Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Understanding and Describing Motion

Overview

The apparent motion of a body depends on its speed, its position, and the motion of the observer. In this Exploration, students will observe the motion of a reference object from the observer’s point of view for different cases.

Student Learning Objectives

- Observe the motion of an object from different frames of reference.
- Analyze the effect of the motion of the observer and reference object on the observed motion.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

The Explore tab displays a top view and an observer’s view. In the Top View section, two walkways are displayed. A reference object is placed on walkway 1 and the observer is standing on walkway 2. The Observer’s View section shows the motion of the reference object from the point of view of the observer. The students can select whether walkways is stationary or in motion. If the walkway is in motion the students can select the direction of motion. Students can place the reference object on walkway 1 or walkway 2 and choose if it is stationary or in motion. Students can select the position of the observer.

Once students click on the Start button, the motion of the reference object and the observer, depending on the selected options, is displayed in the Top View section. The Observer's View section displays the motion of the reference object with respect to the motion of the observer.

Students may use the Reset button to reset the Exploration and observe the motion of the reference object from the observer’s view, for a different set of selections.

The Tracker tab displays a summary of the values for all the runs. Students can observe and compare the motion of the reference object from the observer’s view, for different selected values.
Answers to Questions in the Student Worksheet

1. Describe a case from the Exploration where, even though the reference object is in motion it appears to be stationary to the observer.

   **Answer:** When both the walkways are in motion in the same direction. The reference object and observer are placed on different walkways and the reference object is stationary.

2. Describe a case from the Exploration where, even though the reference object is stationary it appears to be in motion to the observer.

   **Answer:** When the reference object and the observer are on different walkways. The walkway on which the observer is standing is in motion in either left or right direction.

3. Explain a non-inertial frame of reference with an example.

   **Answer:** If a frame of reference has a non-uniform or accelerated motion it is a non-inertial frame of reference. An example of this would be that of an elevator moving under the influence of gravity. A stationary ball placed in the elevator appears to be accelerating to an observer positioned o the ground.


   **Answer:** Newton’s law of inertia states that a body continues to be in a state of rest or uniform motion unless an external unbalanced force acts on it. A non-inertial frame has an accelerated or non-uniform motion. A stationary object placed in non-inertial frame appears to be accelerating to an observer positioned in a different frame. Here, no force is acting; still the object appears to be accelerating.

5. Describe the motion of a reference object with respect to an observer when
   a. The object is moving towards the observer with a speed of 10 m/s and the observer is stationary.
   b. The object is stationary and the observer is moving towards the object with a speed of 10 m/s.
   c. The object is stationary and the observer is moving away from the object with a speed of 10 m/s.

   **Answer:**
   a. The object appears to be moving towards the observer at a speed of 10 m/s.
   b. The object appears to be moving towards the observer at a speed of 10 m/s.
   c. The object appears to be moving away from the observer at a speed of 10 m/s.
6. Classify the following as inertial or non-inertial frames of references.
   a. A car accelerating to reach point A.
   b. A car moving with a constant speed.
   c. An elevator falling freely under the influence of gravity.

   **Answer:**
   a. Non-inertial Frame
   b. Inertial Frame
   c. Non-inertial Frame

7. Describe a real-life example explaining the apparent movement of an object with respect to your frame of reference.

   **Answer:** Consider an example where the observer is sitting in a bus and waiting at the signal. Suddenly when the light turns green and the adjacent car moves forward you feel that the bus is moving backward.

8. If a coin is tossed in a car, what is its motion relative to an observer when the observer is:
   a. Sitting in the car.
   b. Standing on the ground.

   **Answer:**
   a. The coin goes up and then falls down, under the influence of gravity, in a straight line
   b. The coin goes up and falls down but also appears to be moving forward while doing so.

9. A man runs from the front to the back of a bus at a velocity of 2.0 m/s. If the bus is moving forward at 20.0 m/s, determine his relative speed with respect to an observer standing on the road.

   **Answer:** 18 m/s.

10. The measurement of which of these quantities is not affected by the frame of reference.

    - Mass
    - Velocity
    - Length
    - Distance

   **Answer:** Mass and Length.
Hands-On Lab
Understanding and Describing Motion

Timing: one 90-minute class session

Objective(s):
In this lab, pairs of students will explore motion in inertial and noninertial reference frames. They will attempt to throw a soft object through a sewing ring or at a mop handle. Throwers and targets will be in various combinations of stationary, constant velocity, spinning, or revolving frames of reference.

Safety Precautions:
Students will throw objects toward other students holding targets. While the objects should be soft, instruct students to throw only when their receiver is ready. Students also need to be sure there is plenty of space around them and no other students behind the receiver who may be struck by a thrown object if the receiver does not catch it. It is best if the receiver is positioned with a wall directly behind him or her and any throws go in the direction of the nearest wall. All breakable objects in the room should be put away. Intentionally throwing objects irresponsibly at one another will be dealt with harshly. Eye protection should be worn.

Materials:
Per pair of students:
  • 1 soft throwing object, such as a cloth ball or light beanbag
  • 1 ring, to serve as a target
  • 1 mop or broom, to serve as an axis and as a target

Teacher Preparation:
The throwing object should be about the size of a tennis ball or smaller, but it needs to be soft, not elastic. The ring needs to be four to five times larger than the ball. You can cut out the center portion of a sturdy paper plate, for example. A mop or broom will work, but any sort of tool with a straight handle will be fine. Use only soft tools with plastic or wooden handles, not metal. Prepare copies of the Student Investigation Sheets for each student and distribute them before the beginning of the lab.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Explain to students that they will be playing seven variations of a throwing game. One person in each pair will be the thrower and the other the receiver holding a target. As they play, they are to note in the table provided whether the thrower needs to “lead” the target (aim somewhere not directly at it) and whether the horizontal component of the apparent path taken by the object is straight or curved as seen by the thrower and by the receiver. For purposes of the lab data, the thrown objects’ vertical motion (falling) will be ignored, although of course it matters for whether the target is hit. Instruct students to pay attention to the paths of the objects through the air, as if seen from above. Walking should not be so slow that the game is too easy.

These are the seven variations:

1. The thrower and the target are both stationary. The receiver holds the ring target off to one side for the thrower to toss the object through.

2. The thrower is stationary, while the receiver holding the ring target walks past at constant velocity.

3. Both the thrower and the receiver with the ring target walk in parallel directions with the same constant velocity.

4. The thrower and the receiver with the ring target walk in opposite directions with the same magnitude of constant velocity.

5. The thrower stands in one location and spins in place, attempting to toss the object to the receiver holding the stationary ring target. Note: The thrower should try to keep his or her head and eyes facing in the same direction as his or her body, i.e., do not track the target.

6. The thrower holds a mop handle vertically, with its head (cleaning end) down. With fingertips on top of the vertical handle, the thrower walks around the handle at arm’s length and attempts to throw the object so that it hits the handle shaft.

7. If the thrower is right-handed, the thrower and the receiver join left hands and walk counterclockwise as if a vertical axis passes through their hands. The receiver holds the ring target a little in front of his or her body.

The students fill out the first four columns of the table during the lab. The teacher leads a class discussion to fill out the last two.
Guided Inquiry
Ask for a volunteer to serve as a receiver. Throw the object at the stationary target held by the volunteer. Next, have the receiver walk at a constant velocity and again throw the object so that it passes through the ring target. Ask students to describe the motion as seen from overhead in each case. Here are some questions to ask during the discussion:

- Is the path of the object a straight line in both cases?
- What is different about the two paths?

Note that the two paths do not have to be different. For example, if your first throw is perpendicular to the wall behind the receiver, your second throw can be as well if you lead the receiver and time your throw correctly. The important concept here is that the two paths may be identical as seen from the thrower’s perspective but not from the receiver’s perspective.

- Are the two paths the same from the thrower’s point of view?
- Are the two paths the same from the receiver’s point of view?

Students should be asked to design additional situations in which both the thrower and the receiver see both the same straight paths and different straight paths.
Next, students should be asked to design situations in which one or both partners see the object moving in a curved path (as seen from above). Ask them to consider the following questions:

- How would you describe the reference frame of the thrower and the receiver in each of the examples you have constructed: inertial or noninertial? (See example table below for each case.)
- Can you design a situation in which only the thrower sees the object move in a curved path while the receiver sees the object move in a straight path? (See Cases 5 and 6 for descriptions.)
- How would you describe the reference frame of both the thrower and the receiver in this situation? (Whichever person sees a curved path is in a noninertial reference frame.)
- Can you design a situation in which both the thrower and the receiver are in a noninertial reference frame? (See Case 7 for a description.)
- What will the object paths look like for each person: straight or curved? (Curved for both.)

Have the students organize their observations. First, they should break down each type of motion into Case 1, Case 2, Case 3, etc. For each case, fill in a table as shown below.

**Case 1:** The thrower and the target are both stationary. The receiver holds the ring target off to one side for the thrower to toss the object through.

**Case 2:** The thrower is stationary, while the receiver holding the ring target walks past at constant velocity.

**Case 3:** Both the thrower and the receiver with the ring target walk in parallel directions with the same constant velocity.

**Case 4:** The thrower and the receiver with the ring target walk in opposite directions with the same magnitude of constant velocity.

**Case 5:** The thrower stands in one location and spins in place, attempting to toss the object to the receiver holding the stationary ring target. Note: The thrower should try to keep his or her head and eyes facing in the same direction as his or her body, i.e., do not track the target.

**Case 6:** The thrower holds a mop handle vertically, with its head (cleaning end) down. With fingertips on top of the vertical handle, the thrower walks around the handle at arm's length and attempts to throw the object so that it hits the handle shaft.

