed*
   EUREKA! MATH 4 (Optional) — *as needed*

TEACHING TIP

Enlist parents and students to help you gather the supplies you'll need.

Suggestions:
Any two balls of the same size but distinctly different masses may be used, e.g., solid rubber ball and hollow plastic ball, Wiffle ball and softball, soccer ball and lightly stuffed fabric fiberfill ball.

Facial tissue works well instead of feathers

6. **Materials**
Carefully note the materials you need to conduct this simulation. Note, too, the separate listings for Phase 1 (which is optional), Phase 2 and Phase 3 (also optional). Gathering these materials ahead of time will help you run this simulation smoothly. Check the Daily Directions for additional details.

Phase 1

Eureka! Moment 1
- Balls the same size (same volume), very different masses —*two per group*
- Feather — *one per group*
- Science Journals* — *class set (see Setup Directions #2)*
- Small rock — *one per group*

Eureka! Moment 3
- Balls the same size (same volume), very different masses — *two per group*
- Markers or pencils — *class set*
- Meterstick or yardstick — *one per group*
- Smooth floor space

Eureka! Moment 4
- Basketball or volleyball — *one*
- Large poster board — *class set*
- Magazines from which to cut pictures — *several per group*
- Markers or colored pencils — *several per group*
- Rollerskates or in-line skates — *two pairs*

Eureka! Moment 5
- Cardboard base (12" or 30 cm square) — *one per group*
- Clay or glue — *enough for activity*
- Plastic drinking straws (not "flexible") — *two per group*
- Red marker —*one per group*
- Styrofoam ball (1" or 2.5 cm diameter) — *one per group*
- Styrofoam ball (3" or 7 cm diameter) — *one per group*
- Thread spool — *one*

* Denotes items needed in Phase 2 even if you opt not to do Phase 1.

SETUP DIRECTIONS

TEACHING TIP

You may use the balls used in EUREKA! ACTIVITY 1.

You can fashion a track that includes a "road" and two sides by folding a length of heavy cardboard. This will hold the balls on track.

Phase 2

The Anaconda

- Construction paper (11" x 17") — *one per group*
- E-Can — *one per group (see "E-Can Instructions," page 27)*
- Smooth floor
- Stapler — *one per group*

The Phantom Dragon

- Balls the same size (same volume), very different masses — *two per group*
- Model car track (24") — *one length per group*
- Pillow — *one per group*
- Smooth floor
- Textbooks — *three or more per group*
- Timer (stopwatch, clock with second hand) — *one per group*

The Outlaw

- Boot-style roller skate (or large toy truck) — *one per group*
- Doll that will sit (8" - 12" or 20 - 30 cm high) —*one per group*
- Shoelace or string (16" - 22") — *one per group*
- Smooth floor
- Textbook — *one per group*

The Rattlesnake

- Coarse sandpaper (as wide as the block and as long as the tray) — *one per group*
- Cooking oil — *1/4 cup per group*
- Jar lid (3.5" - 4") — *one per group*
- Large rubber band — *one per group*
- Marbles (all same size) — *enough to fill jar lid*
- Spring scale — *one per group*
- Styrofoam tray (smooth, 14" - 16") — *one per group*
- Tape — *one roll per group*
- Wood block (at least 3" x 5" x 1" - larger is better) — *one per group*

The Cobra Spitfire

- Clear plastic container with tight-fitting lid — *one per group*
- Strong string or twine — *one yard (one meter) per group*
- Water (colored) — *one to two cups per group*

Phase 3 *(Optional):*
Marble Coaster

- Base (e.g., a soft drink can tray) — *one per group*
- Cardboard tubes (toilet paper, paper towels, gift wrap) — *several per group*
- Large marble — *one per group*
- Masking tape — *one roll per group*
- Paper and pencil — *one per group*
- Scissors — *one per group*
- Transparent tape — *one roll per group*

Eureka! Moment Re-enactments

- Simple props as desired

7. **Teaching Schedule**
   a. During Phase 1 the class reads a different Eureka! Moment each day. Decide if you will read these short essays aloud with the class, or if students will read and discuss the information within their groups.The general daily format is:
      - Read Eureka! Moment
      - Complete the related EUREKA! ACTIVITY
      - Debriefing discussion
      - Write in science journals

   b. During Phase 2 your students explore problems at the amusement park ride by ride. The general daily format in Phase 2 is:
      - T.E.A.M. ACTIVITY
      - CLUE SEARCH
      - DESIGN TEST
      - SCIENTIFIC DETECTIVE RECORD FORM
      - Virtual ride

TEACHING TIP

Under this plan, you need only one or two sets of supplies for each of the first four EUREKA! Activities. However, students will benefit if each group builds its own model demonstrating Newton's Law of Universal Gravitation.

8. **Teaching Options: Phase 1**
   a. EUREKA! Activities
      You may read and discuss the Eureka! Moments as a class, then allow teams of students to rotate through EUREKA! ACTIVITIES stations set up to investigate the principles. However, provide enough materials so that every group may build a model for EUREKA! ACTIVITY 5.

   b. T.E.A.M. Activities
      For advanced students you may give necessary definitions and guidelines, have groups design their own T.E.A.M. Activity information strips, then exchange and check them between groups.

SETUP DIRECTIONS

9. **Teaching Options: Phase 2**
   If you wish to modify your class presentation, consider the following option:
   a. Students complete all the T.E.A.M ACTIVITIES, one by one.
   b. Set up Design Test stations for all groups to rotate through the five tests. Allow two hours of class time for all five tests.
   c. Provide the five CLUE SEARCHES one at a time and have students fill out the corresponding SCIENTIFIC DETECTIVE RECORD FORMS.
   d. Students take their *virtual rides* as they solve each roller coaster's mystery.
   e. The advantages of this variation include:
      - Since groups rotate through the Design Test stations, you need only one or two sets of supplies for each DESIGN TEST per class.
      - You can easily use longer class periods if this works better in your schedule.
      - Students must assimilate the information they gathered in the T.E.A.M. ACTIVITIES and DESIGN TESTS, then apply this knowledge as they evaluate the CLUE SEARCH information.
      - Students' conclusions on the SCIENTIFIC DETECTIVE RECORD FORMS serve as informal assessments of what they have learned during the simulation.

10. **Eureka! Math (Optional)**
    This layer of the simulation enhances Phase 2, offering you the option of integrating math with science as occurs in the real world. Indeed, the basis of Newton's discoveries was not experimentation, but reasoning confirmed by mathematical computation. Teach the mathematical formulas as shown on each reproducible or use these sheets as models for your own math lessons, extending this material and increasing or decreasing its difficulty. You may allow students to use calculators to complete the reproducibles in order to allow them to focus on the concepts rather than on the computation.

11. **Guest Speakers**
You can enhance this unit by inviting a physicist or an engineer to come and speak to your class during or after this simulation. Local universities or businesses often have someone willing to spend time sparking scientific interest with your students.

12. **Culminating Event**
You may decide to conclude the ROLLER COASTER unit with formal presentations or an open house where students demonstrate what they have learned to administrators, other classes, family, friends and the larger community. Consider one or more of the following suggestions:
    a. **Oral Presentations**—Have groups present their recommendations to "Ms. Roundenround," the owner of Roller Coaster World (school principal, yourself or other dignitary).
    b. **Eureka! Moment Re-enactments**—Students re-enact for Ms. Roundenround and other visitors the moments in history explored in Phase 1.
    c. **Marble Coasters**—Using paper tubes, each student group designs a "roller coaster" for marbles to travel through, labeling and demonstrating as many of the vocabulary words listed in the GLOSSARY as possible.
        - Groups then figure out how to connect their Marble Coasters to make a class working roller coaster.
        - Set aside a day when you invite other classes, administrators, parents and other guests to view demonstrations of your students' creations.
    d. **Challenge Projects**—Students present their projects to Ms. Roundenround and/or other visitors. (see page 66)

RECOMMENDED BOOKS

RESOURCE FOR TEACHERS:

Weiner, A. 2007. *Don't Try This at Home: The Physics of Hollywood Movies*. Kaplan Publishing.

RESOURCES FOR CHILDREN:

Christianson, G.E. 1996. *Isaac Newton and the Scientific Revolution*. New York: Oxford University Press.

Fortey, J. 2007. *Great Scientists* (DK Eyewitness Books). DK Children.

Gianopoulos, A. 2007. *Isaac Newton and the Laws of Motion*. Capstone Press.

VanCleave, J. 1993. *Gravity: Spectacular Science Projects*. New York: John Wiley & Sons.

FICTION THAT TEACHES FACTS:

Goldish, M. 2009. *Heart-Stopping Roller Coasters* (World's Biggest). Bearport Publishing.

Green, D. 2008. *Basher Science: Physics: Why Matter Matters*. Kingfisher.

Krull, K. 2006. *Isaac Newton* (Giants of Science). Viking Juvenile.

VanCleave, J. 2004. *Janice VanCleave's Super Science Models*. Wiley.

Yoon, P. 2005. *At the Amusement Park* (Everyday Science series, Vol. 2). YoungJin, Singapore.

UNIT TIME CHART

This Unit Time Chart is a guideline. Alter as desired.

Phase 1: Momentous History (Optional)

EUREKA! MOMENT 1	EUREKA! MOMENT 2	EUREKA! MOMENT 3	EUREKA! MOMENT 4	EUREKA! MOMENT 5
Student Guide: Phase 1 EUREKA! ACTIVITY 1 GLOSSARY MY SCIENCE JOURNAL YOUR SCIENCE JOURNAL SCIENTIFIC METHOD	Student Guide: Phase 1 EUREKA! ACTIVITY 2 Science Journals	Student Guide: Phase 1 EUREKA! ACTIVITY 3 Science Journals	Student Guide: Phase 1 EUREKA! ACTIVITY 4 Science Journals	Student Guide: Phase 1 EUREKA! ACTIVITY 5 Science Journals

Phase 2: Roller Coaster World

ROLLER COASTER 1	ROLLER COASTER 2	ROLLER COASTER 3	ROLLER COASTER 4	ROLLER COASTER 5
Student Guide: Phase 2 T.E.A.M. ACTIVITY 1 CLUE SEARCH 1 CLUE TRACKING SHEET DESIGN TEST 1 SCIENTIFIC DETECTIVE RECORD FORM Debriefing Science Journals	Student Guide: Phase 2 T.E.A.M. ACTIVITY.2 CLUE SEARCH 2 CLUE TRACKING SHEET DESIGN TEST 2 SCIENTIFIC DETECTIVE RECORD FORM Debriefing Science Journals	Student Guide: Phase 2 T.E.A.M. ACTIVITY 3 CLUE SEARCH 3 CLUE TRACKING SHEET DESIGN TEST 3 SCIENTIFIC DETECTIVE RECORD FORM Debriefing Science Journals	Student Guide: Phase 2 T.E.A.M. ACTIVITY 4 CLUE SEARCH 4 CLUE TRACKING SHEET DESIGN TEST 4 SCIENTIFIC DETECTIVE RECORD FORM Debriefing Science Journals	Student Guide: Phase 2 CLUE SEARCH 5 CLUE TRACKING SHEET DESIGN TEST 5 SCIENTIFIC DETECTIVE RECORD FORM Analysis of all Clues Science Journals

Phase 3: Extensions (Optional)

Day 1	Day 2	Day 3	Day 4	Day 5
You determine the content and timing of PHASE 3. Optional presentations of groups' conclusions Challenge Projects MARBLE COASTER				

PHASE 1: DAILY DIRECTIONS

Estimated activity time
90 minutes

TEACHING TIP

Suggestions: Facial tissue works well instead of feathers; any two balls of the same size but distinctly different masses may be used, e.g., solid rubber ball and hollow plastic ball, Wiffle ball and softball, soccer ball and lightly stuffed fabric fiberfill ball

MOMENTOUS HISTORY (OPTIONAL)

EUREKA! MOMENT 1

Materials

1. Student Guide: Phase 1 — *class set*
2. YOUR SCIENCE JOURNAL — *class set*
3. MY SCIENCE JOURNAL cover — *class set*
6. GLOSSARY — *class set*
7. SCIENTIFIC METHOD — *class set*
8. EUREKA! ACTIVITY 1 (Parts 1 and 2) — *class set*
9. Construction paper (11” x 17”) — *class set + one per group*
10. Balls the same size (same volume), very different masses — *two*
11. Feather — *one*
12. Small rock — *one*
13. Notebook paper — *10 sheets per student*
14. Pencils — *class set*
15. Stapler — *one or two*

Procedure

1. Divide students into groups of four to six students each. These groups will work together throughout the simulation. See Setup Directions, # 4 Grouping Students for more information.

2. Distribute, read and discuss YOUR SCIENCE JOURNAL.

3. Distribute the MY SCIENCE JOURNAL cover, the GLOSSARY and SCIENTIFIC METHOD. Have students make their science journals as described in the Setup Directions #2 (step 2), placing the handouts inside their science journals.

4. Distribute one sheet of construction paper to each group and have them make their group folder. Direct them to store within this folder all important information they gather in the simulation.

5. Distribute a Student Guide: Phase 1 to each student and direct students to read Eureka! Moment 1 about Aristotle.

TEACHING TIP

You may wish to have students design their own experiments to test Aristotle's and Galileo's ideas. If so, skip to #11 and guide students through the process of addressing each part of the scientific method.

6. Distribute one EUREKA! ACTIVITY 1, Part 1 to each student. Review the content of the handout with the class. Make sure that students understand the objective and procedures.

   Problem: Discuss the problem, which is often written in question form. Explain that this is what students want to find out. Have groups circle the work "problem" (question) on their worksheets.

   Hypothesis: This is an educated guess to answer the question stated in the problem. Have students circle the word "Hypothesis." Students will write their predictions regarding the experiment in the blank provided.

   Experiment: This is the procedure used to test the hypothesis. Have students circle the word "Experiment."

   Data: These are accurate records of the results of the experiment. Have students circle the word "Data."

   Conclusion: This is a summary of what the experimenter discovers (concludes) as a result of the experiment. Scientists compare their conclusions with the hypothesis recorded at the beginning of the activity.

TEACHING TIP

Do not evaluate hypotheses at this point. Accept all suggestions.

Although the correct hypotheses will be obvious from the histories given in Phase 1, it is important to give students practice in applying the scientific method systematically.

7. Have students share what they think will happen during the experiment. After the discussion, have each student write his or her own hypothesis in the "hypothesis" blank.

   Sample hypothesis: *The rock will hit the floor before the feather.*

8. Direct groups to perform the experiment. Ask that students record on their worksheet what they observe as they conduct the experiment.

9. When groups have finished the experiment, ask them to share their data.

   Sample data: *The rock hit the floor before the feather.*

10. After the class discussion of the data, direct that the students record the conclusions reached as a result of their group's experiment on their handouts.

    Sample conclusion:

    (1) The rock hit the floor before the feather because the feather floated on the air.

TEACHING TIP

If your students do not know what a "variable" is, direct them to the GLOSSARY or to their Student Guides and discuss this important scientific term.

(2) The variables involved in this experiment include the shape of the objects and their masses.
(3) More than one variable means we can't tell what made a difference between the two objects' behavior.
(4) They would land at the same time, because the feather would not float in the air. The only variable would be the objects' masses.

11. Distribute a SCIENTIFIC METHOD handout to each student.

12. Read and discuss this handout in light of the experiments the students have just completed. As you review the steps of the scientific method, point out that often an experiment has to be repeated or modified as scientists see the results of their initial attempts. This is a normal part of scientific investigation. Make sure students have recorded in the "Data" section of their handout what their test of their hypothesis (the experiment) revealed and any changes they made to their experiment and why.

13. Name and explain the influence of air friction (drag), and discuss how this affected Aristotle's results.

14. Remind students that EUREKA! ACTIVITY 1, Part 1 is not a controlled experiment because there are too many variables and is therefore impossible to interpret accurately.

15. Introduce students to EUREKA! ACTIVITY 1, Part 2. If your students have little experience with the scientific method, you may review the steps in sequence before they begin their work.

TEACHING TIP

You may extend this activity by having students drop two feathers (or two pieces of facial tissue) of the same size and shape. They create the same drag and have the same mass and volume, so they fall at about the same rate. Have students attach a paper clip to one object to increase its mass without increasing its size or changing its shape.

16. After students complete their experiments, debrief as for the Part 1 experiment.
    Sample hypothesis: *The two balls will hit the floor at the same time.*
    Sample data: *The two balls hit the floor at the same time.*
    Sample conclusion:
    (1) Two objects of the same shape and size (volume) but different masses fall at the same rate and hit the ground at the same time because the air resistance is the same.
    (2) The only variable was the mass of each ball.
    (3) The data we collected helped us understand Galileo's idea because it only had one variable.
    (4) They would act the same on the moon because the experiment is already down to only one variable.

17. Point out that EUREKA! ACTIVITY 1, Part 2 is a **controlled experiment** in that there is only one variable—the masses of the balls.

18. Explain that observation of details is an important component to understanding science learning and applying the scientific method. For example, Aristotle ignored many details in setting up and observing his experiment. Help students list these, *e.g., the differences in size and shape of the objects, the effects of air friction.*

19. Debrief students, discussing what they have learned today. Have students record what they think they have learned today in their science journals.

20. You may collect the science journals after class to check for student understanding. If you assign the science journals as homework, you may collect the journals at the beginning of the next day. Plan on checking science journals periodically throughout the unit. Encourage students to fill their journals with drawings, notes, observations, any relevant information.

21. You may collect the Student Guides today and at the end of each class, or have students keep them in their group folders.

PHASE 1: DAILY DIRECTIONS

Estimated activity time
30-45 minutes

EUREKA! MOMENT 2

Materials

1. Student Guide: Phase 1 — *class set*
2. EUREKA! ACTIVITY 2 — *class set*
3. Science journals — *class set*
4. Pencils — *class set*

Procedure

1. If necessary, distribute the Student Guides and direct students to page 2. Either together, in groups or individually read Eureka! Moment 2 about Galileo's and Newton's work regarding the law of inertia.

2. Discuss briefly.

3. Distribute EUREKA! ACTIVITY 2: Newton's First Law of Motion to each student.

4. Review the instructions and have each student record in the "Hypothesis" space what he or she thinks will happen during the experiment.
   Sample hypothesis: *The ball will be able to roll forever in my mind.*

5. Direct students to use their imaginations to perform the activity. This will be more challenging for some students. Encourage them to be as creative as possible.

6. When students have finished the activity, ask them to share their results first with their groupmates, and then with the class. Then have each student record this information on his/her worksheet.
   Sample data: *The ball kept rolling and never stopped in my mind.*

TEACHING TIP

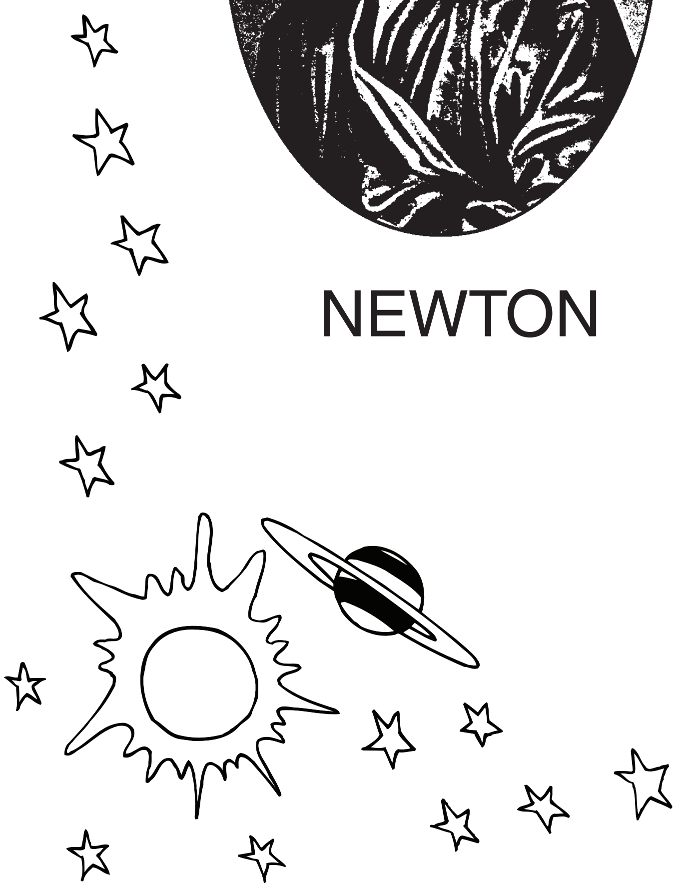
Remember: do not evaluate hypotheses at this point.

7. Finally, have groups determine and share their conclusions. Compare these to the hypotheses recorded at the beginning of the activity. Have each student write his/her conclusion on his/her worksheet.
   Sample conclusion: *Without any forces acting on the ball except inertia and gravity, the ball could roll forever (no friction to slow it down).*

8. Debrief students, discussing what they have learned today. Allow time for students to record and reflect in their science journals.

NEWTON

GALILEO



PHASE 1: DAILY DIRECTIONS

Estimated activity time
60 minutes

EUREKA! MOMENT 3

Materials

1. Student Guide: Phase 1 — *class set*
2. EUREKA! ACTIVITY 3 (Parts 1 and 2) — *class set*
3. Science journals — *class set*
4. Balls the same size (volume) but very different masses — *two per group*
5. Meter stick or yard stick — *one per group*
6. Pencils — *class set*
7. Smooth floor space

Procedure

1. If necessary, distribute the Student Guides and direct students to page 3. Either together, in groups or individually read Eureka! Moment 3 about Newton's Second Law of Motion.

2. Discuss briefly.

3. Distribute both parts of EUREKA! ACTIVITY 3 to each student.

TEACHING TIP

Have students complete Part 1 in its entirety first then do Part 2.

4. Review the experiments and have each student record on his/her worksheet what he/she thinks will happen during each part of the activity.

5. Direct groups to perform the two parts of the activity.

6. When groups finish the activity, ask them to share their results. Then have each student write this information on his/her worksheet.

7. Finally, have groups determine and share their conclusions. Compare these to the hypotheses recorded at the beginning of the activity. Have each student write his/her conclusion on his/her worksheet.

8. Debrief students, discussing what they have learned today. Allow time for students to record and reflect in their science journals.

9. Depending on the abilities of your students, you may guide their discussion with the following:

Sample problem, Part 1: *In what direction does an object move when a force acts on it?*

Sample hypothesis, Part 1: *The ball will go in the same direction my hand (the force) moved.*

Sample data, Part 1: *The ball always moved in the same direction the force (my hand) moved.*

Sample conclusion, Part 1: *An object moves in the same direction as the force applied to it. This illustrates the first part of Newton's Second Law of Motion.*

Sample problem, Part 2: *Using the same amount of force, how do the masses of objects influence the objects' motion?*

Sample hypothesis, Part 2: *The ball with less mass will travel farther than the ball with more mass when using the same force.*

Sample data, Part 2:

(1) The ball with less mass traveled farther than the ball with more mass.

(2) The ball with more mass stopped sooner than the ball with less mass.

Sample conclusion, Part 2:

(1) The ball with less mass traveled farther than an object with more mass when the same amount of force is applied as explained by the second part of Newton's Second Law of Motion – it could go more distance with the same force than the object with more mass.

(2) The ball with more mass acted as it did because the more massive an object is, the more force it takes to move it. So compared to the ball with lighter mass, it could not go the same distance with the same force.

PHASE 1: DAILY DIRECTIONS

Estimated activity time
60 minutes

EUREKA! MOMENT 4

Materials
1. Student Guide: Phase 1 — *class set*
2. EUREKA! ACTIVITY 4 — *class set*
3. Science journals — *class set*
4. Basketball or volleyball — *one*
5. Magazines from which to cut pictures — *several per group*
6. Markers or colored pencils — *class set*
7. Pencils — *class set*
8. Poster board— *class set*
9. Roller skates or in-line skates — *two pairs*

Procedure
1. If necessary, distribute the Student Guides and direct students to page 3. Either together, in groups or individually read Eureka! Moment 4 about Newton's Third Law of Motion.

2. Discuss briefly.

3. Have a volunteer put on the skates. Give him or her the basketball. Read or tell:

READ OR TELL

Thinking about Newton's Third Law of Motion, what do you hypothesize will happen when [student's name] uses a chest pass to throw the ball forward to me?

[Note: A chest pass is when the ball is thrust with both hands straight forward from the chest. The thrower's hands should end up pointing toward the target (you).]

4. Have each student record in his/her science journal what he/she thinks will happen during the experiment. Then have each student label this prediction as a "Hypothesis." Continue through each part of the scientific method as you have the volunteer demonstrate.

PHASE 1: DAILY DIRECTIONS

Problem: *What will happen when a person on skates throws a ball forward?*
Sample hypothesis, Part 1: *[Student] will roll backward.*
Experiment summary, Part 1: *A person is on skates and throws a ball forward.*
Sample data, Part 1: *[Student] rolled backward.*
Sample conclusion, Part 1: *A force moving forward is balanced by a force moving backward. This shows Newton's Third Law of Motion.*

5. Now have a second volunteer put on skates. Put the basketball aside. Read or tell:

READ OR TELL

"What do you think will happen when two people on skates face each other and push on each other's hands?"

6. Have each student record in his/her Science Journal what he/she thinks will happen during the experiment. Then have each student label this prediction as a "Hypothesis." Continue through each part of the scientific method as you have the volunteers demonstrate.
   Problem, Part 2: *What will happen when two people on skates push against each other?*
   Sample hypothesis, Part 2: *They will move apart (backward).*
   Experiment summary, Part 2: *The two people pushed against each other's hands while wearing skates.*
   Sample data, Part 2: *They both moved backward.*
   Sample conclusion, Part 2: *The action force (pushing on each other's hands) caused a reaction force (moving backward). This shows Newton's Third Law of Motion.*

TEACHING TIP

Point out that the skates help reduce friction so that we can see the reaction force more clearly.

7. ***Optional extension***: Ask, "What would the reaction force be if our volunteers did not have skates on?" *(They would need to brace their bodies to avoid falling backward.)*

8. Distribute EUREKA! ACTIVITY 4 to each student.

PHASE 1: DAILY DIRECTIONS

TEACHING TIP

Allow those who wish to work with a partner to make one poster together.

You may assign the poster project as homework and allow more time to complete.

Display completed posters to reinforce learning.

9. Review the instructions and allow groups to complete the chart.
   Sample Chart Answers:
   b. Trampoline's push on feet
   c. Bat's push on bat
   d. Toy's force on hands
   e-h. Answers will vary.

10. Have each student make his/her own poster.

11. Debrief students, discussing what they have learned today. Encourage students to record and reflect in their Science Journals.

EUREKA! MOMENT 5

Estimated activity time 45-60 minutes

Materials

1. Student Guide: Phase 1 — *class set*
2. EUREKA! ACTIVITY 5 — *class set*
3. Science journals — *class set*
4. Cardboard base (12" or 30 cm square) — *one per group*
5. Clay or glue—*enough for activity*
6. Plastic drinking straws (not “flexible”)—*two per group*
7. Pencils — *class set*
8. Red marker—*one per group*
9. Styrofoam ball (1" or 2.5 cm diameter)—*one per group*
10. Styrofoam ball (3" or 7 cm diameter)—*one per group*
11. Thread spool—*one*

TEACHING TIP

Make sure the straws are able to rotate in the spool hole

Procedure

1. If necessary, distribute the Student Guides and direct students to page 4. Either together, in groups or individually read Eureka! Moment 5 about Newton’s Law of Universal Gravitation.

2. Discuss briefly.

3. Distribute EUREKA! ACTIVITY 5 to each student.

4. Review the instructions.

5. Direct groups to make the model.

6. When groups finish the activity, ask them to explain Newton's Law of Universal Gravitation in their own words, using their models as visual aids.
   Sample Answers for EUREKA! ACTIVITY 5
   (1) The straw between the Earth and the moon represents the two objects’ gravitational pull on each other.
   (2) Newton’s Law of Universal Gravitation says that every object pulls on every other object.
   (3) The Earth pulls on my body and my body pulls on the Earth.

TEACHING TIP

You may wish to have students add labels to the straw between the “moon” and “Earth” naming the action and reaction forces.

Be sure to point out that this model is greatly simplified from the real world but still illustrates Newton’s Law of Universal Gravitation.

PHASE 1: DAILY DIRECTIONS

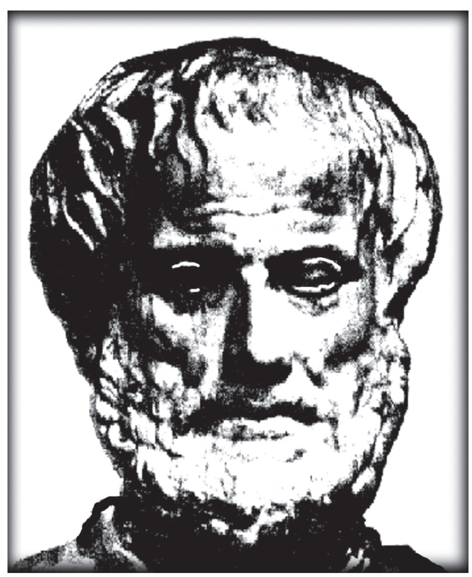
TEACHING TIP

For these—and most—debriefing questions, answers will vary.

7. Debrief students, discussing what they have learned during Phase 1 of the simulation. Ask questions such as the following to stimulate students thinking:
   a. Which historical facts mentioned in the Eureka! Moments were your favorites? Why?
   b. Which EUREKA! ACTIVITY was your favorite? Why?
   c. Which historical person would you most like to eat lunch with? Why?
   d. How were the historical people we studied and their discoveries like your learning today?

8. Allow time for students to record what they feel they have learned today in their science journals.

9. Explain that students should keep their notes and handouts to refer to in Phase 2.



PHASE 2: DAILY DIRECTIONS

ROLLER COASTER WORLD

THE ANACONDA

Estimated activity time two 45 - 60 minute class periods

Materials

1. Student Guide: Phase 2 — *class set*
2. WHAT ARE T.E.A.M. ACTIVITIES? — *class set*
3. T.E.A.M. ACTIVITY 1 — *one set of strips per group*
4. T.E.A.M. ACTIVITY 1 RECORD — *one per group*
5. CLUE SEARCH 1: The Anaconda — *class set*
6. CLUE TRACKING SHEET — *class set*
7. DESIGN TEST 1: The Anaconda — *one per group*
8. SCIENTIFIC DETECTIVE RECORD FORM — *one per group + transparency*
9. Science Journals — *class set (from Phase 1 or new)*
10. Construction paper (11" x 17") — *one per group*
11. E-Can — *one per group*
12. Pencil — *class set*
13. Smooth floor
14. Stapler — *one per group*
15. EUREKA! MATH 1: Potential and Kinetic Energy (optional) — *as needed*

TEACHING TIP

Students continue with their Science Journals from Phase 1. If you elected to not do Phase 1, see instructions for creating Science Journals in the Setup Directions, #2. Allow time for students to create their Science Journals before beginning any Anaconda activities.

The E-can is needed for the first Design Test in this simulation. Depending on your students' abilities (and your motivation to assemble more than one E-can!), conduct the DESIGN TEST 1: The Anaconda as a demonstration. This allows you to guide your students step-by-step through the scientific method, setting clear expectations for future Design Tests.

The performance of the e-Can will be greatly reduced if the sinker hangs so low that it rests on the inside of the can. In this case, add a second rubber band. Alternatively, shorten the band by tying knots into the band at one or both of the paper clips on the outside of the can.

E-Can — *one per group*

Materials

1. Empty coffee can (1 lb, 5" diameter w/ plastic lid) — *one*
2. Fishing sinker (1 oz.) — *one*
3. Hammer — *one*
4. Long rubber band (6" diameter) — *one or two*
5. Paper clips — *two*
6. Nail — *one*

Assembly

1. With the hammer and nail, punch one hole through the bottom of the can and one in the center of the plastic lid.
2. Slide the sinker onto the rubber band and tie a simple overhand knot around the sinker hole at the middle of the rubber band.
3. Thread the paper clip onto one end of the rubberband. Then thread the other end of the rubberband through the hole in the bottom of your can. The clip should be on the outside of the can.
4. Thread the free end of the rubberband through the hole in the lid.
5. Attach the paper clip to the rubberband on the plastic lid so the band won't slip into the can.
6. Place the plastic lid tightly onto the end of the can.

PHASE 2: DAILY DIRECTIONS

Procedure

1. If you elected to skip Phase 1, divide your students into groups of four to six students per group. These groups will work together throughout Phase 2.

2. Distribute the construction paper to each group and have them make their group folder. Direct that they use the folders to store all important group information they gather during Phase 2.

3. Distribute a Student Guide: Phase 2 to each student. Direct students to read the three introductory news articles, examine the coaster diagrams and labels and then read the letter from Ms. Roundenround, Owner of Roller Coaster World. You may elect to read this material together as a class.

READ OR TELL

4. Read or tell:

    "Ms. Roundenround has asked for your help because she heard you are careful and hard-working scientific detectives.

    "To help you better understand how you can help Ms. Roundenround, we will start each day with a group problem-solving mystery. I will now hand out a paper describing how your groups will work together to solve the Roller Coaster World mystery."

5. Distribute WHAT ARE T.E.A.M. ACTIVITIES? and have students read individually, within their groups or as a class.

6. After students read about the T.E.A.M. activities, answer any questions they may have. Emphasize that students must ensure that every member of their group participates in each activity. Brainstorm ways to include everyone and appropriate ways to handle disagreements.

READ OR TELL

7. Read or tell:

> "As we learn about motion, I will record what we learn on an overhead transparency. I will add information to our list every day. Every day you will record the same information in your Science Journals."

TEACHING TIP

If a group has fewer than six members, some students will need to handle more than one T.E.A.M. ACTIVITY strip.

If desired, don't use the T.E.A.M. ACTIVITY 1 RECORD sheet; instead, have students cut apart the information on their strips and glue them to sheets of notebook paper, one labeled "Potential Energy" and the other labeled "Kinetic Energy."

You may do each T.E.A.M. activity as a whole group exercise, using an overhead transparency to display answers.

Have each group check their T.E.A.M. ACTIVITY 1 RECORD, correcting any errors.

8. Distribute the T.E.A.M. ACTIVITY 1 strips, one strip per student, one set per group. Distribute one T.E.A.M. ACTIVITY 1 RECORD to each group. Tell students that the objective of this activity is to practice telling the difference between potential energy and kinetic energy. They should decide what each example best illustrates. Direct each group to record answers on their RECORD as each member reports his or her information.

9. ***Answer Key*** for T.E.A.M. ACTIVITY 1
   Potential energy examples: *child waiting to go out to recess, child at top of slide, rubber band pulled tight, wound up spring toy sitting on shelf, cat at top of tree, boy on sled at top of snowy hill, bucket of water balanced on the top of a door, boulder at top of mountain*
   Kinetic energy examples: *boulder rolling down mountain, bucket of water pouring on your brother's head, moving spring toy, cat jumping out of tree, boy hurtling down snowy hill on sled, child playing on playground, shooting a rubber band at your little sister, child sliding down slide*

10. After the activity, discuss the definitions of potential and kinetic energy and where each item belonged on the RECORD. Have students prove their answers based on the information they have. Have each group store this sheet in their group folder.

Depending on your schedule, you may wish to stop for the day at this point and continue next class.

11. ***Option***: After discussing the definitions of potential energy and kinetic energy and offering a few examples, groups may write their own T.E.A.M. ACTIVITY 1 strips with examples of each for recording on the T.E.A.M. ACTIVITY 1 RECORD. Groups can exchange sets of strips and correct each other's completed work.

PHASE 2: DAILY DIRECTIONS

12. Distribute CLUE SEARCH 1: The Anaconda to each student and one CLUE TRACKING SHEET to each group. Have students in each group study the information and list clues on their group's CLUE TRACKING SHEET, according to how certain they are that the information is really a clue. They should also record any possible clues from the Student Guides: Phase 1 and Phase 2 on their CLUE TRACKING SHEET.

13. Tell students that to better understand motion, they will be conducting experiments to determine how motion functions.

READ OR TELL

14. Read or tell:

> "As Ms. Roundenround mentioned, she has an experiment for us to perform. It will teach you more about potential energy and kinetic energy."

TEACHING TIP

You may perform this experiment as a demonstration instead, requiring only one E-can and giving you more time for modeling and discussing the scientific process.

15. Distribute DESIGN TEST 1: The Anaconda and a SCIENTIFIC DETECTIVE RECORD FORM to each group.

16. Have students perform the experiment then record the results on the worksheet.

17. ***Sample Answers*** DESIGN TEST 1: The Anaconda
Hypotheses:
(1) The potential energy will be highest where the E-Can stops moving away from me after the first push.
(2) The highest kinetic energy will be at the end of the first time it rolls back toward me.
Data:
(1) The E-Can rolled back and forth. Each trip across the floor got shorter. It curved as it moved.
(2) The E-Can rolled back and forth but curved more sharply. It moved faster and for a longer time with the harder push. Each trip got shorter.
(3) An ordinary can doesn't come back to you. It will

just slow down and stop.

Conclusion:

(1) The E-Can acts differently from an ordinary can because it has a rubber band inside it that stores potential energy.

(2) The potential energy was highest at the point where the E-Can stopped moving away from me after the rapid push because that is where the most energy was stored inside it (where the rubber band was wound the most times).

(3) The kinetic energy was highest at the end of the first time it rolled back toward me because that is where it had changed the most potential energy into movement before friction could take some of the kinetic energy.

(4) Potential energy on a roller coaster is highest at the top of the first hill.

(5) Kinetic energy on a roller coaster is highest at the bottom of the highest hill (after the peak).

18. Ask, "Why does the E-Can slow down and stop?" *(Friction interferes.)*

READ OR TELL

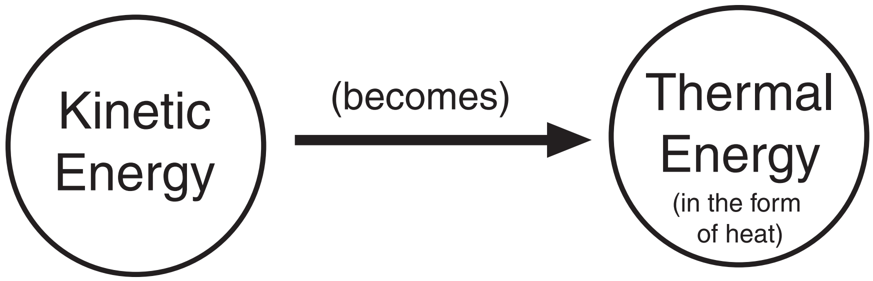
19. Read or tell:

"As the E-Can travels some of its kinetic energy is changed to thermal (heat) energy in the form of friction.

"The thermal (heat) energy (in this case friction) is wasted kinetic energy. It does not help the E-Can move so the can slows down. The potential energy was highest at the point where the E-Can stopped moving away from you after the first push because that is where the most energy was stored inside it. Later trips lose more and more kinetic energy to friction, so it cannot build as much potential energy.

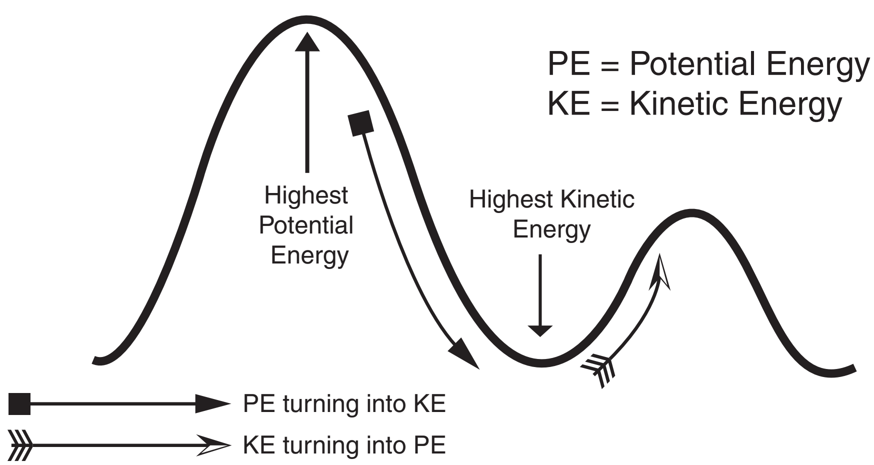
"The same thing happens with a roller coaster. As the coaster train is towed by electrical energy to the top of the first hill, the train gathers potential energy. The top of the first hill is where the train has the most potential energy.