**Case 7:** If the thrower is right-handed, the thrower and the receiver join left hands and walk counterclockwise as if a vertical axis passes through their hands. The receiver holds the ring target a little in front of his or her body.
Encourage students to compare their procedures and results with other groups. Discuss as a class the resolution if there is a disagreement between groups over what they observed or concluded.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. For each situation you design, imagine an outside observer hovering in the air above you. What would the path look like in each case for this observer? *(Straight in each case.)*

2. How would you describe this observer’s reference frame? *(Inertial)*

3. Were your initial results different from another group? Which group was correct in their interpretation or data, and why? *(Answer will vary.)*

4. Can you think of real-world analogs for each of your cases? *(Many good sports analogies possible here, such as throwing a football to a running receiver. For Case 7, it could be children on the opposite sides of a spinning merry-go-round trying to roll a ball to one another.)*
Inquiry and Nature of Science Skills in this Lab:

• Identify Questions
  o Develop a question that:
    ▪ Asks a question about a specific science concept or process
  o Recognize and develop testable questions that:
    ▪ Specify a cause-effect relationship
    ▪ Require the changing of one variable at a time
    ▪ Can be answered with a science investigation or observational study
  o Develop predictions/hypotheses that:
    ▪ State what may happen in an investigation based on prior knowledge or experience (prediction)
    ▪ State the expected cause-and-effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

• Design Investigations
  o Design and conduct investigations using:
    ▪ Fair test - changing only one variable at a time makes comparisons valid
    ▪ Independent variable - the one variable the investigator chooses to change
    ▪ Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    ▪ Constant- identify variables that must remain unchanged
  o Explain the investigative processes by:
    ▪ Describing the logical sequence that was used to conduct the investigation
    ▪ Properly citing all equipment and materials
    ▪ Describing it so that it can be easily repeated by a fellow scientist
  o Practice lab safety by:
    ▪ Following lab-safety procedures
    ▪ Incorporating laboratory-safety practices into the investigation design

• Gather Data
  o Use senses to observe:
    ▪ Kinesthetic (balance, position)
  o Use the appropriate format to record data:
    ▪ Table
    ▪ Writing (journal, worksheet, electronic text)
• **Interpret Data**
  o Identify and interpret patterns using:
    ▪ Trends in data
    ▪ Repeating physical or data patterns
    ▪ Tables and graphs
    ▪ Analysis of data collected during an investigation

• **Evaluate Evidence**
  o Draw and support a conclusion by:
    ▪ Using data to determine the cause-effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
    ▪ Comparing results to hypothesis
    ▪ Answering the testable question
    ▪ Extrapolating results beyond the investigation

• **Communication in Science**
  o Report results using:
    ▪ Written report
    ▪ Table/graph showing data

• **Analyze Scientific Results**
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating a conclusion
Hands-On Lab
Newton’s Laws of Motion

Timing: one 90-minute class session

Objective(s):
Students will plan, develop, and present a demonstration of the application of Newton’s laws of motion.

Safety Precautions:
Students should not wear sandals or open-toed shoes. Students should be careful not to trip over tracks and small cars or drop objects on the ground. Students should not throw balls at each other, and use them only for demonstration purposes. Students should wear safety goggles.

Materials:
Per group:
- 1 large sheet of smooth paper
- 1 book with a hard, glossy cover
- 1 book with a rough cover
- 1 balloon for each member of the group
- 1 meter stick
- 1 marble or lightweight mass cart
- 1 or more springs of varying stiffness, with known spring tension
- 1 inclined plane or ramp
- 1 stand for hanging pendulum or spring
- 1 pendulum bob with string for hanging
- 6 washers
- 1 tennis ball, golf ball, baseball, ping-pong ball
- 1 toy truck

Each group will use only a subset of the listed materials, so it may not be necessary to have all supplies for each group. Also, you may have other ideas of ways for the students to demonstrate Newton’s laws of motion, so feel free to include additional materials. If you choose to allow students to use materials from home, make sure you review them before granting permission.

Teacher Preparation:
Make sure you include a variety of balls of different masses for students to choose from and that the toy truck can hold six washers. Prepare a copy of the Student Investigation Sheet located at the end of the lab for each student. Place cups, saucers, and plates with smooth bottoms on an un-hemmed cloth on a table. Whisk the cloth off the table, leaving the cups, saucers, and plates in the same place. (Practice at home; the trick is in a quick, downward motion.)
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to
the investigational methods being used in the Hands-On Lab, it is recommended that the Directed
Inquiry approach be used to provide scaffolding that will ensure student safety and support the success
of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory
techniques and methods to be used in the activity. A discussion of each step in the investigative
process will also be included. In some cases, students may then be asked to create a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure
to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry
activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or
manipulate variables of their own choosing. It may be necessary to provide additional materials and
supplies for students using Guided Inquiry. It will also be important to set clear limits on students’
activities to ensure their safety and the relevance of their inquiry experience to the content you are
teaching.

Directed Inquiry
Place cups, saucers, and plates with smooth bottoms on an un-hemmed cloth on a table. Whisk the
cloth off the table, leaving the cups, saucers, and plates in the same place. (Practice at home; the trick
is in a quick, downward motion.) Ask students what law of motion this common magic trick
demonstrates (inertia; the first law). Review Newton’s first law of motion, writing it on the whiteboard.
(You may wish to lead a brief discussion of Newton and his major accomplishments.)

Divide students into small groups (4–5 students per group) and give each group a large sheet of
smooth paper and two books, one with a smooth cover and one with a rough cover. Have them
duplicate your demonstration, first with the smooth-covered book and then with the rough-covered
book. Lead a class discussion that allows the groups to share their results.

Next, attach a spring scale calibrated in newtons to a string tied to a book. Pull the book and ask
students which law you are demonstrating ($F = ma$; Newton’s second law). Create a simple data table
on the whiteboard and have one student record how many newtons of force were required to start the
book moving. Repeat the experiment with two and three books (of the same mass), having the student
complete the data table.
The data table might have values similar to the following, depending on the mass of the book(s).

<table>
<thead>
<tr>
<th>Number</th>
<th>Trial 1 (N)</th>
<th>Trial 2 (N)</th>
<th>Trial 3 (N)</th>
<th>Average (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 book</td>
<td>2.0</td>
<td>2.2</td>
<td>2.3</td>
<td>2.2</td>
</tr>
<tr>
<td>2 books</td>
<td>4.5</td>
<td>3.8</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>3 books</td>
<td>6.0</td>
<td>6.3</td>
<td>6.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Give each group of students a toy truck, six washers, a meter stick, and an inclined plane or ramp. Have each group record how far the truck rolls empty, with three washers and with six washers. Lead a class discussion that allows the groups to share their results.

As the final demonstration, use Newton’s cradle to illustrate the third law of motion by pulling one ball back from the end and allowing it to hit the ball next to it. Ask students what happens to the force (it travels through the balls in the center, moving the ball at the other end). Have students predict what will happen if you pull two balls back and demonstrate. Point out that this toy demonstrates Newton’s third law of motion (for every action, there is an equal and opposite reaction). Explain that friction eventually stops the reaction on Earth; ask students what would happen in a vacuum (the balls would never stop).

Give each member of each group a balloon and instruct students to blow up their balloons but not to tie them. Have them release the balloons. Lead a discussion on how the balloons demonstrate Newton’s third law of motion.

**Guided Inquiry**
Place cups, saucers, and plates with smooth bottoms on an un-hemmed cloth on a table. Whisk the cloth off the table, leaving the cups, saucers, and plates in the same place. (Practice at home; the trick is in a quick, downward motion.) Ask students what law of motion this common magic trick demonstrates (inertia; the first law). Review Newton’s first law of motion, writing it on the whiteboard. You may wish to lead a brief discussion of Newton and his major accomplishments.
Divide students into small groups (4–5 students per group) and show them the materials available to them. Have them design a short demonstration for the first law, encouraging them to use an Internet search for ideas. If they want to add any materials from home, make sure they present these to you for approval before using them.

Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- What are the independent variable(s)?
- What is the dependent variable?
- How might you use a pendulum to demonstrate Newton’s first law?
- How might you use marbles and ramps to demonstrate the relationship between mass and distance traveled? Slope and distance traveled?

Next, attach a newton scale to a string tied to a book. Pull the book and ask students which law you are demonstrating ($F=ma$; Newton’s second law). Create a simple data table on the whiteboard and have one student record the number of newtons required to start the book moving. Repeat the experiment with two and three books (of the same mass), having the student complete the data table. The data table might have values similar to the following, depending on the mass of the book (s).

<table>
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<tr>
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<td>4.5</td>
<td>3.8</td>
<td>4.4</td>
<td>4.2</td>
</tr>
<tr>
<td>3 books</td>
<td>6.0</td>
<td>6.3</td>
<td>6.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Have the student groups design a short demonstration for the second law, encouraging them to use an Internet search for ideas. If they want to add any materials from home, make sure they present these to you for approval before using them. Have groups repeat at least three trials, and construct a data table of their results.
Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- How might you use collisions to demonstrate Newton’s second law?
- How does Newton’s second law apply to hitting a baseball, tennis ball, golf ball, ping-pong ball?

As the final demonstration, use Newton’s cradle to illustrate the third law of motion by pulling one ball back from the end and allowing it to hit the ball next to it. Ask students what happens to the force (it travels through the balls in the center, moving the ball at the other end). Have students predict what will happen if you pull two balls back and demonstrate. Point out that this toy demonstrates Newton’s third law of motion (for every action, there is an equal and opposite reaction). Explain that friction eventually stops the reaction on Earth; ask students what would happen in a vacuum (the balls would never stop). Have students brainstorm other demonstrations of Newton’s third law (such as blowing up balloons and releasing them).

Have the student groups design a short demonstration for the third law, encouraging them to use an Internet search for ideas. If they want to add any materials from home, make sure they present these to you for approval before using them.

Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- What are the independent variable(s)?
- What is the dependent variable?
- How does throwing a ball while on roller skates demonstrate Newton’s third law of motion?
- How do rockets exemplify Newton’s third law of motion?