"As the train travels to the bottom of the first hill, this potential energy is converted to kinetic energy. The bottom of the first hill is where the kinetic energy is highest.



"The total of potential and kinetic energy can never be more than what the electrical energy gave the train. In addition, friction converts some kinetic energy into thermal energy instead of movement, wasting some of the kinetic energy."

20. Display and discuss the following diagram:



TEACHING TIP

Group members need only agree on what to tell Ms. Roundenround.

21. After discussing the results and thoughts as a class, have each group fill out a SCIENTIFIC DETECTIVE RECORD FORM. Make sure students note the definitions of potential energy and kinetic energy and how these related to the trouble the Anaconda experienced. Collect the SCIENTIFIC DETECTIVE RECORD FORM from each group to give to Ms. Roundenround.

22. ***Sample Answers*** for the SCIENTIFIC DETECTIVE RECORD FORM DESIGN TEST 1: The Anaconda
    (1) Ms. Roundenround says the coaster won't go over the second hill.
    (2) There is not enough potential energy from the first hill to get over the second hill. This is related to Newton's First Law of Motion. The inertia and momentum were not enough to handle a higher second hill. Friction took some of the energy too.
    (3) T.E.A.M. ACTIVITY 1 had similar examples, such as the child at the top of the slide and the boulder at the top of the mountain. The article "Thrills and Chills" in the STUDENT GUIDE: PHASE 2 talked about how the first hill has to be taller, too.
    (4) The Anaconda's trains could not make it over the second hill because it was higher than the first hill. This means it needed more kinetic energy to get up the second hill than the first hill could give it. So the first hill has to be changed to be higher than the second hill or the second hill has to be changed to be lower than the first hill.

23. Introduce and discuss the **Law of Conservation of Energy**, which states that energy cannot be created or destroyed, only changed in form. For example, some of the kinetic energy becomes thermal (heat) energy as the E-Can and roller coaster travel.

24. Relate this lesson to **Newton's First Law of Motion**. The roller coaster cars will continue moving until another force—in this case friction (wheels on track and the coaster's brakes)—acts upon them.

PHASE 2: DAILY DIRECTIONS

READ OR TELL

25. Read or tell as Ms. Roundenround:

"I got this new computer program for testing out coaster designs in the ride simulator. Can't figure out how to use it though. Maybe you can. Please step into my office and see what you can do."

READ OR TELL

26. Read or tell as yourself:

"You walk into Ms. Roundenround's office and see what looks like a roller coaster car sitting on top of a system of jacks and hydraulic gear. Your group works together to use the new program. First you enter the information for the Anaconda's redesign into the computer. Then your whole group climbs up into the simulator car. As the simulation runs, Ms. Roundenround informs you, the car and the seats will tilt and jolt as if you are on the redesigned Anaconda. On the walls, movie scenes of the Anaconda and Roller Coaster World will fly by you. 'It will be so realistic you will feel as if you're really riding that metal snake!' she concludes."

27. Continue as yourself (Virtual Ride 1):

"Ms. Roundenround clicks on 'Test Ride' to see what happens. The simulation begins running. Slowly, you are towed to the top of the first hill. At the top, a moment of hesitation, then—WHEEEEEEEEEE—you're flying straight down. Your heart catches in

TEACHING TIP

This ride should reveal to students that kinetic energy can never be greater than the total energy, in this case the potential energy stored at the top of the first hill. The second hill requires more kinetic energy to climb because it's higher and because of friction. Therefore, students should have programmed the simulator to make the second hill lower than the first hill (less than 160 feet), or the first hill higher than 200 feet.

Track clues that class consensus says are "Definitely Clues" and "Maybe Clues" on paper strips on a bulletin board. Move, add to and discard clues as students deem appropriate throughout Phase 2.

To extend this lesson, use the Optional EUREKA! MATH 1: Potential and Kinetic Energy as a mini–math lesson or homework assignment. Depending on your students' abilities and your instructional goals, you may use this worksheet with advanced students only.

your throat. As you reach the bottom of the hill, your body presses down deep into your seat. You gasp for breath. Up the second hill you go, wind whistling in your ears. At the top, you feel weightless for a split second and then—WHOOOOSH—you plunge down the second hill into a tight curve. You duck your head, thinking you're going to hit a steel rail overhead. All too soon, you're back at the start, ready to ride again."

28. Allow groups to discuss and decide if the experiment uncovered any new clues. If so, they should record it (them) on their CLUE TRACKING SHEET in the appropriate column.

29. Using a blank transparency on the overhead do the following:
    a. Tell students that each day you will conduct a short debriefing session covering what they have learned.
    b. Ask students, "What have you learned today?"
    c. Note the ideas students share.

30. Encourage students to add these notes to their Science Journals. Any work the students have done today should go in their Science Journals as well.

PHASE 2 - DAILY DIRECTIONS

Expected activity time approximately two 45 minute class periods.

TEACHING TIP

Suggested/alternative materials are a wooden ball and a steel ball, a cue ball and racquetball or tennis ball, or even a full soup can and an empty soup can (be sure to tape any sharp edges).

A sheet of plywood (e.g., 24" x 36") is a good alternative to the model car track. Be sure to choose something that will turn, not a cubic type of object, to keep the influence of spin approximately the same under classroom conditions.

THE PHANTOM DRAGON

Materials

1. Student Guides: Phase 2 — *class set*
2. CLUE SEARCH 1: The Anaconda — *class set (from previous lesson)*
3. CLUE SEARCH 2: The Phantom Dragon — *class set*
4. CLUE TRACKING SHEET — *one per group (from previous lesson)*
5. T.E.A.M. ACTIVITY 2 — *one set of strips per group*
6. T.E.A.M. ACTIVITY 2 RECORD — *one per group*
7. SCIENTIFIC DETECTIVE RECORD FORM — *one per group + transparency*
8. DESIGN TEST 2: The Phantom Dragon — *one per group*
9. Balls the same size (same volume) with very different masses — *two per group*
10. Model car track (24") — *one length per group*
11. Pencils — *class set*
12. Pillow — *one per group*
13. Smooth floor
14. Textbooks — *three or more per group*
15. Timer (stopwatch, clock with second hand) — *one per group*
16. EUREKA! MATH 2: Speed (Optional) — *as needed*
17. EUREKA! MATH 3: Momentum (Optional) — *as needed*
18. SCIENCE JOURNALS— *class set*

Note: *It is always a challenge to simplify experiments for this age group. For age appropriateness, this experiment has been simplified to a narrow focus. Under perfect lab conditions, mass as an issue does drop out, but only for a very, very long track (almost infinite). In addition, under typical classroom conditions, the spin rate, drag (air friction), and friction are not hugely important factors to consider. Even in theory, perfect lab conditions would still require both items to reach terminal velocity for a measurable difference (compared to this experiment). Help students look at all these assumptions together to learn from this lesson.*

Procedure

1. Distribute T.E.A.M. ACTIVITY 2 STRIPS and one T.E.A.M. ACTIVITY 2 RECORDING SHEET to each group. Explain that the objective of the activity is to

TEACHING TIP

If desired, don't use the T.E.A.M. ACTIVITY 2 RECORD; instead, have students cut apart the information on their strips and glue them to sheets of notebook paper, one labeled "Speed," one labeled, "Velocity," and one labeled "Acceleration."

TEACHING TIP

After discussing the definitions of speed, velocity and acceleration and offering a few examples, you may have groups write their own T.E.A.M. ACTIVITY 2 strips with examples for recording on the T.E.A.M. ACTIVITY 2 RECORD. Groups can exchange records and correct each other's completed work.

understand the differences between **speed**, **velocity** and **acceleration**. As a result of completing this activity, students will know *simplified* scientific definitions of these three terms and will be able to offer examples of each. Direct each group to record answers on their T.E.A.M. ACTIVITY 2 RECORD as each member reports his or her information.

2. When groups finish the activity, discuss their results, defining the terms and listing the examples of each. Be sure students recognize that speed examples do not give direction in which the object is traveling. Direction makes the example a velocity example. In scientific terms acceleration means any change in velocity, so this includes things slowing down (deceleration).

3. ***Answer Key*** for T.E.A.M. Activity 2
   Speed examples: *airplane traveling at 325 mph, car going 35 mph, boat travels 1,000m in 300 sec., bat flies at 15 mph*
   Velocity examples: *snake slithers along path at 3 kph, truck traveling eastward at 60 mph, cheetah running toward rabbit at 65 mph*
   Acceleration examples: *peregrine falcon diving at dove faster and faster, ice skater slowing down to make figure eight, deceleration, cyclist increasing from 10-12 mph on westbound road, dolphin swims faster in straight line to catch fish*

4. Read or tell:

READ OR TELL

"Ms. Roundenround wants to hear about the results of T.E.A.M. ACTIVITY 2. Still, she feels that she needs more information about the problems she's having at Roller Coaster World."

5. Distribute CLUE SEARCH 2: The Phantom Dragon to each student and allow each group time to read and discuss the information. Have each group record possible clues on their CLUE TRACKING SHEET.

PHASE 2: DAILY DIRECTIONS

6. Read or tell:

READ OR TELL

"As Ms. Roundenround mentioned, she has an experiment for us to perform. It will teach us more about how mass relates to velocity and momentum."

7. Distribute DESIGN TEST 2: The Phantom Dragon.

8. Have students perform this experiment. Guide them into seeing that the ball with greater mass covers the same distance in a shorter time. This means its velocity is higher. Stimulate your students' thinking by asking the following questions:
   - About how fast do you think a ball with greater mass than the hollow ball, but less mass than the solid rubber ball, would travel? *(Faster than the hollow ball and slower than the solid rubber ball.)*
   - How might the mass of a roller coaster car affect the ride? *(It must have enough mass to build the velocity [and therefore momentum] needed to travel at an interesting velocity.)*
   - How might you redesign the aluminum cars on the Phantom Dragon to make them travel at a higher velocity? *(Add mass in some way.)*

TEACHING TIP

Remind students of the difference between speed and velocity, and of the definition of momentum. Write the formula ***momentum = mass x velocity*** *on the chalkboard or overhead projector.*

If available have the students use more than two balls of the same volume but different masses.

9. Allow groups to discuss and decide if the experiment uncovered any new clues. If so, they should record the clues on their group's CLUE TRACKING SHEET.

10. ***Sample Answers*** DESIGN TEST 2: The Phantom Dragon:
    Hypothesis: *The rubber ball will travel faster than the hollow ball.*
    Data: *The ball with more mass reached the pillow in 4 seconds, and the ball with less mass reached the pillow in 10 seconds.*
    Conclusion: *The greater the mass of a moving object, the higher its velocity, when everything else is the same. This means the momentum is higher, too, because momentum equals mass times velocity.*

TEACHING TIP

Students should see that this ride shows that the mass of an object may affect its momentum and velocity.

PHASE 2: DAILY DIRECTIONS

11. Relate this activity to **Newton's First Law of Motion**. Ask questions to stimulate your students' thinking:
    - What force started each ball moving? *(Releasing at top of track [potential energy allowed to change into kinetic energy].)*
    - What forces stopped each ball's inertia, or tendency to keep moving once it started moving? *(Friction and the pillow.)*

12. Now relate this activity to **Newton's Third Law of Motion** (The Law of Conservation of Momentum).
    - What is the action force when each ball hits the pillow? *(The ball's impact.)*
    - What is the reaction force? *(The pillow pushing back.)*

TEACHING TIP

To extend this lesson, use the optional EUREKA! MATH 2: Speed and the EUREKA! MATH 3: Momentum as mini-math lessons or homework assingments. Depending on your students' abilities and your instructional goals, you may use these worksheets with advanced students only.

13. Have groups fill out a SCIENTIFIC DETECTIVE RECORD FORM to give to Ms. Roundenround.

14. ***Sample Answers*** for the SCIENTIFIC DETECTIVE RECORD FORM DESIGN TEST 2: The Phantom Dragon:
    (1) The cars on one track never win the race.
    (2) It showed that more mass means more velocity and momentum. Newton's First and Third Laws of Motion are shown.
    (3) T.E.A.M. ACTIVITY 2 helped us understand the difference between speed and velocity.
    (4) Ms. Roundenround should increase the mass of each losing car so that it matches the mass of each winning car.

READ OR TELL

15. Read or tell as Ms. Roundenround:

"Go ahead and try your ideas in the simulator. This is going to be fun!"

READ OR TELL

16. Read or tell as yourself (Virtual Ride 2):

"You and your groupmates key in the design changes you decided on. Then you all climb into the simulator seats. Ms. Roundenround clicks on 'Test Ride' and off you go! Slowly you're pulled to the top of the first hill. Near the top, you twist around to look down. Yikes! It's almost 198 feet down! Now you totter at the top. On the simulator screen you see the other train poised to race. 'Yeeeeeeee-HAH,' you yell as you careen down the hill and up over the second hill. Neck and neck with the other train, your train battles to the finish. Brakes force your train to slow down, you're going so fast. You win by one wheel width!"

17. Allow groups to discuss and decide if the experiment uncovered any new clue(s). If so, they should record it (them) on their group's CLUE TRACKING SHEET in the appropriate column.

18. Debrief today's activities, noting on an overhead transparency ideas students share about what they have learned today. Encourage students to add these notes to their Science Journals.

Estimated activity time two 45 minute class periods

TEACHING TIP

You can have students use a toy truck instead of a roller skate. It doesn't matter which way they face the doll (forward or backward). It will flip out of the truck bed if not strapped in when the truck wheels hit the textbook.

After explaining each type of energy and offering an example of each, you may have groups write their own T.E.A.M. ACTIVITY 3 strips with examples of each for recording on the T.E.A.M. ACTIVITY 3 RECORD. Groups can exchange sets of strips and correct each other's completed work.

THE OUTLAW

Materials

1. Student Guides: Phase 2 — *class set*
2. T.E.A.M. ACTIVITY 3 — *one each per group*
3. T.E.A.M. ACTIVITY 3 RECORD— *one per group*
4. CLUE SEARCHES 1 and 2 — *class set (from previous lessons)*
5. CLUE SEARCH 3: The Outlaw — *class set*
6. SCIENTIFIC DETECTIVE RECORD FORM — *one per group + transparency*
7. DESIGN TEST 3: The Outlaw — *one per group*
8. Boot-style roller skate (or large toy truck) — *one per group*
9. Doll that will sit (8" - 12" or 20 - 30 cm high) —*one per group*
10. Pencils
11. Shoelace or string (16" - 22") — *one per group*
12. Smooth floor
13. Textbook — *one per group*
14. SCIENCE JOURNALS — *class set*

Procedure

1. Distribute T.E.A.M. ACTIVITY 3 STRIPS and one T.E.A.M. ACTIVITY 3 RECORD to each group. Explain that the purpose of this activity is to learn more about **types**, **sources** and **uses** of energy. Direct groups record answers on their T.E.A.M. ACTIVITY 3 RECORD as each member reports his or her information. Students assign each example given to the energy category it best fits.

2. **Option:** *If desired, don't use the T.E.A.M. ACTIVITY 3 RECORD; instead, have students cut apart the information on their strips and glue them to sheets of notebook paper, one each labeled "Radiant Energy," "Thermal Energy," "Chemical Energy," "Electrical Energy," "Sound Energy" and "Nuclear Energy."*

3. After the activity, discuss each type of energy, being sure to distinguish among all the types. Confirm students' answers on their T.E.A.M. ACTIVITY 3 RECORD. Have each group store the RECORD in their folder.

PHASE 2: DAILY DIRECTIONS

TEACHING TIP

Note that some of the answers are repeated as they fit into more than one category. Explain to students that whenever one is classifying in science, there are always going to be items that don't fit into neat categories. For example, scientists are still arguing over whether the tomato is a fruit or vegetable. And who can classify the platypus?! Therefore, accept all reasonable answers for which students can explain their thinking.

4. ***Sample Answers*** for T.E.A.M. ACTIVITY 3
   Radiant Energy Examples: *lightbulb glowing, sunshine, solar panels, greenhouse*
   Thermal Energy Examples: *hot sand on a beach, heating element in a toaster, steam, bonfire, car skidding, gasoline engine, sandpaper rubbing against wood, lightbulb glowing, sunshine, lightning*
   Chemical Energy Examples: *baking soda reacting with vinegar, bread rising, bubbles in a soft drink, food digesting, gasoline engine*
   Electrical Energy Examples: *windmill turning a turbine, battery, computer, running, lightning*
   Sound Energy Examples: *drumbeat, violin music, bell ringing*
   Nuclear Energy Examples: *nuclear power plant, atom splitting*

READ OR TELL

5. Read or tell:

   "Ms. Roundenround is interested to hear about the different types of energy. However, she feels you need to know more about the specific problems she's dealing with."

6. Distribute one copy of CLUE SEARCH 3: The Outlaw to each student.
   a. Allow groups to read and discuss this new information.
   b. Have groups record any clues they find on their CLUE TRACKING SHEET.

READ OR TELL

7. "As Ms. Roundenround mentioned, she has another experiment for us to perform. This will help you see what is happening on the Outlaw."

8. Distribute and have groups do DESIGN TEST 3: The Outlaw.

9. ***Sample Answers*** DESIGN TEST 3: The Outlaw
   Hypothesis:
   The passenger keeps moving forward.

Data:
(1) The first push, the roller skate stopped when it hit the book, but the doll flew forward off the skate.
(2) The second push, the roller skate stopped, and the doll started to move forward, but the tie stopped it.
Conclusion:
(1) The doll kept going because of inertia.
(2) The tie gave a force opposite the inertia to keep the doll on the roller skate.

10. Ask questions such as the following to stimulate your students' thinking:
    - What causes the doll to fall forward when the roller skate hits the book? *(Inertia.)*
    - Which of **Newton's Laws of Motion** does this best demonstrate? (***The First:*** *An object at rest will remain at rest and an object in motion will remain in motion unless acted upon by another force. The book acts on the roller skate but not the doll.)*
    - What part of this activity demonstrates **Newton's Second Law of Motion**? *(The roller skate and its passenger move in the same direction as the force applied to it.)*
    - What part of this activity demonstrates **Newton's Third Law of Motion?** *(The action force of the roller skate's hitting the book and the reaction force of the book's pushing back on the roller skate.)*
    - What helped the doll stay in place? *(Being strapped on with the shoelace or string, as people are seat-belted into cars. Seat belts serve as a reaction force to react to the action force created by forward momentum.)*

READ OR TELL

11. Read or tell:

    "As you saw from this activity, a 'person' in motion will remain in motion unless acted upon by another force, as stated in Newton's Third Law."

12. Have groups record any possible clues they think this experiment suggests for solving the mystery on their CLUE TRACKING SHEET.

PHASE 2: DAILY DIRECTIONS

TEACHING TIP

Students should see that this activity demonstrating Newton's Law of Motion explains the problems the Outlaw roller coaster is having. In addition, mention that this law is also known as the ***Law of Inertia****.*

13. Have each group prepare a SCIENTIFIC DETECTIVE RECORD FORM to give to Ms. Roundenround.

14. ***Sample Answers*** for the SCIENTIFIC DETECTIVE RECORD FORM DESIGN TEST 3: The Outlaw
    (1) The passengers fly forward when the train stops, sometimes out the front windows.
    (2) The doll kept moving like the passengers on the OUTLAW. This shows Newton's First Law of Motion. It also shows the Third Law when passengers hit something that stops them—like the passenger in front of them.
    (3) Galileo's mind experiment (EUREKA! ACTIVITY 2) helped us learn about inertia.
    (4) Ms. Roundenround needs to add seat belts to the OUTLAW'S train cars. These will give a reaction force to stop the action force made by the passengers moving forward on the train. Newton's First Law of Motion explains the problem and the Third Law gives the solution.

READ OR TELL

15. Read or tell as Ms. Roundenround:

    "Well, shoot—why didn't I think of that? All the other coasters have restraining bars or harnesses to hold people in their seats. Step this way right into the simulator. I haven't had so much fun since I first opened Roller Coaster World!"

READ OR TELL

16. Read or tell as yourself (Virtual Ride 3):

    "After reprogramming the computer with your design changes, you climb into the simulator once again. Ms. Roundenround climbs in, too. 'Ride 'em, cowboys and cowgirls!' she shouts. Your teacher clicks on 'Test Ride' and suddenly you're in a Wild West town. Just as you're flying down the first hill, a sheriff and outlaw come out shooting at each other across the tracks. The train swerves around the Bank and under a low tree branch, just as robbers run out and begin shooting at the train. You can't help cringing it's so realistic. 'Ha! Ha!' Ms. Roundenround hoots, 'They can't get us!' Three more quick hills and you could swear you left your stomach at the front gate to the park. A tight turn and the ride ends with a jolt, but no one bumps into anyone else."

17. Debrief today's lesson, recording student comments on an overhead transparency. Allow time for students to record these comments in their Science Journals.

PHASE 2 - DAILY DIRECTIONS

Estimated activity time two 30 - 45 minute class periods.

THE RATTLESNAKE

Materials

1. Student Guides: Phase 2 — *class set*
2. CLUE SEARCHES 1, 2 and 3 — *class set (from previous lessons)*
3. CLUE SEARCH 4: The Rattlesnake — *class set*
4. CLUE TRACKING SHEET — *one per group (from previous lesson)*
5. T.E.A.M. ACTIVITY 4 — *one set of strips per group*
6. T.E.A.M. ACTIVITY 4 RECORD — *one per group*
7. SCIENTIFIC DETECTIVE RECORD FORM — *one per group + transparency*
8. DESIGN TEST 4: The Rattlesnake — *one per group*
9. Science Journals — *class set*
10. Coarse sandpaper (as wide as the block and as long as the tray) — *one per group*
11. Cooking oil — *1/4 cup per group*
12. Jar lid (3.5" - 4") — *one per group*
13. Large rubber band — *one per group*
14. Marbles (all same size) — *enough to fill jar lid*
15. Pencils — *class set*
16. Spring scale — *one per group*
17. Styrofoam tray (smooth, 14" - 16") — *one per group*
18. Tape — *one roll per group*
19. Wood block (at least 3" x 5" x 1" - larger is better) — *one per group*
20. EUREKA! MATH 4: Work (Optional) — *as needed*

Procedure

READ OR TELL

1. Read or tell:

   "Today we will start with the CLUE SEARCH and complete the T.E.A.M. ACTIVITY last."

TEACHING TIP

Students should recognize that friction must be just right for the ride to be safe and fun—not too high and not too low.

2. Distribute CLUE SEARCH 4: The Rattlesnake to each group. Allow groups time to read and discuss this latest information. Have groups record any possible clues on their CLUE TRACKING SHEETS.

3. Tell students that, as Ms. Roundenround mentioned today, they will be conducting an experiment to learn more about friction.

4. Explain that a spring scale measures *how much force (measured in newtons [N]) is pulling an object*. Have students refer to the scientific definitions of **force** and **work** in the GLOSSARY.

5. Have each group conduct DESIGN TEST 4: The Rattlesnake.

TEACHING TIP

Circulate among groups, checking to see that each group knows how to read their spring scale correctly.

6. Ask questions such as the following to stimulate your students' thinking:
   - What machine parts are the marbles like? *(Ball bearings)*
   - How and why is oil used in machinery? *(In engines to reduce damage from friction)*
   - What if you pulled a heavier object across each setup? *(The newtons would be higher in each case but the same setups would require more or less force relative to each other)*
   - How else might you reduce friction in this experiment? *(Water, shampoo, use several drinking straws as rollers)*
   - How else might you increase friction in this experiment? *(Sandpaper on the down side of the block as well as to the tray, glue)*

7. After everyone has completed the experiment, allow each group time to share their results with the rest of the class. Make sure students understand that the marbles and oil reduce friction and the sandpaper increases it. In other words, less friction requires less force to move an object (fewer newtons) and more friction requires more force to move an object (more newtons). Finally, explain that anything that reduces the force needed (ie., reduces work) is described as a **mechanical advantage**.

8. Allow groups time to discuss and decide if the experiment has given them any new clue(s) to help them solve the mystery. If so, direct them to record this information on their group's CLUE TRACKING SHEET.

PHASE 2: DAILY DIRECTIONS

TEACHING TIP

If desired, don't use the T.E.A.M. ACTIVITY 4 RECORD; instead, have students cut apart the information on their strips and glue them to sheets of notebook paper, labeled "Higher Friction," "Lower Friction," "Higher Drag," and "Lower Drag."

9. ***Sample Answers*** DESIGN TEST 4: The Rattlesnake
   Hypothesis: *The marbles and oil will reduce friction. The sandpaper will increase it.*
   Data: *empty tray—1.5 newtons; marbles—.25 newtons; sandpaper—2.0 newtons; oil—.5 newtons.*
   Conclusion:
   (1) Rolling the block across the marbles and sliding it through the oil required less force, because the marbles and oil reduced friction.
   (2) Pulling the block across the sandpaper and empty tray needed more force, because the sandpaper and empty tray increased friction.

10. Distribute T.E.A.M. ACTIVITY 4 , one set of strips per group, one strip per student and one T.E.A.M. ACTIVITY 4 RECORD to each group. Explain to students that the objective of this activity is to learn more about friction and drag.

READ OR TELL

11. Read or tell:

    "**Drag** is a special type of **friction**. As each member reports his or her information, use the T.E.A.M. ACTIVITY 4 RECORD to record what each statement best describes—high or low friction or high or low drag."

TEACHING TIP

After discussing the definitions of friction and drag and offering a few examples, you may wish to have groups write their own T.E.A.M. ACTIVITY 4 strips with examples of each condition listed on the T.E.A.M. ACTIVITY 4 RECORD. Groups can exchange sets of strips and correct each other's completed work.

12. After the activity, discuss the definitions of friction and drag. Have students support their answers with the information you gave them. Have each group grade their T.E.A.M. ACTIVITY 4 RECORD, confirming or correcting their answers. Have each group store this sheet in their group folder.

13. ***Answer Key*** T.E.A.M. ACTIVITY 4
    Higher Friction Examples*—rubber bath mat, rubber soles on shoes, scouring pad, hand brakes on bike*
    Lower Friction Examples*—wheels on in-line skates, wet tile floor, wax on snow skis, oil in car engine, gliding on ice*
    Higher Drag Examples*—riding bike wearing wide-leg jeans, car traveling with trunk open, design of delivery truck body*
    Lower Drag Examples*—design of race car body, windshield on car, cone-shaped nose of airplane, wearing bike shorts*

14. Then have each group add any additional information they feel T.E.A.M. ACTIVITY 4 has revealed to the CLUE TRACKING SHEET and complete a SCIENTIFIC DETECTIVE RECORD FORM based on today's lesson to give to Ms. Roundenround.

15. ***Sample Answers*** for SCIENTIFIC DETECTIVE RECORD FORM DESIGN TEST 4: The Rattlesnake
    (1) The Rattlesnake is going too fast, making the wheels get hot and melt.
    (2) Some things increase friction and some things decrease friction. Less friction means less interfering with inertia (Newton's First Law of Motion).
    (3) Inertia can cause safety problems, like when The Outlaw passengers flew forward.
    (4) Mr. Doobad must have oiled part of the tracks of The Rattlesnake, so they need to be cleaned off. That way the train won't go too fast on the ungreased parts, melting the wheels.

TEACHING TIP

Respond to students who point out: Friction turns kinetic energy into thermal energy - the friction does not overcome the speed effect of the oil enough to slow The Rattlesnake.

16. **Option:** To extend this lesson, use the optional EUREKA! MATH 4: Work as mini–math lessons or homework assignments, depending on your students' abilities and your instructional goals. You may use these worksheets with advanced students only.

PHASE 2: DAILY DIRECTIONS

READ OR TELL

17. Read or tell as yourself:

"On the way back to the simulator, Ms. Roundenround stops in front of a closed pizza stand, pulls out a cell phone, and calls someone. You overhear her say, 'Rex, send a crew up here to Pizza Plaza 5 to feed these kids. I've been forgetting how hungry kids get.' You all cheer. You were beginning to think you'd die of starvation on this field trip. 'We'll take a lunch break right after we fix this ride—sorry I didn't think of it earlier,' Ms. Roundenround reassures you. Soon you are back in the simulator room."

READ OR TELL

18. Read or tell as Ms. Roundenround:

"TEEEE-Riffic redesign ideas! I don't know what I ever did without you folks! Hop in—let's go!"

READ OR TELL

19 . Read or tell as yourself (Virtual Ride 4):

"Slowly you're towed to the top of the first hill. You look suspiciously at the wooden structure ahead of you. 'Isn't this too tall for a wooden coaster?' you think. Your seat rumbles low. At the top of the hill, a classmate dares you to lift up your arms. 'AEEEEIA!' you yell as you plunge down the first hill. Your stomach seems to flop as it tries to catch up with the sudden drop. Your body shakes as your seat rumbles and quakes. CREEEEAK! You're going uphill again. 'Will this rickety thing hold up?' you wonder. Wind whistles through your hair and past your ears. Duck! You almost hit an overhead support! One last turn and you're back at the start."

READ OR TELL

20. Read or tell:

"'Thanks, guys! Pizza and soft drinks for everybody! On the house!' Ms. Roundenround exclaims. 'Good thing my stomach was empty on that one!' you tell a friend."

21. Using a blank overhead transparency, record what students share they have learned today. Encourage students to add these notes to their Science Journals.

PHASE 2 - DAILY DIRECTIONS

THE COBRA SPITFIRE

Materials

1. Student Guides: Phase 2 — *class set*
2. CLUE SEARCHES 1, 2, 3 and 4 — *class set (from previous lessons)*
3. CLUE SEARCH 5: The Cobra Spitfire — *class set*
4. CLUE TRACKING SHEET — *one per group (from previous lessons)*
5. SCIENTIFIC DETECTIVE RECORD FORM — *one per group + transparency*
6. DESIGN TEST 5: The Cobra Spitfire — *one per group*
7. Science Journals — *class set*
8. Clear plastic container with tight-fitting lid — *one per group*
9. Pencils — *class set*
10. Strong string or twine — *one yard (one meter) per group*
11. Water (colored) — *one to two cups per group*

TEACHING TIP

Use a ketchup bottle or peanut butter jar. An open plastic ice cream bucket with a colored ball can be substituted for a closed bottle with water.

Procedure

1. Tell the class that with all the information they have collected (including today's information), they should be able to solve the overall mystery by the end of today's class.

READ OR TELL

2. Read or tell:

   "Ms. Roundenround is very interested to learn the results of your friction experiment. You may have discovered some important information that will help Ms. Roundenround solve the mystery. Today we will learn about centripetal force and review Newton's three Laws of Motion."

3. Distribute one copy of CLUE SEARCH 5: The Cobra Spitfire to each student. Allow groups time to read and discuss the information and to review all other clues they have gathered. Have them add any new clues to their group's CLUE TRACKING SHEET.

PHASE 2: DAILY DIRECTIONS

READ OR TELL

4. Read or tell:

    "As Ms. Roundenround mentioned she has one last experiment for us to perform. It will tell us more about centripetal force."

5. Distribute a DESIGN TEST 5 and a SCIENTIFIC DETECTIVE RECORD FORM to each group.

6. Have students perform and record the results of the design test. Stimulate their thinking with questions such as the following:
    - Remind students of DESIGN TEST 1, and ask, "How are the two coasters' problems similar?" *(A later height cannot be higher than an earlier height on a roller coaster because the kinetic energy and momentum are not great enough.)*
    - What influence might friction or drag have on this problem? *(Friction converts some of the kinetic energy into thermal energy.)*
    - Where might centrifugal force be a factor? *(If the coaster car flew off the track and continued in a straight line.)*

7. ***Sample Answers*** DESIGN TEST 5: The Cobra Spitfire
    Hypothesis: *It will push the object outward.*
    Data:
    (1) The water fell toward and into the lid.
    (2) The water stayed at the bottom of the container.
    (3) The water started to move toward the lid.
    Conclusion:
    (1) Gravity pulled the water down.
    (2) Centripetal force overcame gravity.
    (3) Gravity became stronger than the centripetal force because there was not enough momentum.

8. Explain that the circular motion involved in centripetal force is called **curvilinear momentum**, or **angular momentum**, and that the straight-line motion involved in other examples is called **linear momentum**, or **rectilinear momentum**.

9. Relate today's activities to Newton's Laws of Motion:
   - Do you see an example of Newton's Third Law of Motion? *(Yes, the train car pressing on the track and the track pressing on the train car. Also, the water pushing on the container's bottom and the container's bottom pushing on the water.)*
   - Do you see an example of Newton's First Law of Motion? *(Yes, inertia causes the container to keep moving until drag slows it down, same for the train car until drag and friction slow it down.)*

TEACHING TIP

Make sure students note how lack of momentum and centripital force relate to the trouble with the Cobra Spitfire. The fourth loop was larger/ higher than the third loop, so it called for more velocity and momentum to get through it than was available. The force of the track's pushing on the car was greater than the car's pushing on the track. Momentum and the looped shape of the track need to create enough centripetal force to overcome gravity.

10. **Sample Answers** for SCIENTIFIC DETECTIVE RECORD FORM DESIGN TEST: The Cobra Spitfire
    (1) The coaster cars cannot make it through the last loop. They stop about two-thirds up, and the passengers start to fall out.
    (2) The design test showed that you have to have enough momentum to make something loop without its contents falling down (and out if allowed to). This shows Newton's Third Law of Motion: you need a reaction force as great as the action force to keep the stuff in the bottom of the container—and people on a looping coaster in their seats.
    (3) The first design test showed that you have to have enough kinetic energy to get through the whole coaster. Because the last loop is bigger than the third loop, there is not enough kinetic energy left to get through it and keep everyone safe in their seats.
    (4) The last loop has to be made smaller than the third loop so that the cars have enough kinetic energy left for the last loop, even after friction takes some of it.

11. After discussing the results as a class, have each group fill out a SCIENTIFIC DETECTIVE RECORD FORM to give to Ms. Roundenround.

12. Read or tell as Ms. Roundenround:

READ OR TELL

"I can't believe the designers I hired made so many mistakes! Let's plug your suggestions into the simulator and ride this one. Then I want to hear all of your recommendations for my Roller Coaster World."

READ OR TELL

13. Continue as yourself (Virtual Ride 5):

> "You climb into the simulator, wondering how it could possibly make you feel upside-down. The huge screen comes to life and once again you're being towed slowly to the top of the first hill. Then—WHOOOOA—you're in a nose-dive headed for a gigantic loop. Your body presses into your seat as you swoop around. You force your eyes open to peak at the ground below. Concrete stares back at you. Don't they know enough to use a net, like for the tightrope walkers in the circus? WHOOOOSH! You're careening along a steep embankment. Turn. Loop. Twist. Turn. Loop. You think, 'Did I leave my heart at home this morning?' The fourth loop—work's great! PHEW, it's over—you're going to buy the 'I Survived the Cobra Spitfire' T-shirt."

14. Have groups write their recommendations regarding the overall problems at Roller Coaster World and label it "To Ms. Roundenround: Our group's overall recommendations."

15. ***Sample Overall Recommendations***
    - *Each coaster needs to be redesigned and rebuilt according the information on each SCIENTIFIC DETECTIVE RECORD FORM.*
    - *You should take a course in physics so you can spot potential problems in roller coaster design blueprints.*
    - *You should fire the design company you've been using—after they fix everything for free!*

PHASE 3: EXTENSIONS

SIMULATION EXTENSIONS (OPTIONAL)

1. **Oral Presentations**
   Have groups present their recommendations to a “Ms. Roundenround,” the Owner of Roller Coaster World (portrayed by school principal, yourself or other dignitary).

2. **Challenge Projects**
   Assign or allow students to choose from the list of CHALLENGE PROJECTS listed on page 66. You may also have students present these projects to “Ms. Roundenround.”

3. **Marble Coasters**
   Have small groups construct Marble Coasters as described on page 64. These must demonstrate several physics of motion concepts and terms. Briefly teach or review what makes a structure strong (bracing, etc.) before having students do this activity.

TEACHING TIP

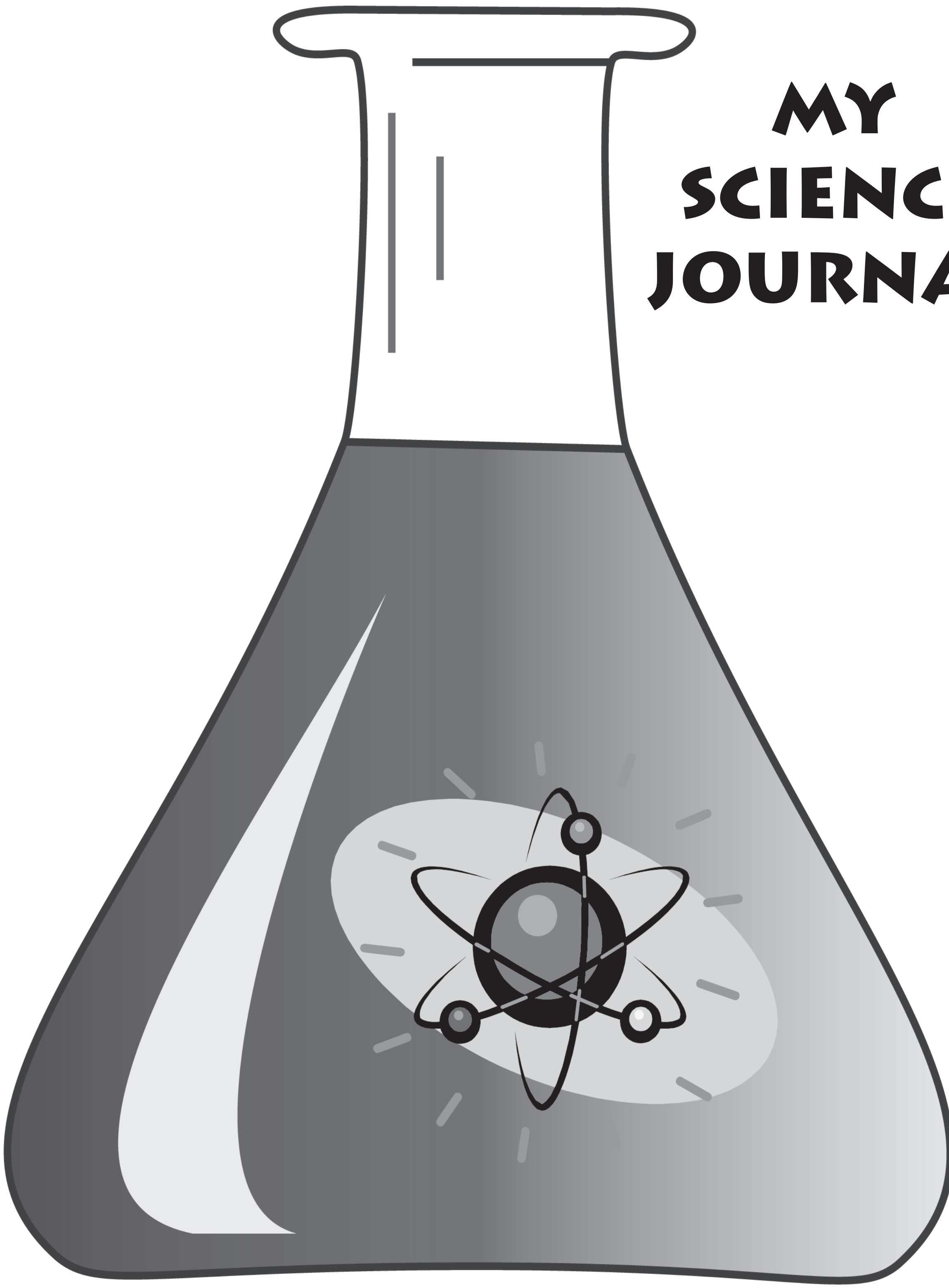
If your students enjoyed building the Marble Coaster, you may wish to teach INSECT ISLAND in which students learn about what makes structures in general and insect structures strong. This simulation includes several exciting building opportunities.