At the end of the lab, encourage students to compare their procedures and results with other groups. Discuss as a class what factors could be altered without affecting the outcome of the demonstrations, and what factors had to be kept constant and why.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What new questions did the lab generate for you? How might you change the lab to make the demonstrations more effective? *(Answers will vary: The demonstration of Newton’s third law made us wonder what would happen if you threw a ball or shot an arrow while in motion. We could extend the lab by using a couple of cars in the parking lot.)*

2. How do you explain variations between trials in your data collected for Newton’s second law of motion? *(Answers will vary: Variations occur because of human error. If we had used the same person each time, maybe the results would have been more uniform.)*
3. What happens if you vary the amount of force applied to objects of different mass? *(The object with lesser mass will accelerate more.)*

4. Describe a real-world example of Newton’s first law of motion. *(Answers will vary: May include wearing seat belts in a car crash, stopping a bike, etc.)*

5. Describe a real-world example of Newton’s second law of motion. *(Answers will vary: Pushing a shopping cart as it fills with groceries, dropping two objects of different mass into a pile of sand, etc.)*

6. Describe a real-world example of Newton’s third law of motion. *(Answers will vary: An airplane taking off, a paddle boat, a catapult)*
Inquiry and Nature of Science Skills in this Lab:

• Design Investigations
  o Design and conduct field studies using:
    ▪ Survey—collects multiple data points at one point in time
    ▪ Observational Study—compares changes in data points over time
    ▪ Interventional Study—adjusts one or more elements and observes resulting changes over time
  o Make or use models that:
    ▪ Simulate a real thing that cannot easily be studied or manipulated
    ▪ Have as many details as possible replicated from the real thing
    ▪ Function exactly like or similarly to the real thing
    ▪ Allow the testing of a hypothesis with results that can be extrapolated to the real thing
    ▪ Apply mathematical operations and principles to replicate the real thing.
    ▪ Have been revised as new knowledge and information has been obtained
    ▪ Are based on logic and evidence
  o Explain the investigative processes by:
    ▪ Describing the logical sequence that was used to conduct the investigation
    ▪ Properly citing all equipment and materials
    ▪ Describing it so that it can be easily repeated by a fellow scientist
  o Practice lab safety by:
    ▪ Following lab safety procedures
    ▪ Recognizing safety equipment and materials and knowing their proper use
    ▪ Incorporating laboratory safety practices into the investigation design

• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Length/distance/depth
    ▪ Force
  o Use the appropriate format to record data:
    ▪ Table

• Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Using data to determine the cause–effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
• Comparing results to hypothesis
• Examining how investigations can be improved
• Showing the application of the scientific concept or process being investigated

• Communication in Science
  o Report results using:
    ▪ Peer presentation
    ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
Exploration Teacher Guide: Newton’s Second Law of Motion

Overview

Newton’s second law of motion describes how the motion of a body and its acceleration are dependent on the mass of the body and the force applied. In this Exploration, students observe the effect of forces of varying magnitudes on an object of certain mass, which may be kept on different surfaces (each with its characteristic co-efficient of friction) for various runs. Students also analyze the motion of the body in terms of the velocity and acceleration, the distance traveled, and the force applied.

Student Learning Objectives

- Verify Newton’s second law of motion using the motion of a cart.
- Analyze the motion of the cart by varying various parameters like magnitude of the applied force, the co-efficient of friction between the surface and the cart, and additional mass on the cart.
- Observe the motion of the cart in terms of the distance traveled, the velocity, and the acceleration.
- Examine the net force and the dependence of acceleration on the mass and the force applied.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Apparatus tab, students view the experimental setup and learn about the force sensor and the accelerometer which are used in the experiment.

In the Explore tab, students verify Newton’s second law of motion and study the motion of a cart subjected to various conditions. A cart is placed the left end of the screen. Below the cart there are observed readings (from the sensor) for the force applied and the acceleration of the cart. A graph showing the various forces (applied force, net force, and frictional force) with respect to time, at the bottom of the screen allows the student to understand the dependence of these forces on conditions like the type of surface, the variation of mass, and the magnitude of applied force. Interactive keys provided at the bottom right allow the students to view a particular plot individually or with other plots. The parameters like Force to be Applied slider, Surface dropdown, and Additional Mass dropdown are at the extreme left of the screen. Default masses of the objects (empty cart, force sensor, and accelerometer) are also provided.

The students select these parameters for a particular run and then click on the Apply Force button. The cart moves to the right and the instantaneous values of the force acting on the
system and the acceleration of the cart are displayed. A graph for the various forces with respect to time is plotted as the cart moves to the right. The Apply Force button toggles to a Reset button, which allows the students to select different conditions for the next run.

The Data tab displays the values for the current run. Students observe the values of Applied Force, Frictional Force, Net Force, Velocity, Acceleration, and Distance Traveled at different intervals of time.

The Graph tab displays plots of various functions used the exploration. Students observe the graph of Force, Acceleration, Velocity, and Distance Traveled as a function of time for the latest run and also the graph of Acceleration vs. Net Force across all the runs.

The Tracker tab is a summary of the values for all the runs. This tab displays the initial parameters selected (Surface, Total Mass, Average Force, Frictional Force) and the observed values for average net force and the average acceleration, and deduction of the type of friction.

**Answers to Questions in the Student Worksheet**

1. State Newton’s Second Law of Motion. Provide an expression for it and explain each term in the expression.

   **Answer:** The acceleration of an object is directly proportional to the net force acting on the object and inversely proportional to the object’s mass.

   Expression: \[ \sum F = m \times a \]
   - \( \sum F \): net force
   - \( m \): mass
   - \( a \): acceleration

2. A house is lifted from its foundations onto a truck for relocation. The unbalanced force lifting the house is 3000 N. This force causes the house to move from rest to an upward speed of 0.15 m/s in 5.0 s. Find the mass of the house.

   **Answer:**
   - \( F = 3000 \text{ N} \)
   - \( v = 0.15 \text{ m/s} \)
   - \( t = 5.0 \text{ s} \)
   - Find \( m \)

   Solution:
   - \( a = v / t = 0.15/5.0 = 0.03 \text{ m/s}^2 \)
   - \( m = F / a = (3000 / 0.03) \text{ kg} = 100000 \text{ kg} \)

3. A locomotive engine pulls a train with a constant force. Comment on whether its acceleration will increase or decrease if more coaches are added to the train.

   **Answer:** Acceleration will decrease. We have \( a = F / m \). As coaches are added to the train the mass of the train increases and hence the acceleration decreases.
4. When you drop a 2 kg iron weight and a 5 kg iron weight from a height, predict which one will fall first to the ground. Justify your answer.

**Answer:** Both masses fall in the same time, as the acceleration due to gravity remains the same for the two bodies (and has a constant value at a particular place).

5. Analyze the role of the type of surface on the motion of a body. From the exploration, infer whether you will move with greater ease on an ice surface or on a wooden stage.

**Answer:** The type of surface determines the co-efficient of friction and hence the frictional force. As the frictional force opposes the motion, a surface on which the frictional force is greater will resist the motion more. For an ice surface, for example an ice-hockey rink, the co-efficient of friction (both static and dynamic) is comparatively lower than that for a wooden stage. Hence a person will slide with greater ease on the ice surface (while also increasing the chance to slip and tumble).

6. An object is accelerating is at the rate of ‘a₁’ m/s². If suddenly the net force exerted is doubled and the mass is quadrupled, find the new acceleration ‘a₂’.

**Answer:**

\[
a_1 = \frac{F_1}{m_1}, \\
F_2 = 2 F_1, m_2 = 4 m_1, \\
a_2 = \frac{F_2}{m_2} = \frac{2 F_1}{4 m_1} = \frac{F_1}{2 m_1} = \frac{a_1}{2}
\]

Hence the new acceleration is \(a_1 / 2\) i.e. half of the initial acceleration.

7. Five men push a stalled car with an average force of 400 N per person. Find the mass of the car if the car accelerates at 1 m/s².

**Answer:**

\[
F_{avg} = 400\, N, \\
No.\, of\, men = 5, \\
F_{tot.} = 400 \times 5 = 2000\, N \\
a = 1\, m/s^2 \\
So, m = F / a = 2000 / 1 = 2000\, kg
\]

8. A 1.08 \times 10^3 kg car uniformly accelerates for 12.0 s from rest. During this time the car travels 132 m north. Find the net force acting on the car during this acceleration.

**Answer:**

\[
m = 1.08 \times 10^3\, kg \\
t = 12.0\, s \\
S = 132\, m\, North \\
Find\, F \\
S= ut + (at^2) / 2 \\
u= 0
\]
So \[ a = \frac{2S}{t^2} = \frac{(2 \times 132)}{(12 \times 12)} = 1.83 \text{ m/s}^2 \]
\[ F = m \times a = 1.08 \times 10^3 \times 1.833 \text{ kg m/s}^2 = 1980 \text{ N} \]

9. A rock falls under a gravitational force of 16.3 N on the moon. Given that the acceleration due to gravity on the moon is one sixth of that on the Earth, find the mass of the rock.

**Answer:**

\[ F_{\text{moon}} = 16.3 \text{ N} \]
\[ g_{\text{earth}} = 9.8 \text{ m/s}^2; \quad g_{\text{moon}} = g_{\text{earth}} / 6 = 9.8 / 6 = 1.63 \text{ m/s}^2 \]
\[ m = F_{\text{moon}} / g_{\text{moon}} = 16.3 / 1.63 = 10.0 \text{ kg} \]

10. Imagine a demo car of total mass 51.0 kg includes nitro boost fuel of 1.0 kg. The car is initially accelerating at the rate of 2.0 m/s\(^2\). When the nitro boost is powered on, the new acceleration is 4.0 m/s\(^2\). Find out the change in force just prior to firing the nitro and just after the fuel is exhausted.

**Answer:**

We use, \( F = m \times a \)

Before firing nitro:
\[ m_1 = 51 \text{ kg} \]
\[ a_1 = 2.0 \text{ m/s}^2 \]
Therefore, \( F_1 = 51 \times 2.0 = 102 \text{ N} \)

Immediately after nitro fuel is exhausted,
\[ m_2 = 50 \text{ kg} \text{ (since 1 kg fuel is burnt out)} \]
\[ a_2 = 4.0 \text{ m/s}^2 \]
Therefore, \( F_2 = 50 \times 4.0 = 200 \text{ N} \)

Change in force = \( F_2 - F_1 = 200 - 102 = 98 \text{ N} \)
Exploration Teacher Guide: Newton’s Third Law of Motion

Overview

According to Newton’s third law, forces always occur in equal and opposite pairs. In this Exploration, students verify this law by using the example of balloons of different sizes and different sizes of release outlets.

Student Learning Objectives

- Observe the motion (reaction) of the balloon for different outlet diameters (action) of the balloon.
- Observe the distance covered by the balloon and the time taken for various selections.
- Analyze the action and reaction forces acting on the balloon throughout the motion.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, an experimental setup to understand Newton’s third law of motion is displayed. In this setup, a balloon which is blown up to its complete size is taped to a straw that has a string running through it. The string is held horizontally by connecting its two ends to stands.

Students can select the diameter of the balloon using options in the Diameter of the Balloon dropdown list. This determines the diameter of the balloon when it is completely inflated. Using the Diameter of the Outlet dropdown list, students can select the size of the outlet of the balloon. This determines the rate at which air escapes the balloon. On selecting View Forces checkbox the students can observe the action and reaction forces acting on the balloon. The magnitude of the force is indicated by the size of the arrows. Larger arrows correspond to a greater force.

Once students click on the Start button, the motion of the balloon for the selected values is displayed. Students may use the Reset button to reset the Exploration and analyze the motion of the balloon for a different selection.

The Data tab displays the values for the current run. Students can observe the velocity and the force acting on the balloon at different intervals of time.

The Tracker tab is a summary of the values for all the runs. Students can observe the time taken and the distance covered by the balloon to deflate completely for different selections.
1. Explain why a person experiences recoil when he fires a gun.

**Answer:** The gun exerts a force on the bullet when it is fired. The bullet exerts an equal and opposite force on the gun. This is the force or recoil experienced by the person holding the gun.

2. Determine the ratio of acceleration of two bodies with mass $M$ kg and $2M$ kg after they have a head-on collision.

**Answer:**

- Mass of body 1 ($B_1$) = $M$ kg
- Mass of body 2 ($B_2$) = $2M$ kg

Forces acting on both the bodies are equal and opposite (Newton’s Third Law of Motion). Force applied by $B_1$ on $B_2$ = - Force applied by $B_2$ on $B_1$ (negative sign indicates opposite direction)

\[ M \times a_{B_1} = - 2M \times a_{B_2} \]

\[ a_{B_1} / a_{B_2} = 2M / M = 2. \]

This indicates that the acceleration of body 1 is twice that of body 2. Heavier object has smaller acceleration.

3. A batter strikes the ball with a large force and hits a home run. Determine which is greater:
   - The force with which the bat strikes the ball.
   - The force with which the ball hits the bat.

**Answer:** Both forces are equal.

4. Explain Newton’s third law of motion using the example of a cannon.

**Answer:** A cannon applies a force on the cannonball when it is launched. This is the action force. At the same time, the cannonball applies an equal and opposite force on the cannon and it is pushed by a smaller acceleration. Even though equal and opposite forces are applied, there is a difference in their accelerations because their masses are different.

5. A boy walking in a playground is dragging his toy car along using a string attached to it. According to Newton’s Third Law of Motion, if the boy pulls his toy car with a certain force, the toy car will pull the boy with the same force. So, the forces should cancel each other. However, the motion of the toy car is still observed. Explain.

**Answer:** In the given scenario, apart from the forces acting between the toy car and the boy there is another set of forces which bring about the motion of the toy car. These are the forces which act between the ground and the boy. When the boy moves forward he pushes the ground backward, in turn the ground pushes the boy forward with an equal and opposite force. The same can be said for the toy car.
6. Determine the action-reaction forces that are involved when a man jumps from his boat onto a pier.

**Answer:** The man jumping off the boat on the pier (action force). The boat is pushed back (reaction force).

7. Explain why a person standing on a skateboard slides forward when he pushes a wall.

**Answer:** For every action there is an equal and opposite reaction. When a person standing on a skateboard pushes a wall with a certain force, the wall pushes the person with the same force in the opposite direction. This force leads to the sliding motion of the skateboard.

8. Determine the action and reaction forces in the following examples.
   a. A man rowing a boat.
   b. A boy pushing the wall.
   c. Rocket propulsion.
   d. A man standing on the surface of the earth.

**Answer:**
   a. Action: Force of oar against the water.
      Reaction: Forward motion of the boat.
      Reaction: Push force of wall on boy.
      Reaction: Upward propulsion of rocket.
   d. Action: Push force of man on Earth; gravitational attraction of Earth by man.
      Reaction: Push force of Earth on man; gravitational attraction of man by Earth.

9. If a football player hits the ball with a force of 50 N, determine the reaction force.

**Answer:** 50 N.

10. Since Newton’s third law of motion suggests that forces occur in equal and opposite pairs. Explain why they do not cancel out each other.

**Answer:** The forces do not cancel out each other because the forces are acting on different bodies.
Exploration Teacher Guide: Newton’s First Law of Motion

Overview

In this Exploration, students will verify Newton’s first law of motion by observing the effects of oppositely directed forces acting on a sled. They will also be introduced to the concept of inertia.

Student Learning Objectives

- Observe the effects of forces acting on an object at rest and in motion.
- Investigate the reasons due to which the object continues to remain in its state of rest or uniform motion.
- Verify the value of the resultant force acting on the object due to the sum of two opposing forces.
- Analyze the increase in acceleration of the object for increasing values of disturbing forces.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

Students can use the Force \((F_1)\) and Force \((F_2)\) sliders to vary the magnitude of leftward and rightward forces acting on the sled. The value of these forces can be varied from 0 N to 100 N in increments of 10 N. The selected values of forces can be applied to the sled using the Apply Force button. Students can observe the subsequent acceleration of the sled along with the resultant force acting on it. When the magnitudes of both the forces acting on the sled are equal, a pop-up box appears which informs the student about the resultant force being zero. The Reset button can be used to restart the Exploration with new values of forces.

Students can use the Tracker tab to view and compare the forces \(F_1\) and \(F_2\), the resultant force, and the direction of the sled for each run of the Exploration.

Answers to the Questions in the Student Worksheet

1. Passengers sitting in a speeding car report experiencing a sudden forward thrust when the driver suddenly applies the brakes. Use Newton’s first law of motion to explain this.

   **Answer:** When the car is in motion, the passengers sitting inside are also in a state of motion. When the driver suddenly applies the brakes, the car comes to a halt immediately, but the passengers are still in motion due to their inertia. This is experienced in the form of an apparent forward thrust.
2. Define inertia. Explain why Newton’s first law of motion is also called the Law of Inertia.

**Answer:** Inertia is the tendency of an object to resist change in its state of rest or of motion. This is postulated by Newton’s first law of motion, which also came to be known as the Law of Inertia.

3. Analyze why a body undergoing uniform motion eventually comes to rest, even in the apparent absence of an external unbalanced force.

**Answer:** A body undergoing uniform motion eventually comes to rest, even in the absence of any visible external unbalanced force because of the friction between the body and the surface on which it is moving.

4. In the Exploration, the sled does not move at all when two equal forces are applied in opposing directions. Explain the reason behind this.

**Answer:** When two forces, equal in magnitude, but opposite in direction, act simultaneously on a body, they nullify each other and the resultant force acting on the body is zero. This is the reason the sled does not move in this case.

5. Compare and contrast static and kinetic friction. Also explain why speed or acceleration are not accounted for in the numerical value of these quantities.

**Answer:** Friction can be classified as either static friction or kinetic friction. An object must overcome the static friction to be set in motion. The kinetic friction is the one that acts on the body when it is in motion. The coefficient of kinetic friction is the ratio of the kinetic frictional force to the force of contact between the surface and the object. Force is the product of mass and acceleration, which is the rate of change of velocity. The kinetic frictional force is not affected by the object’s speed or acceleration. Acceleration is the result of a net force, not the other way around.

6. List two measures that can be used to reduce the effect of friction.

**Answer:** Lubrication and smoothening or polishing of the surfaces undergoing friction, are two measures that can be used to reduce the effect of friction.

7. A car is moving at 50.0 mph when the driver applies brakes. Determine the distance it covers before coming to a halt. Coefficient of static friction between the tires and surface of the road is 0.514. Mass of the car is 1000 kg.

**Answer:**

\[
\begin{align*}
v &= 50 \text{ mph} = 22.352 \text{ m/s} \\
D &= v^2 / (2 \mu_s g) \\
D &= 499.612 \div (2 \times 0.514 \times 9.8) = 49.6 \text{ m}
\end{align*}
\]
8. Demonstrate an example of how Newton’s first law could be practically explained using commonly used objects.

**Answer:** Place a piece of cardboard over an empty glass. Ensure that the cardboard is slightly bigger than the rim of the glass. Place a coin in the center of the cardboard. Now flick the cardboard swiftly using your fingers to dislodge it from over the glass. Due to the inertia of the coin, it will drop inside the glass, thereby validating Newton’s first law of motion.

9. Gather information about Newton’s cradle and explain how it validates Newton’s First Law.

**Answer:** Newton’s cradle is a set of five metal balls suspended by two strings each. If one of the balls is pulled and left to strike the others, another ball at the opposite end is pushed up by an equal force. By observing this conservation of momentum, Newton’s First Law is verified.

10. Analyze why it takes more effort to push a heavier object as compared to a light one.

**Answer:** Mass is the measure of inertia. A heavier object has greater mass as compared to a lighter one. Owing to this, its tendency to resist change in its state of rest is higher than that of the lighter one. This is the reason that more effort is required to push the heavier object.
Use your knowledge of Newton’s First Law of Motion to answer the following questions.

1. Why is Newton’s First Law of Motion sometimes referred to as the Law of Inertia? 
   [answer: Inertia is defined as the ability of an object to resist a change in motion. Newton’s First Law of Motion states that an object in motion will stay in motion and an object at rest will remain at rest unless acted upon by an outside force. If an object is at rest, than a force is needed to overcome the objects inertia. Likewise, if an object is in motion it will continue until a force overcomes the objects inertia to change the motion.]