4. **Eureka! Moment Re-enactments**
   You may wish to have each small group select a moment in history explored in Phase 1 to re-enact for Ms. Roundenround and/or other visitors. Encourage students to use simple props, such as the experiment materials. If desired, use the rubric on page 65 to guide your assignment and assessment of this activity.

5. **Formal Assessment**
   Use of the RUBRICS provided on page 65 turn either of the previous two projects into a formal assessment opportunity. You may then wish to have all the groups in your class work to together to connect their MARBLE COASTERS into one large coaster.

6. **Roller Coaster Virtual Rides**
   You may wish to have students make audio cassettes with sound effects of one or more Virtual Rides to play for visitors.

MY SCIENCE JOURNAL



Name:________________________________

MASTER

YOUR SCIENCE JOURNAL

Scientists and Detectives - Scientists are really detectives who work diligently to solve a problem. Like detectives who work for the police department, scientists have tools they use to solve mysteries. For example, both scientists and detectives keep notebooks (or journals). Here they carefully document what they find, observe, question or believe to be a possible solution to the mystery they are attempting to solve.

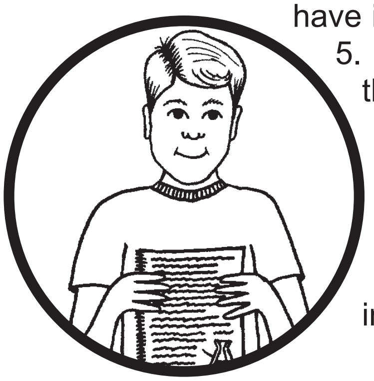
"I'm recording questions that need to be answered."

Keeping a Journal - As you work through the ROLLER COASTER mystery, you will keep a journal, just as a real scientist or a real detective does. Your Science Journal will be important because in it you will record everything you learn!

Making an Authentic Journal - To keep an authentic—that is, a real and worthwhile—Science Journal, include the following elements:

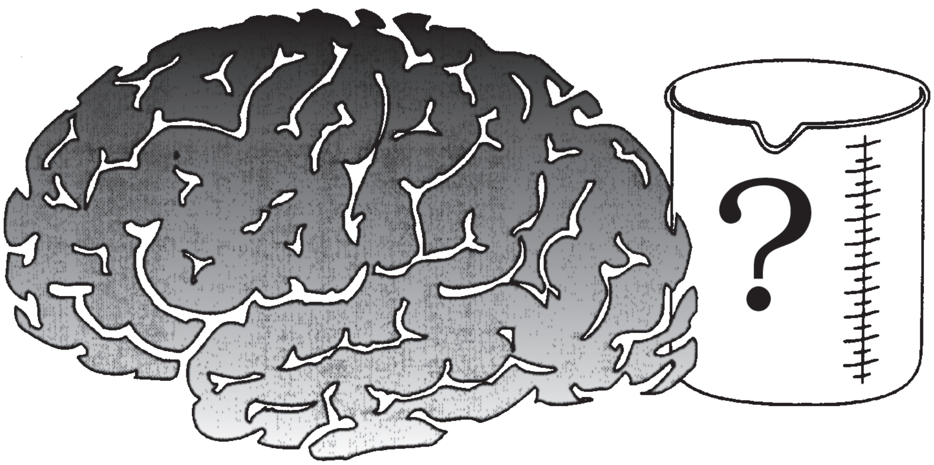
1. **Dates** - Every time you write in your Science Journal, you must include the date! This date will help you keep track of when you did activities and experiments and made observations.
2. **Complete Descriptions** - Descriptions of all activities, experiments and observations must be very complete so that someone with no knowledge of motion or the activities and experiments you did could pick up your Science Journal, read it and understand exactly what you did.
3. **Illustrations** - Have you heard the expression, "A picture is worth a thousand words?" Illustrations will help someone reading your Science Journal to understand even more than they would from words alone. Illustrations do not have to be complex; they can be simple diagrams or sketches. These illustrations will not only help someone reading your Science Journal; they will also help you when you look back at your notes. Scientists often take pictures at different points in their experiments. If you have a camera, you may also take pictures as you work through this ROLLER COASTER mystery.
4. **Important Questions** - Scientists use their Science Journals to record carefully any questions that occur to them as they are working. These questions help them determine what else they should study further. You should include questions you have in your Science Journal as you work through this mystery.
5. **Possible Solutions** - Scientists are always thinking about the solution to the problem troubling them. In their journals, they record possible solutions whenever one comes to mind. Do the same thing in your Science Journal.

Good luck with your Science Journal. It will help you keep track of most of your thoughts and actions as you solve this intriguing mystery!



"I've been drawing some pictures in my journal."

Using your brain in sequential steps...



Problem: What do you wish to find out?

Hypothesis: What do you think the answer is?

Experiment: Design a procedure (experiment) to test your hypothesis.

Data: Conduct the experiment and keep accurate records of your results. Repeat the experiment a number of times. Record the information you collect (data) in a Science Journal. (You may also put some information on a graph.)

Conclusion: Summarize what you have discovered (concluded) as a result of doing this experiment.

GLOSSARY

Acceleration—the rate of change in velocity of an object

Angular momentum—the energy of an object moving along a curve around a fixed point, e.g., such as the moon traveling around the Earth; also called **curvilinear momentum**

Centripetal force—the force needed to create and maintain circular motion

Centrifugal force—the tendency of a moving object to move outward into space along the same straight line (not a "force" at all, but a description of a behavior)

Clothoid loop—a "squashed" loop that evens out the forces on the human body as it travels around it; keeps passengers safe and comfortable on a looping roller coaster

Constant acceleration—velocity increasing or decreasing steadily

Controlled experiment—a scientific test in which there is only one variable

Deceleration—a non-scientific word for acceleration that is decreasing; also called **negative acceleration**

Drag—a force caused by air rubbing on an object

Energy—the ability to do work

Force—a push or pull, measured in newtons or pounds

Friction—a force created by the rubbing of two objects against each other

Gravity—the force of the Earth's pull on an object (this is a partial definition only)

Inertia—the tendency of an object at rest to stay at rest and an object in motion to stay in motion

Kinetic energy—the energy of motion

***Law of Conservation of Energy**—Energy cannot be created or destroyed, only changed in its form, for example, kinetic energy can be changed to heat due to friction.

GLOSSARY

Linear momentum—the energy of an object moving in a straight line; also called **rectilinear momentum**

Mass—a measure of how much material an object contains for the space it takes up (that is, for its **volume**)

Mechanical advantage—anything that reduces the amount of force needed to move an object (e.g., a pulley or lever, oil to reduce friction)

Momentum—has to do with the amount of energy a moving object has; expressed as the mass of the object multiplied by its velocity (Momentum = mass x velocity)

***Newton's First Law of Motion**—An object at rest will stay at rest, and an object in motion will stay in motion, unless acted upon by an outside force. Also known as the **Law of Inertia**.

***Newton's Second Law of Motion**—This law has two parts: (1) If a force acts on an object, the body moves faster, or accelerates, in the direction of the force, and (2) the more force used to push an object, the more the object will move, but the more massive an object is, the more push (force) it takes to move it. Also known as the **Law of Constant Acceleration**.

***Newton's Third Law of Motion**—For every action, there is an equal and opposite reaction. Also known as the **Law of Conservation of Momentum**.

Potential energy—an object's stored energy

Speed—the rate at which an object moves; speed is the distance the object has traveled divided by the time it took to travel (Speed = distance ÷ time)

Variable—changing part, as in a scientific experiment

Velocity—the speed of an object in a particular direction

Volume—the amount of space an object occupies

Weight—a measure of how much gravity is pulling down on an object

Work—using a force to make an object move a certain distance (Work = Force x Distance; W = F x D), measured in foot-pounds or newton-meters (joules)

MASTER

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CLUE TRACKING SHEET

Student Name______________________________ **Clue Tracking #** __________

Maybe a clue	Date	Definitely a clue	Date

SCIENTIFIC DETECTIVE RECORD FORM

Name of Roller Coaster:______________________________________

Names of Detectives:______________________________________

____

Design Test Number and Name:______________________________

1. According to Ms. Roundenround, what problem does this roller coaster have?____

____

____

2. What clues did the ROLLER COASTER DESIGN TEST uncover? Which Law(s) of Motion seem(s) to be involved?___________________

____

____

3. What other information have you learned so far in ROLLER COASTER that may apply to this roller coaster's problems? ___________________

____

____

4. What recommendations do you make to Ms. Roundenround about how she can correct the problem and get her roller coaster back in operation again? __________________________________

____

____

MASTER

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MARBLE COASTER

Follow the instructions below to make a roller coaster for a marble to travel through.

Rules

1. Show an example of each of the terms listed at the bottom of this page.
2. You may not use the same place on the coaster to show two different terms.
3. The “feet" of the coaster do not all have to fit on the base.

You Will Be Graded On

- accurate labeling of terms
- successful verbal explanations
- smoothness and reliability of operation
- creativity
- teamwork
- stability of the structure

Materials

- Cardboard tubes (from toilet paper, paper towels, gift wrap)
- Masking tape and transparent tape
- Scissors
- Base (for example, a soft drink can tray)
- Large marble
- Paper and pencil

Procedure

1. Use the paper and pencil to sketch a rough design of your coaster.
2. Use the cardboard tubes, masking tape and base to build your coaster.
3. Test your coaster by sending the marble through it.
4. Make any necessary adjustments to ensure its operation is smooth and reliable.
5. Cut out the terms listed below and tape them onto the appropriate places on your coaster.

Inertia	**Angular Momentum**	**Linear Momentum**
Centripetal Force	**Highest Kinetic Energy**	**Highest Potential Energy**
Friction	**Negative Acceleration ("Deceleration")**	**Another term of your choice**

Marble Coaster Rubric

Names____Date_________

Name of Marble Coaster____
Teacher may score between levels.

	Excellent (8)	Very Good (6)	Good(4)	Fair (2)
Accurate labeling of terms				
Successful verbal explanations				
Smoothness and reliability of operation				
Stability of structure				
Creativity				
Teamwork				
			Total points:	

Eureka! Moment Re-enactment Rubric
Names ____Date_____________
Title of presentation____
Teacher may score between levels.

	Excellent (8)	Very Good (6)	Good (4)	Fair (2)
Historical accuracy				
Creativity				
Teamwork				
We could hear you in the back of the room				
			Total Points:	

MASTER

PHASE 3 - CHALLENGE PROJECTS

These projects are **optional.** **required.** (circle one)

If required, you must complete ______ project(s) by ____________________.

1. Using a length of easy-to-bend wire, build your own roller coaster. Shape the wire to show the path the riders will take, applying all you've learned about safe and effective roller coaster design. Use clay to anchor your model to a plywood or cardboard base. Write a paragraph describing the reasons for your design choices.

2. Make your own E-Can. List at least three ideas you would try to make it "walk" further. Test these ideas and compare it to the E-Can used in class.

3. Imagine a new roller coaster and give it a name. Write a detailed description of a ride on your roller coaster, creating your own "Virtual Ride". Read it to a friend to get his or her reaction. Revise and adjust your description to make your ride as realistic and exciting as possible. Remember to obey the laws of physics.

4. Research how Galileo and Newton influenced the science of astronomy, the study of natural objects outside the Earth's atmosphere, including the sun, moon and planets. Write a Eureka! Moment and present and illustrate it in poster form.

5. Investigate how the moon's gravity brings about the rise and fall of tides on the Earth. Be sure to explain these terms: high tides, low tides, spring tides, neap tides. Discuss this in relation to Newton's Third Law of Motion.

6. Research and construct a poster on bike safety. List at least five "Rules of the Road" that will keep a person safe on a bike. Point out how each of Newton's Laws of Motion affects a bicyclist's safety.

7. Design a new experiment related to this simulation. Make sure it only has one variable. Test it with some friends.

8. Write a song or rap that reviews much of the information learned in this simulation. Perform it for your class.

9. Based on descriptions, draw each of the roller coasters visited in Phase 2. Make a booklet or poster. Include as many GLOSSARY words as you can in your diagrams.

10. Bring in at least three toys that demonstrate something you've learned during this simulation. Demonstrate and explain to your class why you chose these toys.

11. Experiment with how pendulums might demonstrate Newton's three Laws of Motion. Demonstrate and explain your findings to your class.

12. After receiving your teacher's approval, develop any project related to this topic that interests you.

MASTER

EUREKA! ACTIVITY 1, Part 1

Free Fall - Aristotle's Experiment

GLOSSARY words: **mass, volume, weight, gravity, variable**

Problem: Will two objects hit the ground at the same time when dropped from the same height at the same time?

Your Hypothesis: ____

Materials: 1 small rock, 1 feather, carpeted/padded surface

Experiment:

1.Hold one object in each hand. Hold your hands the same height above the floor (about waist-high).

2.Let go of the rock and feather at the same time over the carpeted surface.

Data: Describe what you observed about each object.

____

____

Conclusion:

1. Why do you think each object hit the floor when it did? ____________________

____

2. What variable(s) were involved in this experiment? ____________________

____

3. How did the design of the experiment influence the data you collected? ________

____

4. How would a rock and feather act if this experiment were conducted on the moon (no air, low gravity)?

____

____

MASTER

EUREKA! ACTIVITY 1, Part 2

Free Fall - Galileo's Experiment

Problem: Will two objects of the same volume, but different masses, hit the ground at the same time when dropped from the same height at the same time?

Your Hypothesis: ____

Materials: 2 balls the same size and shape, different masses

Experiment:

1. Hold one ball in each hand. Hold your hands the same height above the floor (about waist-high).

2. Let go of the balls at the same time.

Data: What did each ball do?

____

Conclusion:

1. Why do you think each ball hit the floor when it did?

____

2. What variable(s) were involved in this experiment?

____

3. How did the design of the experiment influence the data you collected?

____

4. How would these two objects behave if this experiment were conducted on the moon?

____

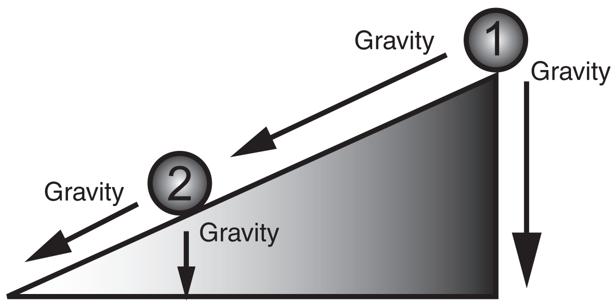
MASTER

EUREKA! ACTIVITY 2

Newton's First Law of Motion

GLOSSARY words: **energy, force, inertia**

Galileo identified inertia in objects through his ability to "think away" forces that would interfere. He imagined a perfectly smooth ball and a perfectly smooth surface for it to roll along. Here is a sketch of his idea:



The "1" identifies the perfectly smooth ball at the top of a perfectly smooth surface. A force (gravity) pulls straight down on the ball (see the "2"). This holds the ball on the slope. Gravity also pulls the ball down the slope.

In this activity, you are to "think away" forces that would interfere with the ball's rolling action, just as Galileo did.

Problem: What would happen if a force caused a perfectly smooth ball to roll along a perfectly smooth surface?

Your Hypothesis: ____

Materials: Your imagination!

Experiment:
1. Imagine a perfectly smooth ball at the top of a perfectly smooth slope.
2. Imagine a force pushing the ball down the slope.
3. Imagine the ball continuing along a perfectly flat and perfectly smooth surface.

Data: What did you imagine would happen to the ball? ______________________

____

____

Conclusion: Why do you think the ball could travel in your imagination as it did?

____

____

____

MASTER

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EUREKA! ACTIVITY 3, Part 1

Newton's Second Law of Motion

GLOSSARY words: **centripetal force, centrifugal force**

Problem: Test the first part of Newton's Second Law of Motion. In what direction does an object move when a force acts on it?

Your Hypothesis: ____

Materials: ball

Experiment:
1. Choose a ball and set it on the floor where there is plenty of room for it to move.
2. Hit one side of the ball gently with your hand.
3. In what direction does the ball travel?
4. Hit the ball gently with your hand from each of the three other sides.
5. Each time, in what direction does the ball travel?

Data: Record your observations in this chart (continue on the back of this sheet if you need more space):

Hit Number	Direction in which the ball traveled
1	
2	
3	
4	

Conclusion: Why do you think the ball responded to the force (each hit) as it did?

____

____

EUREKA! ACTIVITY 3, Part 2

Newton's Second Law of Motion

Problem: Test the second part of Newton's Second Law of Motion. Using the same amount of force, how do the masses of objects influence the objects' motion?

Your Hypothesis: ____

Materials:
- Smooth floor
- 2 balls the same size, but very different masses
- Meter or yardstick

Experiment:
1. Place the two balls side by side on the smooth floor, about 12 inches (30 cm) apart. Make sure there is plenty of room for them to move.
2. Use the meter stick to hit the two balls at the same time with the same force.

Data:

1. What did the ball with the less mass do when hit? ____________________

____

____

2. What did the ball with more mass do? ______________________________

____

____

Conclusion:

1. Why do you think the ball with less mass acted as it did? ________________

____

____

2. Why do you think the ball with more mass acted as it did? _______________

____

____

MASTER

EUREKA! ACTIVITY 4

Newton's Third Law of Motion

Newton stated and explained his laws of motion in his masterpiece, *Mathematical Principles of Natural Philosophy*. In this book, first published in Latin in 1687, he offers two examples of his Third Law from his life:

a. "If you press a stone with your finger, the finger is also pressed by the stone."
b. "If a horse [pulls] a stone tied to a rope, the horse ...will be equally drawn back towards the stone; for the ...rope...will draw the horse as much towards the stone as it does the stone towards the horse."

Materials:

- Large poster board
- Markers or colored pencils
- Magazine pictures (optional)

Procedure:

1. Complete the chart below to get some ideas of examples you can illustrate.
2. Think of your own ideas, too. Add them to the chart below. Use the back of this sheet if you need more space.

Situation	Action Force	Reaction Force
a. Space station orbits Earth	Earth's pull on space station	Space station's pull on Earth
b. Child jumps on trampoline	Feet push on trampoline	
c. Bat hits baseball		Ball's force on bat
d. Baby squeezes toy	Hands' force on toy	
e.		
f.		
g.		
h.		

3. Make a poster titled "Actions and Reactions" that shows at least six examples from your life.
4. For each picture on your poster, label the action force and the reaction force (see example in the chart).

MASTER

EUREKA! ACTIVITY 5

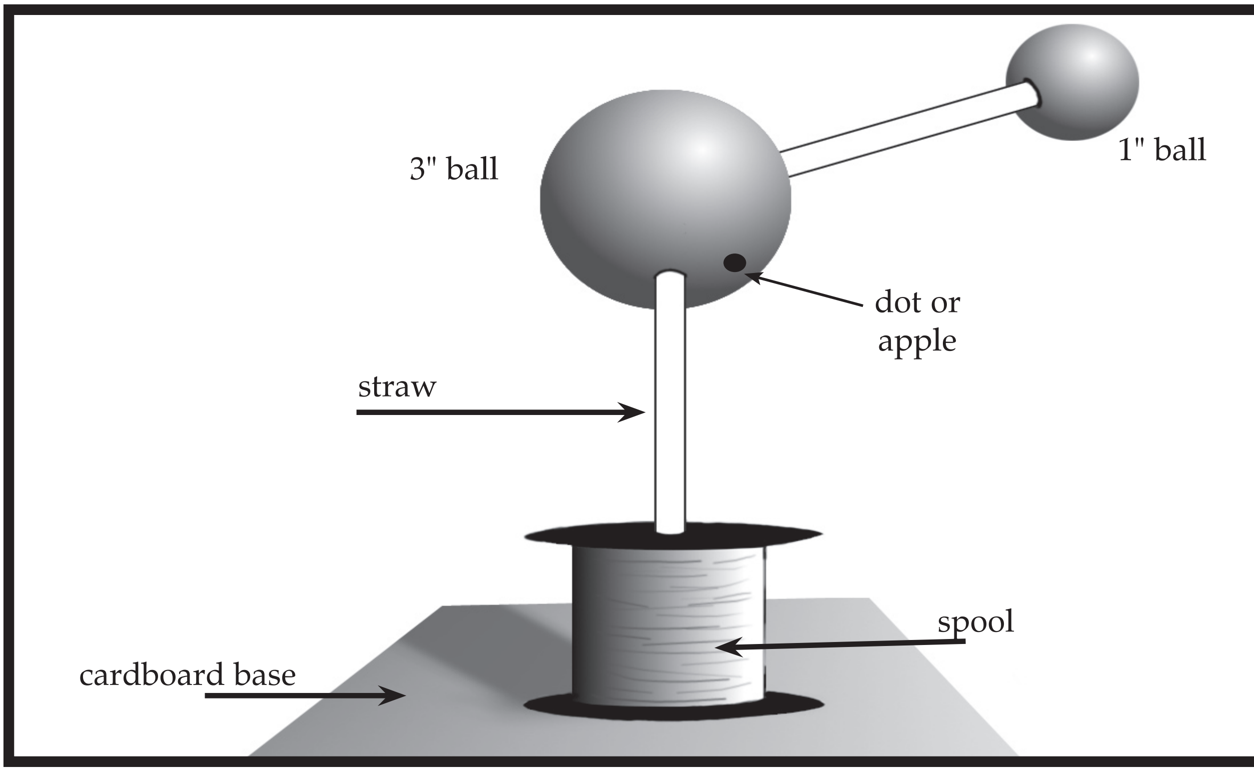
Gravitation Model

GLOSSARY words: **gravity**

Experiment: Make a model showing how objects pull on each other.