2. As a student is sitting in her chair she is not moving, but there are forces that are acting upon her. What must be true about the forces acting upon the girl? 
   [answer: Since the student is not moving the forces must be balanced and acting in opposite directions upon the girl.]

3. An airplane is traveling at a cruising speed of 217 m/s. If the airplane’s engines provide a forward force of 19,530 N, calculate the force of the air resistance (friction) that is acting on the plane.
   [answer: Because the airplane is moving with a constant velocity (speed and direction are unchanged), according to Newton’s First Law, all forces acting on it must be balanced. The force of air resistance (friction) acting opposite to the direction of motion must therefore be equal to the force of the engine acting in the direction of motion. The force of friction on the car must also be 19530 N.]

4. As a skydiver with a mass of 54 kg falls toward the Earth, she accelerates at 9.8 m/s². What is the force of gravity acting upon the skydiver? What must be true about the force of air resistance working on the skydiver? [answer: Since F=ma, the force of gravity is equal to the girl’s mass (54 kg) times the acceleration due to gravity (9.8 m/s²). This value is 530 N (529.2 N; answer is given in significant figures). Since the girl is still falling, her motion has not changed. That means that the force of air resistance is not great enough to overcome her inertia and therefore the force of air resistance is less than the force of gravity.]
Calculating a Hardy-Weinberg Equation
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:

Load Work
You have existing data.
To reload your most recent version of this lab since last saving, click here.
There is only one saved data set per user per lab. Your most current saved data set for this lab will be overwritten should you save data.
To load data from another user in your group, enter the 6 digit code they gave you and click “Load”.
If you would like to start a new session, simply close this popup.
There are several elements to enter on this screen.

- **Name the data table**: select a descriptive title or name for the data table.
- **Name each of the columns in the data table**: Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Using Vectors and Scalars

**Timing:** one 90-minute class session

**Objective(s):**
In this lab, students will study motion using materials in the science classroom and then characterize it using scalars and vectors.

**Safety Precautions:**
Students should be aware of their surroundings to ensure that objects do not hit other students or interfere with other activities.

**Materials:**
- 1 model cart
- 1 track
- 1 stopwatch
- 1 mass balance
- 1–5 balls
- 1–5 inclined planes (pieces of wood are fine)
- 1 spring scale

**Teacher Preparation:**
Since different student groups will be doing a variety of activities, any balls or object expected to be in ballistic motion should be soft and not elastic. Materials should be kept on a common table and shared by students as needed. Students will be asked to produce several different situations involving vectors and scalars. For example, students might use a spring scale to pull a wooden block across the table with a constant velocity. Scalars could include block mass, elapsed time, kinetic energy, and coefficient of kinetic friction. Vectors could include displacement, velocity, pulling force, gravitational force (weight), normal force, and friction force. They will need to make use of different equipment during the lab time. Prepare copies of the Student Investigation Sheets for each student and distribute them before the beginning of the lab.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Review with students the kinds of quantities that are represented by either scalars or vectors. Show students the selection of materials available for them to create their lab project.

Work through an example together in class using a spring scale to drag a block of wood across a table at a constant velocity. Ask for ideas about what scalars are present, such as the mass of the block, elapsed time, speed, and distance. Next, ask what vectors are present, such as displacement, velocity, pulling force, gravitational force (weight), normal force, and friction force.

Pairs of students will work together to set up a situation involving motion that illustrates scalar and vector quantities. Each pair will produce a labeled diagram of the situation with the relevant scalars listed and vectors drawn and labeled. The instructor may wish to check the accuracy of each diagram before the materials are put away.

Optional: In a second session, teams attempt to collect materials and recreate situations recorded in diagrams made by other teams.

**Guided Inquiry**
Review with students the kinds of quantities that are represented by scalars and those that are represented by vectors. Show students the selection of materials available for them to create their lab project.

Pairs of students will work together to set up as many situations involving motion that illustrate scalar and vector quantities as time permits.

Optional: In a second session (or if time allows in the first session), teams attempt to collect materials and recreate situations recorded in diagrams made by other teams.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning the questions as homework:

1. Give an example of a vector quantity and an example of a scalar quantity witnessed in the lab. 
   *(Speed is a scalar quantity, and velocity is a vector quantity.)*
2. Describe a situation in which the distance traveled by an object is greater than the magnitude of its displacement. (Sample answer: Any motion that changes direction.)

3. Describe a situation in which an object moves at a constant speed where the average velocity of the object over a given time interval is zero. (Sample answer: Circular motion with a time interval equal to the period. Another possibility is a person walking back and forth between the same two points at a constant speed.)

4. An object moves 4.0 m south from an initial position, makes a 90° turn to the east, and moves another 4.0 m. What is the object’s distance traveled? What is its displacement? Draw a diagram of the situation. (The distance traveled is 8.0 m, and the displacement is 5.7 m, southeast. Diagram:

5. Is the average speed of an object always the magnitude of its velocity? (No. The average speed is defined as the distance traveled divided by time, and velocity is defined as the displacement divided by time. In order for the average speed to equal the magnitude of velocity, the distance has to equal the magnitude of the displacement. The average speed of an object is only the magnitude of its velocity if the motion is in one direction.)
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause-and-effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab-safety procedures
    - Incorporating laboratory-safety practices into the investigation design

- **Gather Data**
  - Use senses to observe:
    - Kinesthetic (balance, position)
  - Use the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)
    - Sketch
    - Diagram
• Interpret Data
  o Sort and classify using scientific reasoning by:
    ▪ Applying a classification scheme to objects, substances, or organisms
  o Identify and interpret patterns using:
    ▪ Analysis of data collected during an investigation

• Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Reporting trends and patterns in the data
    ▪ Extrapolating results beyond the investigation

• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Scientific illustration with proper labeling
    ▪ Scientific explanations/arguments

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating a conclusion
Use the equations for acceleration in one-dimension to solve the problems below.

1. A car moving with a velocity of 6.4 m/s, forward, accelerates to a velocity of 10.6 m/s, forward, in 16 s. What is the car’s acceleration? [answer: 0.26 m/s², forward]

2. A train changes velocity from +64 km/h to +25 km/h in a period of 10.0 minutes. What is the train’s acceleration? [answer: -230 km/h², or -0.065 m/s²]

3. If a runner starts from rest to run a distance of 50.0 m in 16.5 s, what is the runner’s acceleration? [answer: 0.367 m/s²]
4. A ship travels 2200 m, east in 425 s. If the ship’s initial velocity is 5.7 m/s, east, what is the ship’s acceleration? [answer: $2.5 \times 10^{-3}$ m/s$^2$, west]

5. A driver travels +2170 m in 35.0 s. If the driver’s initial velocity is +62.0 m/s, what is her acceleration? [answer: 0 m/s$^2$]
Hands-On Lab
Acceleration on an Incline

Timing:
Directed Inquiry: 90 minutes
Guided Inquiry: 110 minutes

Objective(s):
The purpose of this lab is to investigate the motion of an object on an inclined surface and calculate its acceleration. Students have ideally been introduced to the general idea that objects accelerate on an incline. The purpose of this lab is to understand the nature of uniform acceleration in more depth.

Figure 1: General Lab Setup

Students will use a lab cart, an inclined surface, and a stopwatch to measure the effect of the incline on the acceleration of the cart.

Safety Precautions:
Students should wear closed-toe shoes. Also, students should be reminded to be careful with the lab materials and not allow the lab cart to fall on the floor.

Materials:
Per group:
- 1 physics lab cart
- 1 physics lab cart track (1.2 m long)
- 2 stopwatches
- 1 meter stick or metric ruler
- 4–6 text books of the same width (around 3 cm each)
- 1 protractor
• 1 photogate or motion detector with compatible computer (optional)
• graph paper

Teacher Preparation:
Teachers should set up each lab station with the materials listed above. Teachers may wish to mark a start, initial angle, midpoint line, and finish line in advance if lab time is an issue. The distance should be as large as possible to reduce the experimental error. Measure the width of one text book. Calculate how much the angle changes if you put a textbook under one end of the track. Make notes of the number of books needed for three different angles. Be prepared to tell the students how many books elevate the track at angles of 1°, 2°, and 4° (or other similar values that you will provide).

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Teachers should provide an overview of the purpose of the lab and then quickly demo the initial lab setup. Instruct students on the proper use of stopwatches.

Hypothesis:
After viewing the demo of the lab setup, have students answer the following questions in the hypothesis section of their lab handout:

1. The velocity of an object increases when it rolls down an inclined surface. Therefore, the object will have acceleration. Do you expect that this acceleration will continue at a constant rate throughout, or will the acceleration change?

2. What do you think the position, velocity, and acceleration vs. time graphs will look like for an object traveling down an incline? Draw a rough sketch of each on graph paper using measured or calculated data.
3. Explain your thinking behind the graphs you drew in the previous question.

Procedure:
1. Record in International System (SI) units the displacement of the lab cart from the starting line to the finish line in the data table. This distance will not change throughout the experiment, so the value may be copied for all rows in the data table.
2. Record in SI units the displacement to the midpoint line. It will be half of the total displacement.
3. Set the incline of the lab track, using a stack of books to around 1 degree (ahead of time, figure out how many books this will be. For a 1.2-m track, a book that is 3 cm thick will elevate the track about 1 degree) (If real-time technology, such as photogates or motion detectors, are available, attach these (according to the type and design of the device) to the starting and midpoints or ending points of the track.)
4. Position the lab cart at the starting line of the track near the top of the incline.
5. Let go of the lab cart and start the two stopwatches at the same time. Note: Be careful not to give the lab cart any forward or backward push as it is released.
6. Stop one stopwatch as the lab cart crosses the midpoint of the track; stop the second stopwatch as the lab cart crosses the finish line. Alternatively, note the times or speeds as indicated by the real-time measurement device.
7. Record the times in the data table.
8. Use equations of motion to determine the average acceleration for the top half of the track and for the entire track.
9. Determine the average time for the three trials and use this to determine the average of the average accelerations for the top half and entire track. If using real-time measurement devices to determine the speed of the cart at the end of the track, obtain the average acceleration for the three trials, and then calculate the average of the average accelerations.
10. Repeat the process for larger inclines (try for 2 and 4 degrees, or other small values).