Materials:
- 1 one-inch (2.5 cm) Styrofoam ball
- 1 three-inch (7 cm) Styrofoam ball
- 2 plastic drinking straws (not "flexible")
- 1 thread spool
- Clay or glue
- 1 cardboard base, about 12" x 12" (30 cm x 30 cm)
- 1 red marker

Instructions:
1. Fix the spool in the center of the cardboard base with clay or glue (allow to dry before doing Step 5).
2. Insert both straws into the three-inch ball as shown. This ball represents the Earth.
3. Insert the other end of one straw into the one-inch ball as shown. This ball represents the moon. The straw between the two balls represents the gravitational pull the Earth and moon have on each other.
4. Make a small red dot anywhere on the three-inch ball. This dot represents an apple.
5. Place the remaining free straw end into the center of the spool.
6. Test to ensure the straw will turn in the spool so that the moon rotates around the Earth.



MASTER

EUREKA! ACTIVITY 5

1. What does the straw between the "Earth" and the "moon" represent?

____

____

____

2. In your own words, what is Newton's Law of Universal Gravitation?

____

____

____

3. What is another example of two objects pulling on each other?

____

____

____

MASTER

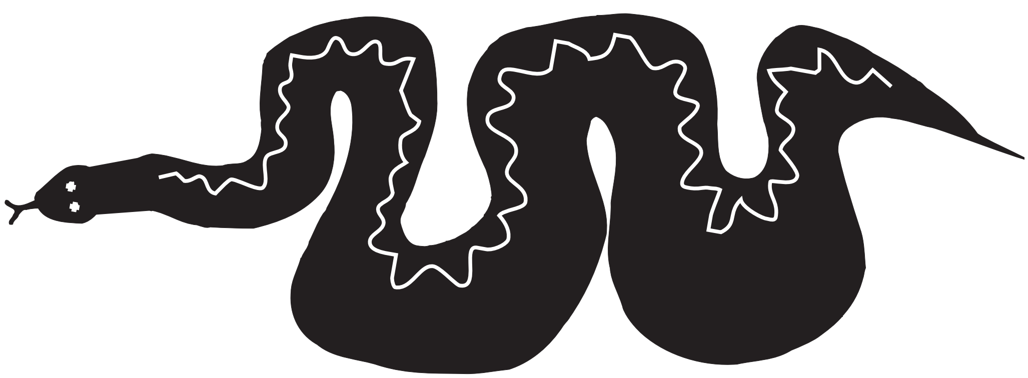
CLUE SEARCH 1 - The Anaconda

Excited about the prospect of riding roller coasters all day, you and your classmates hurry along behind Ms. Roundenround. You soon find yourself standing at one end of a large thoroughfare. Roller coasters loom along both sides. Other types of rides dot the landscape as well. Shuttle train cars dangle overhead, still and silent.

Ms. Roundenround sighs and says, “Can’t stand to see it this way. No long lines of people waiting to be scared to death. No screech of coaster breaks. No whistling of coaster-made wind. Oh well, let’s look at the Anaconda.” You stop in front of a towering steel snake. “She’s a beaut, she is,” Ms. Roundenround says. “Doubled our attendance when we opened her 20 years ago. People came from as far away as France and Japan to ride her. But ever since we renovated her this spring, we can’t get her to run right.”

You stand back a bit and start sketching the Anaconda as Ms. Roundenround continues: “With a first hill 160 feet high, she’s mighty tall for a coaster so old, giving a thrilling first drop. Riders hurtle through the first tunnel at 61 miles per hour. We decided to make the second hill even taller because coaster enthusiasts really love a terrific second drop. So it’s 200 feet high! Count ‘em—200 feet! But the cars won’t go over the second hill. They just make it up part way and slide back and forth, finally stopping in the tunnel between the first and second hills. Go figure!” She concludes, “I wonder if you would conduct a test I read about in this book, *Complete Roller Coaster Design*, and see if you discover anything that will help me get this coaster up and running again.”

MASTER



CLUE SEARCH 2 - The Phantom Dragon

After your success with the Anaconda, you hop proudly out of the simulator and follow Ms. Roundenround to inspect another troublesome roller coaster. You pass silent refreshment stands, wishing they were open for business. A large soft drink and a bucket of popcorn sure would be nice right about now, but you've got work to do.

Shortly, Ms. Roundenround stops in front of another metal skeleton. A sign identifies it as the “Phantom Dragon”. It sprawls across an even larger area than the Anaconda. Ms. Roundenround says, “We built this racing coaster just last year. The cars on the two tracks race each other. We thought people would like these aluminum cars on the one side. It would feel like they were flying. But the cars don't go fast through the whole ride. They barely make it to the finish. Can’t understand why—the cars on the other side are the exact same design and size, but they're made of a mixture of heavier metals. We thought they would be the slowpokes. Now visitors only want to get in the heavy ones to be sure to win, and we can't get people through here quick enough so they can go back to buying food and souveniers.” She sends one of each type of car around by itself to prove her point.

You step back and begin to sketch the Phantom Dragon’s hills and twists and turns. Ms. Roundenround tells you the first hill is 198 feet high and the second hill is 140 feet high. You can see that each of the rest of the hills is lower than the hill before it. The coaster starts at the “mouth,” goes out to the “tail,” then returns to the mouth. Flashes of red light and smoke simulate the Phantom Dragon’s “breathing fire.” Sure enough, the heavier car wins the race and the aluminum car barely putters back to the start.

Ms. Roundenround asks, “I wonder, would you be willing to conduct another test in *Complete Roller Coaster Design*, and see if you can help again?”

MASTER

CLUE SEARCH 3 - The Outlaw

Fresh off another successful test run, you bound along behind Ms. Roundenround until she stops at the next roller coaster. This one, a sign proclaims, is the “Outlaw.” It is a large wooden structure, featuring a Wild West theme. Lifelike robots dressed in cowboy and other pioneer garb line the course, as do facades of buildings labeled, “Saloon,” “Bank,” “General Store,” “Blacksmith,” and so on. Ms. Roundenround explains, “The robots are animated during the ride. They have shootouts and go about the daily business of a Wild West town. Riders really feel like they’ve gone back in time.”

“It sure looks old and rickety,” you all mumble. “That’s just an illusion,” Ms. Roundenround says. “‘Woodies,’ as we call them in the roller coaster business, are modern roller coasters that are just designed to look and feel old.

“For one thing, the design allows them to vibrate a lot to use up some of the energy created by climbing to the top of the first hill. A maintenance worker spends up to two hours every morning walking next to the tracks, hammering down loose nails.”

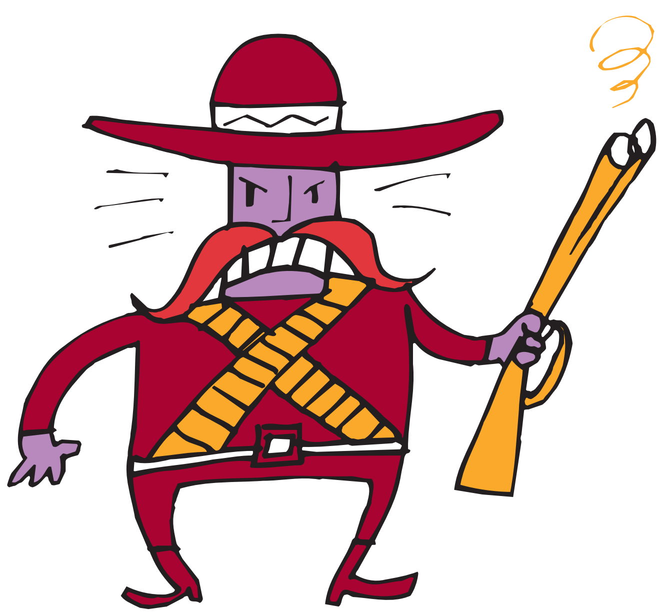
The Outlaw trains look like old-fashioned steam engines, except they do not have glass in their windows. A worker lifts two “cowboys” into the front passenger car of a train. Ms. Roundenround presses a button, sending the train on its way.

She continues, “We wanted this train to be as authentic as possible, and our younger guests love it. Unfortunately, though, at the end of the ride, everyone bumps into the people in front of them, and the the front passengers sometimes fly out of the front window opening - if they’re not lucky enough to catch themselves.”

Sure enough, the train returns, stops, and the “passengers” fly out the front window onto the track. “Can’t have *that* and afford insurance for long!” exclaims Ms. Roundenround.

Ms. Roundenround asks, “I know it’s a lot to ask after all you’ve done, but would you be willing to conduct another test in *Complete Roller Coaster Design*, and see if you can help again?”

MASTER



CLUE SEARCH 4 - The Rattlesnake

Soon you stop in front of another wooden roller coaster, this one is called the Rattlesnake. You ask, “I can understand why the Outlaw was made of wood so it would look old-fashioned, but why another one? Don’t people prefer metal coasters?”

“Many roller coaster fans still love woodies even though they don’t turn you upside-down and can’t be as big as metal coasters. This is because every day the ride on a woodie is different, depending on the weather. Humidity, heat, cold, dryness—these all change the ride a bit so you never quite know what to expect.

“But you should be able to expect to be safe—but old Denby Doobad has done something to the Rattlesnake to ruin it! Remember I told you I caught him in my park last week after closing time. I think there was something in that pail of his that wrecked this coaster. Watch!”

Ms. Roundenround operates the controls, sending an empty train off. After climbing slowly to the top of the first hill, it plummets to the bottom of the hill, faster than anything you’ve seen so far today.

“Look at the computer sensor read-out. It’s going 85 miles per hour! The State Inspector says we can’t have a train that goes that fast, and it sure is hard on the passengers. It also wears out the track and the wheels of the trains faster. Before I caught Doobad, the maximum speed of this ride was 68 miles per hour.”

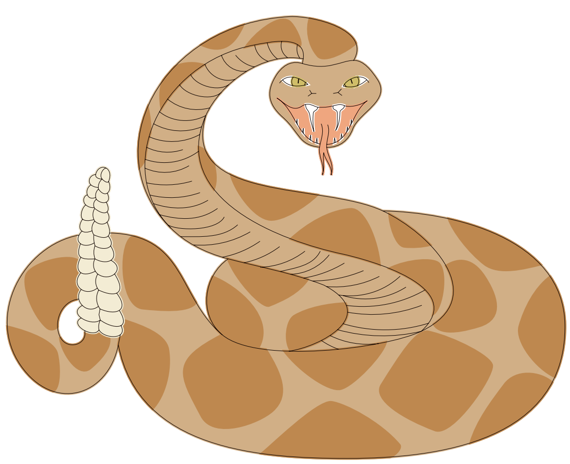
The train returns. You look closely at its wheels. They seem to have melted a bit. “That’s from going too fast. The wheels get too hot and melt,” Ms. Roundenround explains.

You and your classmates ask if you can walk along the track like the maintenance person does, to look for clues. After hesitating a moment, your teacher and Ms. Roundenround agree. “Hold on to the guardrails!” they both say.

After slowly climbing to the top of the first hill, you all spot something glistening on the downhill tracks. You carefully touch the track with one finger. “Oil!” you shout, “vegetable oil!”

“That stinker oiled my track,” shouts Ms. Roundenround, “Why, I’ll tie his new Fire Serpent into knots, I will! When the oil rubs off, the train is still going too fast for the rest of the ride! Please help me with another design test.”

“Where’s that pizza?” you think.



CLUE SEARCH 5 - The Cobra Spitfire

Aaaah! You have finally gotten to eat the pizza. “Not bad,” you say. “Better than the school cafeteria,” agrees a friend.

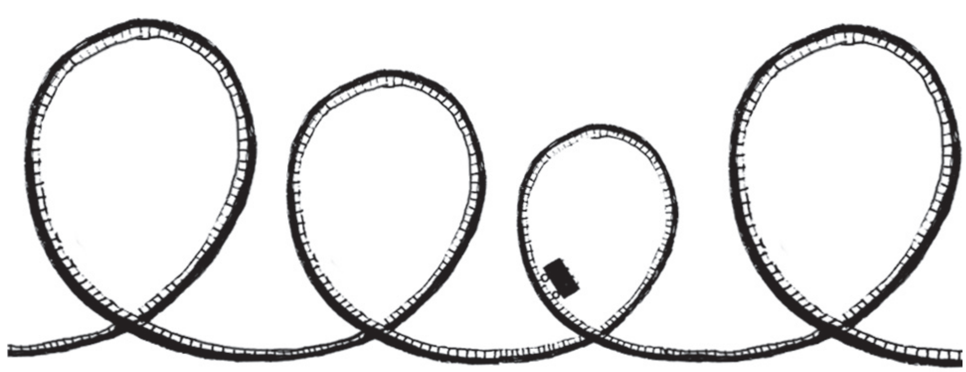
Now you are standing in front of a huge metal coaster with four large loops. “The Cobra Spitfire” reads a sign. Ms. Roundenround explains, “In the old days, people made loops as perfect circles, but the g forces were too strong—over 8 g’s. Sometimes people even broke their necks riding them! We only need to be a bit above 1 g (normal Earth gravity) to keep us in our seats while upside-down. So nowadays we use squashed loops, called **clothoid loops**. Some big mathematician figured it out in the 1800s. A clothoid loop smooths out the forces your body undergoes but still keeps you safe.”

“How?” you ask.

“Well, let me see,” replies Ms. Roundenround, scratching her head. “It was explained to me something like this: In a clothoid loop, the distance from the middle of the ‘circle’ (the radius) decreases as you go up the loop. This keeps the centripetal force higher at a slower speed. And you don’t get more than 3 or 4 g’s battering your body. So as long as you’re going fast enough along the right shape, you won’t fall out of the cars.

“Trouble is, the test dummies start to fall out of the cars in the fourth loop—almost slipping right out of the shoulder restraints. The cars don’t crash, though, because they’re locked on with wheels above, below, and beside the track—as are all our coaster cars in this park. However, the cars just stop about two-thirds of the way up the loop. The automatic brake system locks them in place so they won’t slip backward.”

As Ms. Roundenround sends a test car with dummies around the track, you step back and sketch the four loops’ shapes and sizes. You stretch out your drawing as if the ride doesn’t turn back to the beginning so you can see each loop clearly. This is what your sketch looks like:



Sure enough the dummies start to fall out at the top of the fourth loop. “Do you suppose Doobad has greased this track too?” Ms. Roundenround asks. “Will you please help me with one last design test?”

MASTER

DESIGN TEST 1: The Anaconda

Problem: Explore potential and kinetic energy with a toy, keeping this mathematical formula in mind: Potential Energy + Kinetic Energy = Total Energy

Two Sides of the Same Problem:	Your Hypotheses:
1. Where is potential energy going to be the highest?	1.
2. Where is kinetic energy going to be the highest?	2.

Materials:
- E-Can
- Smooth floor

Experiment:
1. Push the E-Can slowly across a smooth floor.
2. Watch the E-Can travel until it stops by itself.
3. Push the E-Can rapidly across the smooth floor.
4. Watch the E-Can travel until it stops.

Data:
1. What did the E-Can do when pushed slowly?

2. What did the E-Can do when pushed rapidly?

3. How is the behavior of the E-Can different from that of an ordinary can?

Conclusion:

1. Why do you think the E-Can acts differently from an ordinary can?

2. Where was potential energy the highest? Why?

3. Where was kinetic energy the highest? Why?

4. Where is potential energy the highest on a roller coaster?

5. Where is kinetic energy the highest on a roller coaster?

As a group, write any possible clues this activity has given you on your group's CLUE TRACKING SHEET, then complete a SCIENTIFIC DETECTIVE RECORD FORM to give to Ms. Roundenround.

MASTER

DESIGN TEST 2: The Phantom Dragon

Problem: How does mass affect velocity (and therefore momentum)?

Your Hypothesis: ____

Materials:
- 2 balls the same size (volume) and very different masses (e.g., solid rubber and hollow plastic)
- 24" (60 cm) of track
- 3 or more textbooks
- Pillow
- Stopwatch or clock with second hand
- Smooth floor

Experiment:
1. Place the stack of textbooks on the floor.
2. Place the pillow at least 6 feet (2 meters) from the textbooks.
3. Have one group member hold or anchor one end of the track on top of the textbooks (be sure this is at the same exact place each trial).
4. Release one ball at the top of the track and time how many seconds it takes for the ball to hit the pillow. BE SURE TO START TIMING UPON RELEASE AND STOP TIMING WHEN THE BALL HITS THE PILLOW.
5. Repeat steps 3 and 4 with the other ball.

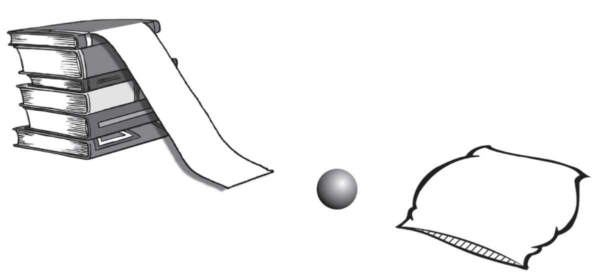
Data: Record what happens with each ball in the chart below.

Ball	Seconds
Less mass	
More mass	

Conclusion: Why did that ball get to the pillow faster (travel at a higher velocity)?

____

As a group, write any possible clues this activity has given you on your group's CLUE TRACKING SHEET, then complete a SCIENTIFIC DETECTIVE RECORD FORM to give to Ms. Roundenround.



MASTER

DESIGN TEST 3: The Outlaw

Problem: What happens to a passenger when a vehicle stops?

Your Hypothesis:___________________________

Materials:
- 1 boot-style roller skate
- 1 doll that will sit (8-12" [20-30 cm] high)
- 1 textbook
- Smooth floor

Experiment:
1. Balance the doll on the front of the roller skate so that the lace or Velcro area forms a seat for the doll.
2. Place the textbook about one yard (1 m) in front of the roller skate.
3. Firmly but under control, push and release the roller skate toward the textbook.
4. Now use the shoelace or string to tie the doll to the roller skate around its waist.
5. Repeat steps 2 and 3.

Data: Record what happens each trip in the chart below:

Trip	What the doll did:
1. Doll sitting freely	
2. Doll attached to the vehicle.	

Conclusion:
1. Why do you think the doll acted as it did the first trip?

____

2. Why do you think the doll acted as it did the second trip?

____

As a group, record any possible clues this activity has given you on your CLUE TRACKING SHEET, then complete a SCIENTIFIC DETECTIVE RECORD FORM and give it to Ms. Roundenround.

MASTER

DESIGN TEST 4: The Rattlesnake

Problem: Which items reduce friction? Which increase it?

Record your hypothesis in the chart below.

Materials:
- 1 spring scale
- 1 large jar lid
- Marbles (all same size; enough to fill jar lid)
- 1 wood block (at least 3 x 5 x 1"; larger is better)
- 1 large, smooth Styrofoam meat tray
- Coarse sandpaper as wide as the block and almost as long as the tray
- Tape
- 1/4 cup cooking oil
- 1 large rubber band

Experiment:
1. Put the rubber band around the length of the block and hook the spring scale onto the rubber band at one end of the block.
2. Pull the wood block with the spring scale and complete the chart below:

Data: Record what happens in the chart:

Setup Description	Increase or decrease friction		Force (NEWTONS [N])
	Hypothesis	Result	
a. Pull the wood block across the empty tray.			
b. Place the marbles in the lid and the lid in the tray. Pull the block across the marbles.			
c. Tape the sandpaper, coarse side up, along the length of the tray. Pull the wood block across the sandpaper.			
d. Remove the sandpaper, and spread the oil in the tray. Pull the wood block through the oil. (Careful - don't get oil on the scale.)			

Conclusion:
1. Which setup(s) required the least force to move the wood block? Why?

____

2. Which setup(s) required the most force to move the wood block? Why?

____

As a group, record any possible clues this activity has given you on your CLUE TRACKING SHEET, then complete a SCIENTIFIC DETECTIVE RECORD FORM and give it to Ms. Roundenround.

MASTER

DESIGN TEST 5: The Cobra Spitfire

Problem: How does centripetal force act on an object?

Your Hypothesis:____

Materials:
- Clear plastic container with tight-fitting lid (for example, ketchup bottle or peanut butter jar)
- 1 yard (1m) strong string or twine
- Water (colored)

Experiment:
1. Pour two inches (5 cm) of water into the jar.
2. Tie the string around the neck of the bottle.
3. Screw the lid back on the container tightly.
4. Gently swing the jar a little to make sure the string is securely attached.
5. Now tie a loop in the other end of the string to create a hand-hold.
6. Turn the container upside-down on your desk to test for leaking and to observe the water.
7. Now firmly grasp the string loop.
8. ***Caution:*** Make sure you have enough room to do this safely: Swing the container by the string overhead.
9. Slow down the swinging action gradually.

Data:
1. What did the water do when you turned the container upside-down on your desk?

____

2. What did the water do when you swung the container overhead?

____

3. What did the water do as you slowed down the swinging action gradually?

____

Conclusion:
1. Why did the water act as it did when you turned the container upside-down on your desk?

____

2. Why did the water act as it did when you swung the container overhead?

____

3. Why did the water act as it did when you slowed the container down gradually?

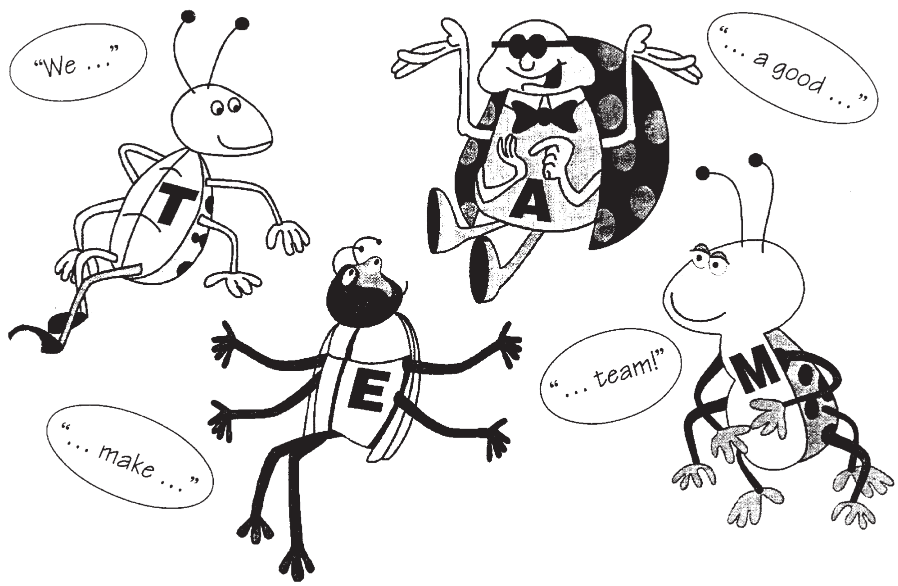
____

As a group, record any possible clues this activity has given you on your CLUE TRACKING SHEET, then complete a SCIENTIFIC DETECTIVE RECORD FORM and give it to Ms. Roundenround.

MASTER

WHAT ARE T.E.A.M. ACTIVITIES?

For the next few days you will be doing TEAM ACTIVITIES with your group members. T.E.A.M. Stands for **T**ogether **E**veryone **A**ccomplishes **M**ore. Each T.E.A.M. ACTIVITY will not only give you important information about science that you will need to solve the mystery; it will also give you the opportunity to work together with other group members to solve a problem. As you do each activity, you will discover two things: that everyone in the group has something top offer, and that many brains working together help tremendously when you are trying to solve a problem.



HOW DO YOU DO T.E.A.M. ACTIVITIES?

1. Your team's goal is to solve the problem presented to the group.
2. Each group member will receive some special information that no one else in your team has.
3. Each group member will share all the information (clues) to solve the problem.
4. Each group member will share information only one way—*orally.*
5. No one may take or look at another group member's clues.
6. Each group member will participate! (Of course, clues may be repeated orally, if needed.)
7. Once all members have individually shared their clues, each group member should continue to contribute in solving the activity.
8. Each group member will take a turn to talk and give ideas or opinions.
9. And what is the most important skill all group members must practice? *Listening!* It is very important that everyone listen carefully while other members of the group are talking since we can all learn from one another.

Good luck on your T.E.A.M ACTIVITIES!
You will enjoy uncovering the information each day and then using what you learn to solve the Roller Coaster World mystery.

MASTER

T.E.A.M. ACTIVITY 1

Cut this sheet into strips along dotted lines. Give each team member a different strip.

1. Child waiting to go out to recess
   Boulder rolling down mountain
   Bucket of water pouring on your brother's head

2. Moving spring toy
   Potential energy is an object's stored energy.
   Child at top of slide

3. Cat jumping out of tree
   Boy hurtling down snowy hill on sled
   Rubber band pulled tight

4. Wound up spring toy sitting on shelf
   Cat at top of tree
   Child playing on playground

5. Boy on sled at top of snowy hill
   Kinetic energy is the energy of motion
   Shooting a rubber band at your little sister

6. Child sliding down slide
   Bucket of water balanced at the top of a door
   Boulder at top of mountain

MASTER

T.E.A.M. ACTIVITY 1 RECORD

Potential Energy	Kinetic Energy

MASTER

T.E.A.M. ACTIVITY 2

Cut this sheet into strips along dotted lines. Give each team member a different strip.

---

1. The cyclist is increasing his velocity from 10 to 12 miles per hour along a westbound road.

   Speed is the rate at which an object moves.

   The snake slithers along the path at 3 kilometers per hour.

---

2. **Acceleration** is the rate of change in velocity.

   The truck is traveling straight eastward at 60 miles per hour.

   Momentum equals mass multiplied by velocity.

---

3. **Velocity** is the speed of a moving object in a particular direction.

   The bat flies at 15 miles per hour.

   Swimming in a straight line, the dolphin moves faster to catch the fish.

---

4. You can find the **speed** of an object if you take the distance something has traveled and divide it by the time it took to travel that distance (speed = distance ÷ time).

   The airplane is traveling at 325 miles per hour.

   The peregrine falcon dives faster and faster, straight at a dove, ending its dive at a velocity of 180 miles per hour.

---

5. Newton's Second Law of Motion is also called the **Law of Constant Acceleration** because a moving object steadily increases its velocity as it continues to move (unless another force interferes).

   The car is going 35 miles per hour.

   The ice skater is slowing down to make a figure eight.

---

6. The boat travels 1,000 meters in 300 seconds.

   Deceleration is a non-scientific word for acceleration that is decreasing.

   The cheetah is running toward the gazelle at 65 miles per hour.

T.E.A.M. ACTIVITY 2 RECORD

Speed	Velocity	Acceleration

MASTER

T.E.A.M. ACTIVITY 3

Cut this sheet into the individual boxes. Give each team member a different box.

1. Sunshine
   Baking soda reacting with vinegar
   Windmill turning a turbine
   Nuclear power plant
   Radiant means *light.*

2. Drumbeat
   Atom splitting
   Lightbulb glowing
   Food digesting
   Thermal means *heat.*

3. Solar panels
   Battery
   Violin music
   Chemical energy comes from *chemical reactions.*
   Hot sand on a beach

4. Bonfire
   Computer running
   Electrical energy involves *the flow of electrons* to provide power.
   Sandpaper rubbing against wood
   Greenhouse

5. Bread rising
   Nuclear energy involves the *splitting of atoms* to produce energy.
   Heating element in a toaster
   Steam
   Car skidding

6. Bell ringing
   Lightning
   Gasoline engine
   Bubbles in a soft drink
   Sound energy *moves air molecules* and vibrates our eardrums.

MASTER

T.E.A.M. ACTIVITY 3 RECORD

Radiant Energy	Thermal Energy

Chemical Energy	Electrical Energy

Sound Energy	Nuclear Energy

MASTER

T.E.A.M. ACTIVITY 4

Cut this sheet into strips along dotted lines. Give each team member a different strip.

The wheels on your in-line skates

A rubber bath mat

Riding a bike wearing wide-leg jeans

The design of a race car body

Drag is a force caused by air rubbing on an object.

A wet tile floor

Wax on snow skis

Rubber soles on shoes

Riding a bike wearing bike shorts

Scouring pad for washing pots and pans

The oil in a car engine

A windshield on a car

Squeezing the hand brakes on your bike to stop suddenly

A car traveling with its trunk open

The design of a delivery truck body

Friction is a force created by the rubbing of two objects against each other.

A cone-shaped nose of an airplane

A hockey player wearing ice skates gliding across an ice rink

MASTER

T.E.A.M. ACTIVITY 4 RECORD

Higher Friction	Higher Drag
Lower Friction	**Lower Drag**

MASTER

EUREKA! MATH 1

MASTER

Potential and Kinetic Energy

Energy is the ability to do work. How much work something can do because of its motion is called **kinetic energy**. **Potential energy** is an object's stored energy. Use this mathematical formula to solve the math problems on this page:

Potential Energy + Kinetic Energy = Total Energy

Unit of measurement: Work and energy are measured in joules (J). A **joule** equals one newton (N) multiplied by one meter (m). That means a joule equals the force (N) times the distance (m) the object is covering. 1J = 1N × 1m. Scientists describe a joule as a "newton-meter."

A. Complete the chart (all answers are in joules):

	Potential Energy	Kinetic Energy	Total Energy
1	40	60	100
2	112	69	
3	267	1,359	
4	37	284	
5	917		1,592
6	71		535
7.		4,561	7,789
8.		99	151

In real life, some kinetic energy is turned into thermal (heat) energy due to friction. So:

Kinetic Energy = Movement + Thermal Energy (friction)

No energy is lost, though. The **Law of Conservation of Energy** states: Energy cannot be created or destroyed. It can only change forms.

B. Use both energy formulas to complete the chart: (all answers are in joules)

	Potential Energy	Movement	Friction	Total Energy
1.	46	89	20	155
2.	124	31		169
3.	2,009		59	2,565
4.		1,276	316	1,592
5.	821	787	212	
6.	55	429		550

Bonus: If object 4 in Chart B were a roller coaster train, where would the train be—at the top or the bottom of a hill?

Speed

Speed is the rate at which an object moves. It is the distance the object has traveled divided by the time it took to travel:

Speed = Distance ÷ Time

Sample units of measurement: Speed is measured in many different units. Some familiar ones include: miles per hour (mph), kilometers per hour (kph), and meters per second (m/s). As an example, an object traveling 50 miles in 2 hours would be traveling at 50/2 = 25 mph.

Use the information in the problems below to find each object's speed.

1. A car travels 152 miles in 4 hours.
2. A dolphin travels 200 miles in 8 hours.
3. A house fly travels 16 kilometers in 2 hours.
4. A train travels 612 kilometers in 6 hours.
5. A sailfish travels 630 kilometers in 6 hours.
6. A truck travels 729 miles in 9 hours.
7. A turtle travels 0.6 miles in 6 hours.
8. A cheetah runs 30 miles in 0.5 hours.
9. Lava flows at a rate of 15 meters every 5 seconds.
10. A rocket travels at 6,075 miles for 15 minutes to escape earth's gravity.

Bonus: One mile is about 1.6 kilometers. Which is faster—the dolphin or the sailfish?

EUREKA! MATH 3

Momentum

Momentum has to do with the amount of energy a moving object has. It is expressed as the mass of the object multiplied by its velocity:

Momentum = Mass × Velocity or M = m × v

Sample unit of measurement: The preffered unit for linear momentum is kilogram-meters per second, or kg−m/s.

Complete the chart:

	Mass (kg)	Velocity (m/s)	Momentum (kg-m/s)
1.	2	21	42
2.	64	10	
3.	1,000	500	
4.	2,246	3	
5.	72	54	
6.	127	93	
7.	907	4	
8.	6	231	
9.	88	49	
10.	3,700	19	
11.		75	225
12.	11		242
13.	0.5	0.25	
14.	181		10,860
15.		99	396

Bonus: Which object above is most likely to be a box turtle? Why do you think this?

MASTER

Work

Work is using a force to make an object move a certain distance. We measure **force** in newtons (for example, with a spring scale)

Work = Force × Distance

Sample units of measurement: Work is commonly measured in foot-pounds or newton-meters (joules). In the chart below, “N” is short for newtons, “m” is short for meters, and “J” is short for joules.

Complete the chart. Use the back of this sheet or additional paper for your calculations.

	Force (N)	Distance (m)	Work (J)
1.	5	4	
2.	8	3	
3.	45	15	
4.	62	98	
5.	532	2	
6.	2	112	
7.	84	1,000	
8.	167	72	
9.	0.5	4	
10.	35	15	
11.	46		92
12.	4		60
13.		12	84
14.		65	195
15.	22		22,000

Bonus:
If examples 7 and 15 above are the same object, in which case was more friction involved?__________

How can you tell?____

____

MASTER

ANSWER KEY EUREKA! MATH 1

Potential and Kinetic Energy

Energy is the ability to do work. How much work something can do because of its motion is called **kinetic energy**. **Potential energy** is an object's stored energy. Use this mathematical formula to solve the math problems on this page:

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Unit of measurement: Work and energy are measured in joules (J). A **joule** equals one newton (N) multiplied by one meter (m). That means a joule equals the force (N) times the distance (m) the object is covering. 1J = 1N × 1m. Scientists describe a joule as a "newton-meter."

A. Complete the chart (all answers are in joules):

	Potential Energy	Kinetic Energy	Total Energy
1	40	60	100
2	112	69	**181**
3	267	1,359	**1,626**
4	37	284	**321**
5	917	**675**	1,592
6	71	**464**	535
7.	**3,228**	4,561	7,789
8.	**52**	99	151

In real life, some kinetic energy is turned into thermal (heat) energy due to friction. So:

Kinetic Energy = Movement + Thermal Energy (friction)

No energy is lost, though. The **Law of Conservation of Energy** states: Energy cannot be created or destroyed. It can only change forms.

B. Use both energy formulas to complete the chart: (all answers are in joules)

	Potential Energy	Movement	Friction	Total Energy
1.	46	89	20	155
2.	124	31	**14**	169
3.	2,009	**497**	59	2,565
4.	**0**	1,276	316	1,592
5.	821	787	212	**1,820**
6.	55	429	**66**	550

Bonus: If object 4 in Chart B were a roller coaster train, where would the train be—at the top or the bottom of a hill? ***Bottom***

MASTER

ANSWER KEY EUREKA! MATH 2

Speed

Speed is the rate at which an object moves. It is the distance the object has traveled divided by the time it took to travel:

Speed = Distance ÷ Time

Sample units of measurement: Speed is measured in many different units. Some familiar ones include: miles per hour (mph), kilometers per hour (kph), and meters per second (m/s). As an example, an object traveling 50 miles in 2 hours would be traveling at 50/2 = 25 mph.

Use the information in the problems below to find each object's speed.

1. A car travels 152 miles in 4 hours.

   38 mph

2. A dolphin travels 200 miles in 8 hours.

   25 mph

3. A house fly travels 16 kilometers in 2 hours.

   8 kph

4. A train travels 612 kilometers in 6 hours.

   102 kph

5. A sailfish travels 630 kilometers in 6 hours.

   105 kph

6. A truck travels 729 miles in 9 hours.

   81 mph

7. A turtle travels 0.6 miles in 6 hours.

   0.1 mph

8. A cheetah runs 30 miles in 0.5 hours.

   60 mph

9. Lava flows at a rate of 15 meters every 5 seconds.

   3 meters per sec.
   10,800 m/hr

10. A rocket travels at 6,075 miles for 15 minutes to escape earth's gravity.

    24,300 mph
    405 miles per minute

Bonus: One mile is about 1.6 kilometers. Which is faster—the dolphin or the sailfish?

The sailfish is faster.
(1 mile is about 1.6 km. The dolphn travels 25×1.6 = 40 kph)

MASTER

ANSWER KEY EUREKA! MATH 3

Momentum

Momentum has to do with the amount of energy a moving object has. It is expressed as the mass of the object multiplied by its velocity:

Momentum = Mass × Velocity or M = m × v

Sample unit of measurement: The preffered unit for linear momentum is kilogram-meters per second, or kg−m/s.

Complete the chart:

	Mass (kg)	Velocity (m/s)	Momentum (kg-m/s)
1.	2	21	42
2.	64	10	**650**
3.	1,000	500	**500,000**
4.	2,246	3	**6,738**
5.	72	54	**3,888**
6.	127	93	**11,811**
7.	907	4	**3,628**
8.	6	231	**1,386**
9.	88	49	**4,312**
10.	3,700	19	**70.300**
11.	**3**	75	225
12.	11	**22**	242
13.	0.5	0.25	**0.125**
14.	181	**60**	10,860
15.	**4**	99	396

Bonus: Which object above is most likely to be a box turtle? Why do you think this?

Object 13 is most likely a box turtle because its mass and velocity are appropriate.

MASTER

ANSWER KEY EUREKA! MATH 4

Work

Work is using a force to make an object move a certain distance. We measure **force** in newtons (for example, with a spring scale)

Work = Force × Distance

Sample units of measurement: Work is commonly measured in foot-pounds or newton-meters (joules). In the chart below, "N" is short for newtons, "m" is short for meters, and "J" is short for joules.

Complete the chart. Use the back of this sheet or additional paper for your calculations.

	Force (N)	Distance (m)	Work (J)
1.	5	4	**20**
2.	8	3	**24**
3.	45	15	**675**
4.	62	98	**6,076**
5.	532	2	**1,064**
6.	2	112	**224**
7.	84	1,000	**84,000**
8.	167	72	**12,024**
9.	0.5	4	**2**
10.	35	15	**525**
11.	46	**2**	92
12.	4	**15**	60
13.	**7**	12	84
14.	**3**	65	195
15.	22	**1,000**	22,000

Bonus:
If examples 7 and 15 above are the same object, in which case was more friction involved? ***Example 7 involved more friction***

How can you tell?

More force was needed to move it and so more work had to be done.

MASTER

TEACHER FEEDBACK FORM

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ROLLER COASTER

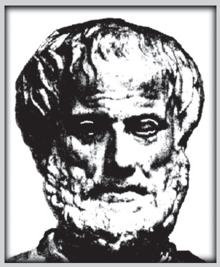
A simulation solving a scientific mystery while learning about the science of motion

Scientific discovery is the result of endless hours of careful observation, deep thought, and tireless persistence—with a large helping of genius. In ROLLER COASTER you will learn some exciting professional and personal details of the men who first explained the science of motion. Through accompanying EUREKA! ACTIVITIES, you will see for yourself how their perseverance provided humankind with truths we take for granted today.