Student Data Table:

<table>
<thead>
<tr>
<th>Incline of Track: ____ degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance from Start to Finish (m)</td>
</tr>
<tr>
<td>--------------------------------</td>
</tr>
<tr>
<td>N/A</td>
</tr>
</tbody>
</table>
Guided Inquiry
Students should be introduced to the general goal of determining the acceleration on the top half of the track versus the entire track. One option for guided inquiry is to show students the data table for the experiment and ask that they develop their own procedure. Another option is to provide students with the procedure and ask that they design their own data table. As students complete the lab, it may help to ask some of the following guiding questions:

- How can you minimize the experimental error? What do you need to be careful about?
- How will you calculate the acceleration on the top half of the track? On the entire track?
- How can you determine the acceleration using the time you record on the stopwatches? (If using the motion-detector or photogate option, how can these be used to obtain values for time or speed?)
- How will you know if the acceleration is constant throughout or higher for one half of the track?

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Does it take more time for the lab cart to cover the first or second half of the track? *The first half.*

2. Calculate the average velocity of the cart over the first half of the incline and then calculate the average velocity of the cart over the second half of the incline. *The actual calculated values will vary, but students should calculate an increase in velocity (a positive acceleration).*

3. Compare the acceleration of the lab cart over the first half of the incline with the acceleration over the entire incline. What do the data suggest about acceleration over time? *The acceleration is constant throughout the whole incline.*

4. Looking at your data table, how does the average (or mean) acceleration change as the angle of the incline increases? *As the angle is increased, the average acceleration increases.*

5. Examine all your measured time values, as well as the values for distance and angle, and identify any causes of uncertainty. What effects do these uncertainties have on your calculated acceleration results? *If using stopwatches, a major source of uncertainty is in the starting and stopping of the timepieces at exactly the right moments. (These uncertainties are reduced when using real-time measurement devices, which are activated at a given location by the moving cart itself. Even still, there is an error as to the cart’s exact location, and uncertainty in the exact placement of the photogates or motion detectors.) Uncertainty also arises from the measurement of the length of the track, due to possible inaccuracy in reading the meter stick, and in being sure of when the cart is exactly at the midpoint and end of the track. Finally, there is uncertainty in measuring the angle of inclination because of limits in the precision of the protractor. Uncertainties in time and displacement will combine to increase the uncertainty in velocity, which will then increase the uncertainty in the average acceleration.*

6. Judging from the instruments used to measure time, distance, and angle, estimate the amount of uncertainty for each of the measured quantities. From this information, quantify the effects that these uncertainties have on the measured data, as well as on the calculated values.
Answers will vary. The uncertainty in time is, at best, no better than a few tenths of a second, given that starting and stopping the stopwatches limits the precision of the instruments. (Real-time technology may be more precise, but uncertainty in positioning the photogates or detectors may still limit uncertainty in time to a few tenths of a second.) Uncertainty in displacement will probably be on the order of a centimeter or so. Uncertainty in the angle is on the order of a few degrees. Because of measurement uncertainty, uncertainty in speed is at least a few centimeters per second. Uncertainty in acceleration would therefore be no less than a several centimeters per second squared.

7. Using your data, draw the acceleration–time, velocity–time, and position–time graphs. Explain the graph shapes, given what you have learned about the acceleration on an incline. State whether your original hypothesis needs to be revised and, if so, how. The acceleration is constant over time, indicated by the horizontal line on the acceleration–time graph. The velocity increases at a constant rate, indicated by the line with a positive slope on the velocity–time graph. The position increases at a quadratic rate on the position–time graph, because as the cart's velocity increases it changes position at a greater and greater rate for each successive time interval.
• **Inquiry and Nature of Science Skills in this Lab:**

  • **Identify Questions**
    - Develop predictions/hypotheses that:
      - State what may happen in an investigation based on prior knowledge or experience (prediction)
      - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

  • **Design Investigations**
    - Design and conduct investigations using:
      - Fair test—changing only one variable at a time makes comparisons valid
      - Independent variable—the one variable the investigator chooses to change
      - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
      - Constant—identify variables that must remain unchanged
      - Control (control group)—used for comparison in which the independent variable is not changed
    - Practice lab safety by:
      - Following lab safety procedures

  • **Gather Data**
    - Use tools and the SI (metric) system to accurately measure:
      - Length/distance/depth
      - Time
      - Angle
    - Choose appropriate tools to conduct an investigation
      - Meter stick
      - Protractor
      - Clock/stopwatch
      - 4–6 books of the same width (roughly 3 cm each)
    - Use the appropriate format to record data:
      - Table

  • **Interpret Data**
    - Identifies and interprets patterns:
      - Trends in data
      - Analysis of data collected during an investigation

  • **Evaluate Evidence**
    - Draw and support a conclusion by:
      - Using data to determine the cause–effect relationship observed in the investigation
      - Reporting trends and patterns in the data
      - Comparing results to hypothesis
      - Answering the testable question
      - Extrapolating results beyond the investigation
      - Showing the application of the scientific concept or process being investigated

  • **Communication in Science**
• Report results using:
  ▪ Written report
  ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    ▪ Scientific investigation leads to more questions.
    ▪ What people expect to observe can affect how they perceive what they observe.
  o Scientific Data and Outcomes:
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ It is important in science to keep honest, clear, and accurate records.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ A law is a description of a specific relationship under given conditions in the natural world.

• Engineering and Technology
  o Uses of Technology:
    ▪ Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.
Use the equations for motion in one-dimension to solve the problems for two-dimensional motion below.

1. A rock is kicked off the edge of a cliff that is 127 m high. If its initial velocity is 4.20 m/s in the horizontal direction, how far from the base of the cliff will the rock land? [answer: 21.4 m]

2. How long will it take the rock described in the previous question to land below the cliff? [answer: 5.09 s]

3. A football player kicks a football upward at an angle of 45°, so that the horizontal and vertical components of velocity are equal. If it takes 2.20 s for the ball to reach its maximum height, and another 2.20 s for the ball to return to the ground, what is the maximum height of the ball's trajectory? [answer: 23.7 m]
4. If the horizontal range of the football in the previous question is 47.5 m, what is the horizontal component of the ball’s speed? What is the total speed with which it is kicked? [answer: horizontal component of speed = 10.8 m/s; total speed = 24.1 m/s]

5. After opening her parachute, a skydiver falls at a constant rate of 3.50 m/s. At the same time, a steady wind from the west moves her eastward with an acceleration of 1.70 m/s². If the skydiver is 275 m above the ground, how long will it take her to reach the ground? [answer: 78.6 s]

6. In the previous question, how far to the east will the skydiver land? [answer: $5.25 \times 10^3$ m = 5.25 km]
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Activity
Falling Quarters

Objective:
To determine whether a horizontal velocity affects the rate at which a projectile travels a vertical distance.

Estimated time to complete: 10 minutes

Materials:
For a class-wide demo:
- 1 horizontal surface with a flat edge (any tabletop without a lip on the raised surface at the edge)
- 2 quarters

Procedure:
1. Place one quarter on the edge of the table face down such that almost half of the quarter is hanging off the edge of the table.
2. Explain that you will roll the second quarter over the first such that the first quarter will fall straight down while the second quarter will have an initial horizontal velocity.
3. Ask students to predict which quarter, if any, will hit the ground first. Students should explain the thinking behind their responses.
4. Perform the demo. Both quarters will hit the ground at the same time if the demo is performed properly. Instruct students to listen for the sound(s) of falling quarters.
5. Use this fact as an introduction to the idea that the horizontal and vertical motions of a projectile are independent of each other. The horizontal velocity of the second quarter in this case has no impact on its vertical motion.
Inquiry and Nature of Science Skills in this Activity:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Analyzing scientific explanations
    - Analyzing scientific arguments

- **Scientific Investigation**
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
Hands-On Lab
Flying off the Edge

Timing: one 90-minute class session

Objective(s):
Students will use a trajectory apparatus to investigate the two-dimensional motion of a falling ball that has an initial velocity in the horizontal direction. They will then analyze the resulting graph of the object’s trajectory to determine how fast the ball initially leaves the track of the apparatus.

Safety Precautions:
Remind students to follow all general lab safety rules. Be sure students wear safety goggles and closed-toe shoes.

Materials:
Per group:
- bubble (spirit) level
- adhesive tape
- pencil or wax pencil
- metric ruler
- safety goggles, one pair per student
- Option 1: trajectory apparatus (includes steel ball, graph paper, and recording strips)

Option 2:
- steel ball
- carbon paper
- sheets of white paper
- board
- track or ramp for the ball to roll down

Equipment Notes
This Hands-On Lab can be performed with either a trajectory apparatus or a vertical board covered with carbon paper. The procedure is written for a trajectory apparatus (Option 1).

To use carbon paper instead (Option 2), tape the carbon paper to the board with the carbon-side out. Tape a piece of white paper to the board. The board can be placed horizontally at different measured vertical heights from the ball’s launch point. As the ball strikes the paper taped to the board, it will create a carbon mark on the paper’s underside. By determining the horizontal and vertical distance of the mark from the ball’s launch point, the students can find the same data for $\Delta x$ and $\Delta y$ as if they were using a trajectory apparatus in the procedure.
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- Prior to the activity, briefly demonstrate how students attach recording strips and graph paper to the trajectory apparatus, and how they are to use the recorded impact marks to plot the trajectory points on the graph paper.

Procedure

1. Have students place the trajectory apparatus on a flat surface. Instruct them to use a bubble (spirit) level to adjust the apparatus position, so that it is not leaning away from true vertical. Use the level to check the end of the launch track of the apparatus, making sure that it is aligned with the horizontal. This can also be checked by placing the steel ball on the end of the track, and adjusting the track angle until the ball just rests at the edge, without rolling backward or falling off the track.

2. Students should become familiar with the use of the apparatus by placing the ball at different positions along the track. To do this, they will first set the "stop," which holds the ball in place, at a chosen position. Advise them to be careful in doing this, so as not to upset the alignment of the track. Students will then place the ball behind the stop and gently release the ball. They will then observe the path that the ball follows when it leaves the track.