Student Guide

Phase 1

EUREKA! MOMENT 1
ARISTOTLE (384–322 B.C.E.) and GALILEO GALILEI (1564–1642)



Aristotle is best known as a Greek philosopher who founded a school and encouraged his students to think with their senses—what they heard, saw and felt. He used this philosophy to explore scientific topics. For example, he tried to explain why a light object fell through the air more slowly than a heavy object. He believed that all objects are made up of four elements: earth, air, fire and water. Objects made mostly of earth or water try to return to their natural resting place—the earth. So when allowed to do so, they drop back to Earth. Objects made mostly of air try to return to their natural resting place—the sky. Therefore, for example, a rock wants very strongly to return to its resting place, the Earth, and a feather, which Aristotle said was made mostly of air, falls more slowly to earth because it really prefers to stay in the air. This explained, he claimed, why a rock falls faster to Earth than a feather.

Aristotle also claimed that all objects fall at a constant speed. That is, the speed at the end of the fall is, he believed, still the same as the speed at the beginning of the fall.

Aristotle was so well respected that few people questioned his conclusions. It would be almost 2000 years before anyone proved that Aristotle's conclusions were wrong. Even then many refused to believe the new information.

Galileo Galilei, better known simply as "Galileo," was an Italian mathematician and scientist who pioneered the way to true science by testing ideas through controlled experiments. A controlled experiment has only one variable, or changing part. In this way, an observer can see exactly what the effect of changing the variable is. Galileo recognized that Aristotle's rock and feather free fall experiment could not be interpreted accurately. It had too many variables because the two objects compared were so different in shape, mass and size.

Galileo tested the free falls of objects that had similar shapes and sizes but different masses. His controlled experiments (with mass as the only variable) led him to a conclusion very different from Aristotle's as to why a rock falls faster than a feather.

Galileo also proved that objects do not fall at a constant speed. Instead, they undergo **constant acceleration**. In other words, they speed up steadily as they fall toward earth.

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EUREKA! MOMENT 2
GALILEO and ISAAC NEWTON (1642–1727)

Galileo became interested in the behavior of free-falling objects as he studied the behavior of the stars and planets. He needed to explain why certain heavenly bodies rotated around others. As he explored the idea of gravity and used a new invention known as the telescope, he concluded that the planets, including our Earth, revolved around the sun. This greatly angered Italian authorities who believed that the Earth was the center of the universe. Galileo was tried, convicted and held under "house arrest" for refusing to admit he was wrong. Eventually, a broken man, Galileo denied his discoveries to avoid torture. Even so, he spent the last 10 years of his life continuing his studies of motion. Fortunately, he was able to smuggle his notes out of Italy. They were published in Holland and brought him international fame—much to the embarrassment of the authorities in Italy.

One of Galileo's most interesting theories was that an object in motion will keep moving in a straight line unless a force acts on it. This **law of inertia** applies to a ball rolling on Earth as well as a planet moving in space.

Isaac Newton was born in England the same year Galileo died in Italy, 1642. His scientific investigations picked up where Galileo left off. As a young man, Newton excitedly read Galileo's published work concerning astronomy, motion and the nature of matter. He believed Galileo was correct in using controlled experiments rather than the senses (as Aristotle had) to determine scientific truths.

Newton took Galileo's explanation of inertia further, applying it to the behavior of all matter. He asserted, "Every body continues in its state of rest, or of uniform motion in a (straight) line, unless it is compelled to change that state by forces impressed upon it" (1). Today, we call this Newton's **First Law of Motion**. We can state it more simply as, "An object at rest will stay at rest, and an object in motion will stay in motion, unless acted upon by an outside force."

End note:

1. Newton, Isaac. [1687] *Mathematical Principles of Natural Philosophy*. Translated by Andrew Motte and revised by Florian Cajori (translation copyright 1934, The Regents of The University of California). Reprint, Chicago: The University of Chicago. 1952.

Galileo Galilei
(1564–1642)

EUREKA! MOMENT 3
Isaac Newton and CHRISTIAAN HUYGENS (1629–1695)
NEWTON'S SECOND LAW OF MOTION

As Newton studied the solar system, he wondered, Why don't these planets simply go off into space along the straight path, as the law of inertia seemed to say they would? Christiaan Huygens, a top Dutch scientist who lived at the same time as Newton, called this tendency to move outward into space along the same straight line centrifugal force. (We know now that this is not really a force but a description of a behavior.)

What force held the planets in their orbits around the sun, then? Newton determined that the sun pulled the planets inward with what he called *centripetal force*. Centripetal force perfectly balances the planets' natural tendency to continue traveling straight, thus keeping them in their orbits around the sun.

From this comes the first part of Newton's **Second Law of Motion**: If a force acts on an object, the object moves faster, or *accelerates*, in the direction of the force.

The second part of Newton's Second Law of Motion is: the more force used to push an object, the more the object will move. But the more massive an object is, the more push (force) it takes to move it. Stated another way, we can say, "How much a force changes the motion of an object depends upon the amount of the force and the mass of the object."

EUREKA! MOMENT 4
NEWTON'S THIRD LAW OF MOTION

All his adult life, Newton worked tirelessly to discover and prove more scientific principles. As a young student at Trinity College, Cambridge University, he was so intrigued by his observations of the night sky that he slept little and became, in his own words, "much disordered" (1). It was here that he described his laws of motion in a meticulously detailed notebook. Later in life as a professor at the same college, others reported that he seldom combed his long, silver hair nor hitched up his stockings. He was sometimes seen in his garden drawing figures in the gravel walks, which others stepped around for fear of destroying some new discovery. A distant relative, Humphrey Newton, reported, "When he has some Times taken a turn or two he has made a sudden stand, turn'd himself about, run up the Stairs like another Archimedes [a Greek, considered to be the greatest mathematical genius of ancient times], and with a eureka fallen to write on his Desk standing, without giving himself the Leisure to draw a chair to sit down on" (2). Newton was so lost in his own world of scientific thought that often the dates on his papers were incorrect. He was truly an "absentminded professor."

His ability to focus helped Newton persist until he completed his description of motion. Specifically, once Newton had reasoned out his first two laws of motion and proven them with mathematical calculations, he still had to answer the question, Why does the force of the sun's pull perfectly balance the force of the planet's inertia? Newton's **Third Law of Motion** resulted: For every action there is an equal and opposite reaction. So the action of the pull of the sun on a planet causes an equal and opposite reaction in the inertia of the planet's motion.

Thus, Newton's three Laws of Motion work together to explain the behavior of matter. Sir Isaac Newton's body of work laid the foundation for an entirely new branch of physics: *dynamics*.

End notes:

1. Christianson, Gale E. 1996. *Isaac Newton and the Scientific Revolution.* New York: Oxford University Press, p. 27.
2. Ibid, p. 79.

EUREKA! MOMENT 5
Isaac NEWTON and the LAW OF UNIVERSAL GRAVITATION

Another principle that Newton reasoned must be true was that the pull of gravity of the Earth must decrease as the distance away from it increases. In addition to his Third Law, this would help explain why the moon did not crash into the Earth. Newton became totally consumed in finding a mathematical formula to explain the attraction between the center of the Earth (its axis) with the center of any other mass (such as the moon). With a rough formula, he showed how the pull of the Earth extended a limitless distance from the Earth, but the power of the pull decreased with the square of the distance between their centers (axes). (In math terms the square of a number is the number multiplied by itself. So, for example, the square of three is nine: $3^2 = 3 \times 3 = 9$.)

Newton came up with a rough formula to describe the gravitational pull of the Earth on the moon and how the gravitational pull is affected by distance. He also asserted that all objects large and small pull on each other—not just the planets, sun and moon. A small object at a close distance, such as an apple, pulls on the Earth, but is overpowered by the Earth's pull. However, larger objects at greater distances, such as the moon, are not. This realization—that all objects pull on each other at least to some degree—has become known as Newton's **Law of Universal Gravitation.**

Newton was not immediately successful in trying to get his calculations to work out perfectly. But he eventually fine-tuned his formula through endless mathematical calculations. Scientists still use Sir Isaac Newton's formula describing the Law of Universal Gravitation today.

Sir Isaac Newton (1642–1727)

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Student Guide

Phase 2

The following newspaper articles are written from information gathered across the country. Read them carefully. Take note of their common theme—roller coasters. Then consider the following question: How do Newton's Laws of Motion and related ideas affect roller coaster rides? As you read the three articles, examine the roller coaster diagrams, then read the letter from Ms. Roundenround on page 4. You will now become a "science detective" and work with an investigative team to solve the mystery of Roller Coaster World.

A COASTER IS BORN

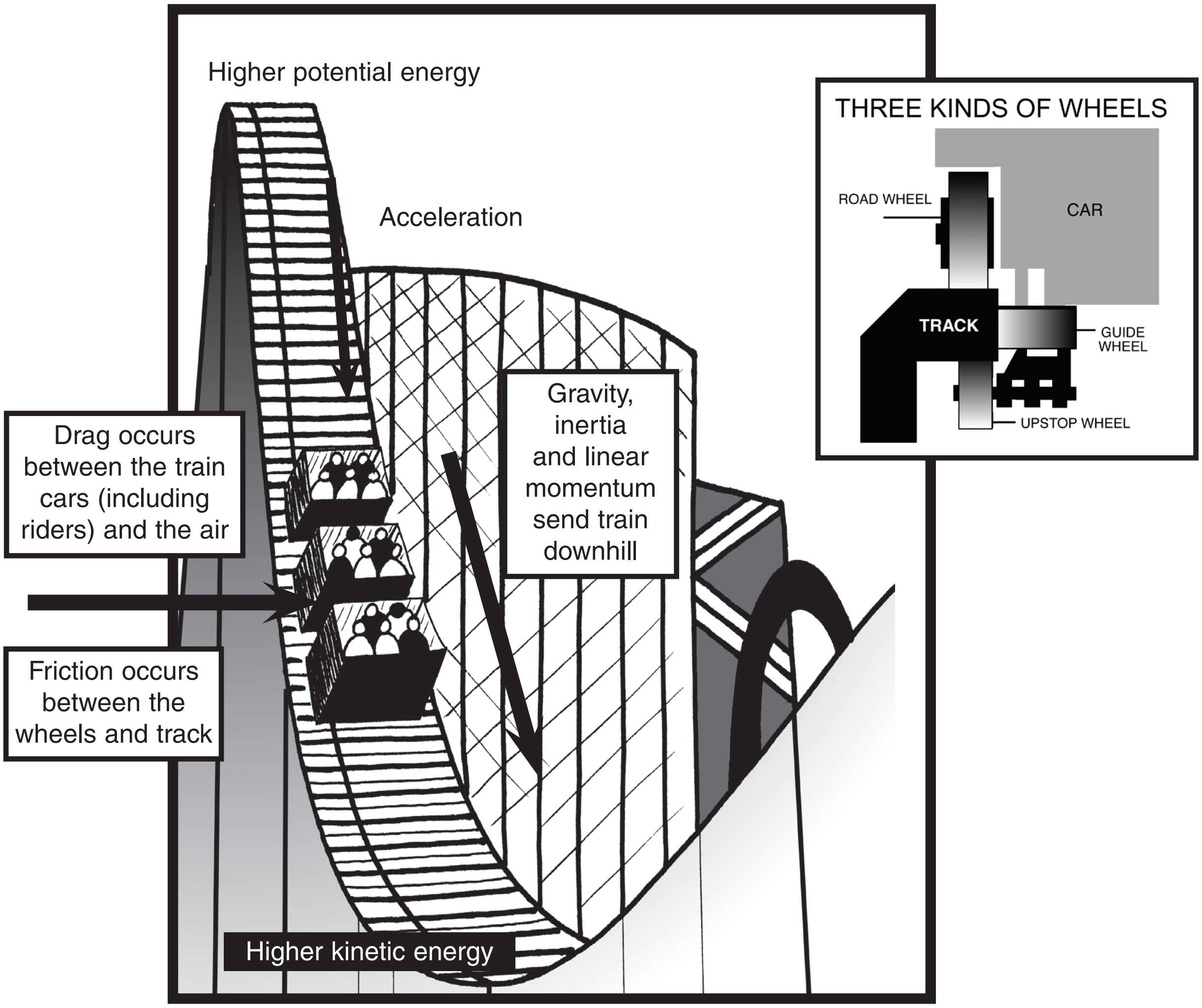
Failing Theme Park Seeks New Business

Cleveland, OH (April 13)—The small town of Weeksville, just ten miles south of greater Cleveland, boasts one of the world's largest amusement parks, Roller Coaster World. Owner Igoa Roundenround claims that with the addition of her latest roller coaster, the Cobra Spitfire, Roller Coaster World holds the world record for the most roller coasters in a single park: 14.

The Cobra Spitfire features a first hill of 202 feet, a top speed of 71 miles per hour and looping elements—all while riders swing in ski-lift type cars. Locals have enjoyed watching as the prefabricated pieces were brought in and assembled according to computer design, like a giant puzzle. The Cobra Spitfire promises to attract thousands on opening day next week.

Unfortunately, all has not been a smooth ride in the last few years. Numerous accidents have all but shut down the park. Ms. Roundenround reports, however, that "All rides have been renovated over the winter, and safety is our top priority. Our engineers have x-rayed each section of every roller coaster and performed stress tests to ensure rider safety."

Nevertheless, the more reliable Creaky Acres Amusement Park here in Cleveland will continue to provide stiff competition for Roller Coaster World.



HISTORY OF ROLLER COASTERS

From Russian Mountains to Steel Serpents

Coney Island, NY—As home of America's first true roller coaster, Coney Island brings to mind the fun and adventure of a long history of "gravity rides."

Roller coasters originated in Russia in the 1400s and 1500s. These "Russian Mountains" were made of snow and ice packed on wooden frames. Brave riders rode down the steep hills on sleds.

In the 1800s, the French began building roller coasters that ran on rollers. Although guard rails were added to later designs, cars still jumped the tracks all too often.

Then in the late 1800s, coasters began to appear in the United States. The first one, called a "switchback railway" used an old mine train track as a pleasure railroad. Steam engines pulled the train to the top of Mount Pisgah in Pennsylvania and then the cars glided down a gentle slope.

In 1884, LaMarcus A. Thompson designed and built the "Gravity Pleasure Switchback Railway" at Coney Island to provide wholesome entertainment for young people. It went six miles per hour and was an instant success. Other Coney Island businessmen rushed to compete, building faster and more exciting coasters.

Today, the competition for the millions of visitors to amusement parks is still fierce, producing one exciting coaster after another.

THRILLS AND CHILLS

Roller Coasters, Danger and Physics

Atlanta, GA—Millions throng to amusement parks each year for a chance to be scared half to death on the contraption known as the roller coaster. What makes these mechanical monstrosities so thrilling? How do parks afford the insurance?

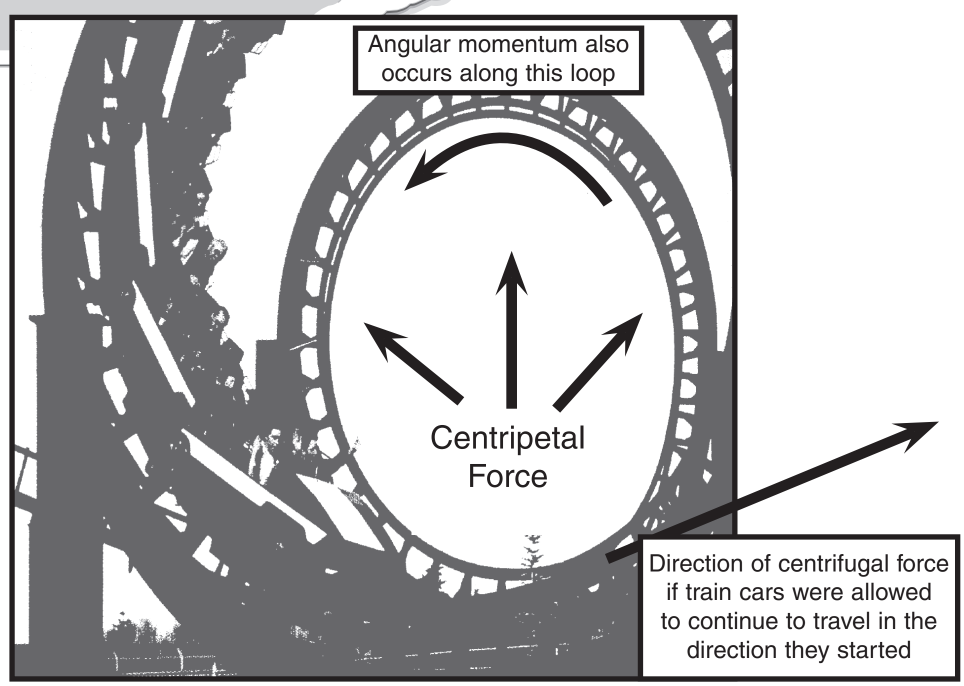
Roller coasters are actually fairly simple machines. An engine-driven chain pulls the train cars to the top of the first—and tallest—hill. Then the cars move by gravity and momentum. The initial momentum carries the train through the lesser hills and tight curves to come.

Science, especially physics, also keeps coasters safe: Turns are banked to take advantage of centripetal force—the same force that allows you to swing a bucket of water overhead without spilling it—as long as you have enough momentum.

Wheels above, below and beside the tracks make sure the cars do not derail. However, inspections reveal rusted track where wheels have left the tracks by a fraction of an inch as the trains crest the hills. (Elsewhere friction from the wheels polishes the tracks, preventing rust.) This “air time” gives the thrilling feeling of weightlessness, or “zero g” (no gravity), to riders. Modern wheels are coated with a special polyurethane which prevents their melting from friction at high speeds. Computers use sensors to monitor forces and apply brakes along the tracks as necessary to slow down cars.

For the most part, the danger is illusion. Chill-producing tricks include (1) towing cars slowly to the top of the first hill, building anticipation and fear among riders; (2) making the first drop seem steeper than it is; (3) using tighter curves, tunnels and tight spaces to hide the fact that momentum decreases after the first drop; (4) alternating strong g forces (as on curves and at the bottom of hills) with zero-g (on the tops of hills); and (5) allowing the wind to whistle past riders instead of enclosing the cars, enhancing the illusion of speed.

This diagram and the diagrams on page 2 show many of the forces acting during a roller coaster ride. Use your GLOSSARY and Student Guide: Phase 1 to help you understand the science of roller coasters.



Now that you have read the newspaper articles and examined the roller coasters, please read this letter from Ms. Roundenround. Then ask yourself, “How should we answer it?”

Dear Students,

I am writing to ask you to help me keep my amusement park, Roller Coaster World, open. I am convinced that my archrival, Denby Doobad, is determined to put me out of business. His Creaky Acres amusement park is just fifteen miles down the road from mine. I believe he is sabotaging my rides. For example, I caught Doobad in my park after closing time one night last week fiddling with The Rattlesnake, one of our most popular attractions. It is a roller coaster with a 191-foot-high peak. Riders plunge at 68 miles per hour after a slow tow to the top. Of course I called the police, but that rascal ran off, carrying a pail of something, before they arrived. When I tested the ride the next morning, the cars plummeted down the first hill way too fast. We could not allow anyone to ride it. I called a repairperson, but he could find nothing wrong with the machinery.

What's more, during some test runs, crash dummies almost fell out of the cars on a loop on my new Cobra Spitfire, and the cars stopped before finishing the ride. The repairperson found nothing wrong with the machinery that time either. It must be that scoundrel, Doobad! I can't use my five most popular roller coasters until they pass State inspection again. It's hurting business more and more. Worse still, Doobad's Dump (as I call it) is doing great, setting attendance records because of its new roller coaster, the Fire Serpent, which just may be the fastest ride in the country.

I have heard what terrific and careful scientists you are, so I am begging you to help me get Roller Coaster World running smoothly again. The police say I don't have a case against Doobad. The State Inspector says I need to look more closely at coaster design. She will shut down my entire operation if I don't solve this mystery quickly – before someone gets hurt. If I can't figure out the trouble, I will have to close Roller Coaster World for good. This is terrible to think about considering all I've spent renovating my rides! Without the State Inspector's seal of approval, I won't even be able to sell the remaining equipment to pay off my debts. I'll have to go work on my brother's brussels sprouts farm. Could anything be worse?

It's only June, so if I can get the problems fixed quickly, I might still have a profitable season. Please let me know as soon as possible if you will be able to help me.

Sincerely,
Ms. Igoa Roundenround
Owner, Roller Coaster World Amusement Park