3. Students will now place a sheet of graph paper against the board of the apparatus, and secure the upper corner of the paper to the board, closest to the launch track. This can be done using clasps provided with the apparatus or with adhesive tape. Make sure students position the paper high enough and far enough to the side of the apparatus, so that the upper corner part of the grid is horizontally level with or above the launch track, and vertically even with or past the edge of the launch track. Be sure they align the graph paper so that the horizontal lines are parallel to the upper edge of the board, and the vertical lines are parallel with the nearest side edge of the board.

4. Once the graph paper is correctly aligned, students will then secure the other three corners to the board using available clasps or adhesive tape. Tell them to be sure that the paper is smoothly and uniformly placed against the board, and that the alignment from step 3 has not been disrupted.

5. Have students position the ball at the edge of the track and, using the pencil or wax pencil, make a mark on the graph paper of the point vertically above the edge of the track and horizontally even with the center of the ball. This will be point “1” in their data table.

6. Students will now affix a strip of the recording paper to the inner surface of the vertical target plate, using either magnetic strips or adhesive tape. The target plate is located on the side of the apparatus opposite the launch track. As with the graph paper, the recording paper should lie smoothly and tightly against the target plate, with no folds or bends.

7. Students will now move the target plate toward the launch track until it is 2–3 cm from the edge of the track. Have them make sure that the target plate is aligned with the vertical lines of the graph paper.

8. Have students carefully adjust the position of the ball stop, if they wish to change it from its previous position. Then have them release the ball, making sure that it strikes the target plate firmly. Students may need to repeat this step several times, until a clear mark is left on the target plate.

9. Tell students to use the mark on the recording paper of the target plate to make a mark on the graph paper. This is done by holding the metric ruler next to and level with the mark on the target plate, and also against the graph paper. Students will then use the pencil or wax pencil to make a small mark on the graph paper at the point where the graph paper and target plate “intersect.”

10. Repeat steps 7 through 9 several times, each time positioning the target plate 2–3 cm farther from the edge of the launch track.
11. As the target plate is moved farther from the track edge, the ball strikes the plate closer to the bottom of the graph paper. Instruct students to use the points they have already recorded to estimate where the target plate should be positioned, so that the ball will strike it at the bottom line of the graph paper. Then have them place the target plate at that position and observe if they correctly predicted the point of impact.

12. When students have obtained about five or six points on the graph, have them remove the graph paper from the apparatus and measure the horizontal and vertical distances of the marks. They should use as their reference point the intersection of the bottom line of the paper and vertical line that passes through point 1, which indicates the edge of the track. Have students measure the height of the track ($y_0$) above the bottom horizontal line of the graph paper.

13. Explain that the graph paper typically used with the trajectory apparatus has large grid marks that are 1.0 cm apart, and smaller marks that are 1 mm apart. If graph paper with a different scale is used, students will need to use the metric ruler to make measurements in International System (SI) units. Students will record all measured values in the data table.

14. Instruct students to draw a smooth curve through their data points on the graph paper. Have them also draw axes along the bottom horizontal line and the vertical reference line of the graph paper. Indicate that the intersection between these two lines should be treated as the origin of the coordinate system for the graph. For convenience, have students treat the distance along the horizontal axis as positive, regardless of whether the increasing distance is to the right or left of the origin. Also have them mark the vertical and horizontal positions ($x$ and $y$) for each point of impact next to the mark for that point.

Data Table: Sample Data:

<table>
<thead>
<tr>
<th>Point</th>
<th>Horizontal position from edge of track (x) (cm)</th>
<th>Vertical position from bottom of graph (y) (cm)</th>
<th>Calculated initial horizontal speed of the ball ($v_0$) (cm/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>16.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.00</td>
<td>15.4</td>
<td>90</td>
</tr>
<tr>
<td>3</td>
<td>6.00</td>
<td>13.5</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>9.00</td>
<td>10.3</td>
<td>83</td>
</tr>
<tr>
<td>5</td>
<td>12.0</td>
<td>5.9</td>
<td>83.6</td>
</tr>
<tr>
<td>6</td>
<td>15.0</td>
<td>0.2</td>
<td>83.6</td>
</tr>
</tbody>
</table>

Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What does the curve drawn from the ball’s plotted positions represent? How does this graph differ from one showing the change in position with time?

   Answer: The graph represents the trajectory of the ball. A position vs. time graph would take the form of either a diagonal line (for horizontal position ($x$) vs. time ($t$)) or an increasing parabolic curve (for vertical position ($y$) vs. $t$).
2. Use the correct kinematic equations to describe the motion of the ball in the horizontal and vertical directions. Then combine these equations to derive the equation that describes the trajectory of the ball in terms of x and y. What is this equation, and why does it not depend on time?

Answer: For horizontal motion, \( x = v_0 t \); for vertical motion, \( y = -(g/2)t^2 + y_0 \). Substituting for \( t \) and rearranging the equation yields \( y = y_0 - (g/2)(x/v_0)^2 \). There is no time dependence, because the equation for trajectory shows only the change in one position of the ball with the change in the other position. The common time component has been replaced with the other displacement and velocity terms.

3. What is the horizontal range of the ball (\( \Delta x \)) at the bottom of the graph paper (that is, \( \Delta y = 0 \))? Using this value and the derived trajectory equation, what is the initial horizontal speed of the ball?

Sample answer: range = \( x_0 = 15.1 \) cm. For \( y = 0 \) and \( y_0 = 16.0 \) cm, \( v_0 = \sqrt{\frac{g}{2y_0}}x_0 = 83.6 \) cm/s.

4. Using the data for each point on your graph, and the equation for the trajectory of the ball, compute the value for the initial horizontal speed of the ball. Record these in the fourth column of the data table. Are these values all the same? How do they compare with the value calculated in the previous step? What factors might account for any differences among the values for initial velocity?

Sample answer: No, they differ slightly among each other, and only the last few values are the same as previously calculated value for \( v_0 \). The differences among the values are in part due to limits on significant figures, but may also arise from limited accuracy in the measurements of the ball’s position after it has struck the target plate. Slight differences in the impact point for a given target plate position also introduces errors in the precision with which \( y \) can be known. The position of the target plate is known to limited accuracy as well. Also, there may be factors regarding the releasing of the ball, such as consistent level of the track or disturbances when releasing the ball stop, that can affect its speed from trial to trial.
In this lab, students will demonstrate the following Inquiry Skills:

- Identify Questions Design Investigations
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct investigations using:
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
  - Choose appropriate tools to conduct an investigation
    - Trajectory apparatus
    - Graph paper
  - Use the appropriate format to record data:
    - Table
    - Graph

- Interpret Data
  - Identifies and interprets patterns:
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Comparing results to hypothesis
    - Answering the testable question
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Written report
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Analyzing scientific explanations
    - Analyzing scientific arguments

- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
- Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
- Scientific investigation leads to more questions.

Scientific Data and Outcomes:
- Scientific claims are based on data and reliable scientific sources.
- Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
- Comparisons of data are not accurate when some of the conditions are not kept the same.
- It is important in science to keep honest, clear, and accurate records.
Hands-On Activity
Measuring Friction

In this activity, students will determine the amount of static and kinetic friction between several surfaces using friction blocks. Students will also use proportional reasoning to make mathematical predictions about the relationship of friction to force and surface properties.

Suggested Materials
For each group of 2-3 students:
- one friction block
- one balance (this is to measure the mass of the friction block)
- one 500-gram mass
- one spring scale
- At least three different types of surfaces, with varied coefficients of friction (Examples: Carpet, plastic, various grades of sandpaper, wood, etc.)

Procedure
1. Make sure students understand how to calibrate and read measurements using a spring scale.
2. Ask students to make a hypothesis about the surfaces with the greatest amount of friction and least amount of friction. Students can also rank all of the surfaces in terms of the amount of friction they expect.
3. Students will first measure the mass of the friction block using the balance. Have students record this mass.
4. Students will place the 500 gram mass on top of the friction block to provide extra normal force on the friction block. They then will add this quantity to the mass of the friction block.
5. Students place the friction block on one of the available surfaces.
6. Using the spring scale, students gradually pull the friction block horizontally with increasing force until it just begins to move. They then record the amount of force on the scale necessary to move the block. This represents the maximum force of static friction between the block and the surface beneath it. Point out that they are to repeat this step three times, in order to reinforce the idea of using repeated trials to reduce error.
7. Once they have the block moving, students will continue pulling the friction block at a constant velocity and record the amount of force needed to keep the block in motion. This represents the force of kinetic friction between the block and the underlying surface. Again, students should repeat this step three times, to obtain the average of the force generated.
8. Students can record their data in a table, like the one shown after this Procedure.
9. Ask students to compare the amount of friction present for each surface with their original hypothesis.
10. Ask students to compare the amount of static friction they recorded for each surface with the amount of kinetic friction. Note: If the data is accurate, the force of static friction should be slightly greater than the force of kinetic friction.
11. Have students express a relationship symbolically by making a mathematical prediction about friction. In this case, instruct them to use proportional reasoning, along with their force and mass data, to make a mathematical prediction about the coefficient of friction between surfaces. Have them compare their predictions with the accepted equation.

**Data Table**

<table>
<thead>
<tr>
<th>Type of Surface</th>
<th>Mass of Friction Block (kg)</th>
<th>Total Mass Moved (kg)</th>
<th>Force Required to Move from Rest (N)</th>
<th>Force Required to Maintain Constant Motion (N)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

Analysis and Conclusions

1. How did the applied force vary with the properties of the tested surface?

(\textit{The rougher or coarser the surface, the greater the applied force had to be.})

2. What was your original hypothesis regarding the relationship between surface properties and applied force? Did the data support or refute your hypothesis?

(\textit{Answers will vary. A sample hypothesis could be: “An increase in the coarseness or roughness of a surface will cause the frictional force between that surface and another to be greater.”})

3. How did the force needed to overcome static friction compare to the force needed to overcome kinetic friction? Was this result consistent in every trial?

(\textit{If the data was accurate, the force of static friction was consistently greater than the force of kinetic friction by a small amount.})

4. What was the form of your mathematical prediction about the coefficient of friction between surfaces, based on your data and proportional reasoning? How did your result compare with the accepted equation for frictional force? What quantity was part of your proportionality constant that is a variable in the accepted equation?

(\textit{Answers will vary. An example of a correct mathematical expression would be } F_{\text{applied}} = F_{\text{frictional}} = k\mu, \text{ where “} \mu \text{” is the coefficient of friction for a given combination of surfaces, and “} k \text{” is the proportionality constant. Implied in the proportionality is a constant normal force, which suggests a constant mass of the object being moved. This is normally a variable in the accepted equation (} F_{\text{frictional}} = N\mu = mg\mu). \)
Inquiry and Nature of Science Skills in this Activity:

- **Identify Questions**
  - Develop predictions/hypotheses that
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Force
  - Choose appropriate tools to conduct an investigation
  - Spring scale
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns:
    - Trends in data
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
- Evaluating data for accuracy
- Identifying alternative explanations
- Analyzing scientific explanations
- Analyzing scientific arguments

**Scientific Investigation**
- **Scientific Investigation:**
  - Science investigation begins with a testable question.
  - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
  - Scientific investigation leads to more questions.
  - What people expect to observe can affect how they perceive what they observe.
- **Scientific Data and Outcomes:**
  - Scientific claims are based on data and reliable scientific sources.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - It is important in science to keep honest, clear, and accurate records.

**Scientific Endeavor**
- **Characteristics of Science:**
  - A law is a description of a specific relationship under given conditions in the natural world.

**Engineering and Technology**
- **Uses of Technology:**
  - Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.
High School Explorations

Exploration Teacher Guide: Solving Motion Problems

Overview

Differentiating between physical quantities such as distance and displacement and calculating quantities like average speed and average velocity is important for analyzing and understanding the motion of a body. In this Exploration, the students analyze the motion of a car on a straight line path and a curved path and observe values of physical quantities like average acceleration and average speed.

Student Learning Objectives

- Analyze the motion of a car for a curved path or straight path.
- Observe the values of instantaneous speed, instantaneous velocity, and average speed for different values of initial speed and friction.
- Observe the displacement of the car for different selected paths.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students select a path (straight or curved) on which they wish to analyze the motion of the car. A car is at position A for both the curved and the straight path. The students select the start position from the Initial Position dropdown and the end position from the Final Position dropdown available in the Path section. The initial speed of the car is selected using the Speed slider. Students select a value of friction by selecting the Vary Friction checkbox, and observe the effect of friction on the motion of the car. Students may select the View Displacement checkbox and observe the displacement of the car displayed by an arrow originating from its initial position.

The motion of the car based on the selected values is displayed when the Start button is clicked. Students can observe the values of instantaneous speed and instantaneous velocity. An arrow is displayed along with the values of instantaneous velocity, which indicates the direction of velocity. Once the car stops, the values of total distance covered and total time taken by the car and the corresponding value of average speed are displayed.

Students may use the Reset button to reset the Exploration and observe the motion of the car for different values.

The Data tab displays the values for the current run. Students can observe the values of distance and displacement along with speed and velocity values at different intervals of time.
The Graph tab displays the graphs of position versus time, velocity versus time, and acceleration versus time. The students can select a graph from the Select Graph dropdown. An option to view all the graphs together is also provided for comparative analysis of all three graphs.

The Tracker tab is a summary of the values for all of the runs. Students can observe values of total time taken to cover the distance along with corresponding displacement values. Students may also compare the values of average velocity and average speed.

Answers to questions in student worksheet

1. In the Exploration, the magnitudes of instantaneous velocity and instantaneous speed are always equal. Explain why the magnitudes of average velocity and average speed for a curved path are different.

   **Answer:** This question has multiple answers. A possible answer can be an example where an athlete completes a 400 m race around a circular track. In this case the distance he covered is 400 m and displacement is zero.

2. Using a real-world example other than a car rounding a corner, explain a situation when the distance an object travels is different than the displacement it travels.

   **Answer:** Consider an object moves along a circular track of radius 'r'. If the initial and final positions of the object are diametrically opposite then the distance covered by the object is half of the circumference of the circle (\(\pi r\)). In this case displacement of the object is equal to the diameter of the circle (2r).

3. An object moving with an initial velocity of 6.0 m/s comes to a complete stop in 4.0 seconds. Calculate its average acceleration.

   **Answer:** Average acceleration = ( change in velocity ) / ( time taken ).
   
   Let average acceleration = a.
   
   Change in velocity = \(\Delta v\) = final velocity - initial velocity = 0.0 m/s - 6.0 m/s = -6.0 m/s.
   
   Time taken = t = 4.0 s.
   
   \[ a = \frac{\Delta v}{t} = \frac{-6.0}{4.0} = -1.5 \text{ m/s}^2 \] (negative sign indicates a decrease in velocity).

4. Observe the instantaneous velocity data along the curved path. Identify whether the velocity of the cornering car is constant or varying.

   **Answer:** Velocity is a vector described by its direction and its magnitude. Even though the magnitude of velocity is always constant, the direction of velocity is constantly changing. So, the velocity of car on the curved path is varying.
5. A graph of velocity versus time (velocity displayed in m/s and time in seconds) displays a constant slope of 2 and a y-intercept of 4. Explain what can be inferred from the given data.

**Answer:** Slope of a velocity versus time graph is equal to the acceleration. Slope of the graph is 2, therefore the body moves with an acceleration of 2 m/s\(^2\). Since the graph is a straight line it can be inferred that velocity increases at a constant rate. For a uniformly accelerated motion, velocity increases at a constant rate. The intercept of 4 units on y axis indicates that the body has an initial velocity of 4 m/s.

6. Calculate the acceleration of a truck moving along a straight path if its speed increases from 0.0 m/s to 15 m/s in 10.0 s.

**Answer:** Acceleration of the truck = rate of change of velocity
Change in velocity = 15 m/s - 0 m/s = 15 m/s.
Rate of change of velocity = \(\frac{15}{10}\) = 1.5 m/s\(^2\).

7. If an object has an initial velocity of 2.0 m/s and its rate of change in velocity is 3.0 m/s\(^2\), calculate its final velocity after 4.0 seconds.

**Answer:** Let acceleration = \(a\)
Final velocity = \(v\)
Initial velocity = \(u\)
Time = \(t\)
\(a = \frac{v - u}{t}\)
3.0 = \(\frac{v - 2.0}{4.0}\)
\(v = 12.0 + 2.0 = 14\) m/s.

8. Determine which of the following statements are true or false. If false, use the space below to correct the statement so that it is true.
   a. Two bodies moving in opposite directions but with the same speed have the same velocity.
   b. An object covers a distance of 10 m and returns to its initial position. The values for distance and displacement are the same.

**Answer:**
   a. False. Velocity indicates the direction and magnitude of motion. The magnitude of velocity is same (same speed) but directions are opposite. So the velocities are not same.
   b. False. Distance covered by the object is 20 m but its displacement is 0 m since displacement is the measure of difference in position of the object.
9. Calculate the acceleration of a car if its speed increases from 4.0 m/s to 16 m/s in 3.7 s.

**Answer:** Let acceleration = \( a \)
Final velocity = \( v \)
Initial velocity = \( u \)
Time = \( t \)
\[
a = \frac{(16 - 4.0)}{3.7} = 3.24 \text{ m/s}^2.
\]
\[
a = 3.2 \text{ m/s}^2.
\]

10. An object covers a distance 6.0 km and then turns left and then covers a distance of 8.0 km. It takes 10.0 seconds to cover the entire distance. Determine the average speed and average velocity of the object.

**Answer:** The object covers a total of 6.0 km + 8.0 km = 14 km
Its displacement is 10 km (using Pythagorean Theorem)
Since the object takes 10 seconds to cover the entire distance
\[
\text{Average speed} = \frac{\text{total distance}}{\text{time taken}} = \frac{14}{10} = 1.4 \text{ m/s}
\]
\[
\text{Average velocity} = \frac{\text{displacement}}{\text{time taken}} = \frac{10}{10} = 1.0 \text{ m/s}.
\]
Hands-On Lab
Two-Dimensional Motion

Timing: one 90-minute class session

Objective(s):
Students will investigate the two-dimensional projectile motion of a ball launched vertically from a moving ballistic cart. They will compare the one-dimensional vertical motion of the ball in a fixed frame of reference (the non-moving cart) to the two-dimensional motion of the ball in a moving frame of reference (the cart moving with uniform horizontal velocity). Students will then use the kinematics equations for the ball's vertical and horizontal displacements to predict the speed of the cart under certain conditions. Finally, they will make measurements to determine the speed of the cart under those conditions.

Safety Precautions:
Remind students to follow all general lab safety rules. Be sure students wear safety goggles and closed-toe shoes. Instruct students to not let the ballistic carts fall off the lab tables, as they are prone to damage.

Materials:
Per group of four or five:
- ballistic cart, with steel or plastic ball
- string
- meter stick
- metric ruler
- glass, wood, or metal rod (20 cm in length)
- wax pencil
- adhesive tape
- electric motor (optional)
- stopwatch or timer (alternatively, use data acquisition probes, such as a pair of photogates or motion sensor, with a compatible computer or data collection device)
- ring stands or brackets (for use with photogates)
- index card (for use with photogates)
- safety goggles, one pair per student

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- If possible, obtain electric motors that are equipped to wind string at a constant speed. Ideally, the motor should have variable speed, so that it can pull an object at speeds between 0.5 m/s and 2 m/s.
- If available (along with computers or other data collection devices with which they can be used), obtain pairs of photogates, checking to be sure that the ballistic cart can pass through and interrupt the light beams. (Alternatively, attach a perpendicular dowel to the ballistic cart, so it will pass through the photogates.) Otherwise, select timing devices on availability.
Procedure:

1. Before they perform the activity, have students become familiar with the “trigger” mechanism of the ballistic cart. If they need help, show them how to set the spring-loaded piston of the cart. If the cart uses a manual pin release mechanism, instruct students not to insert the pin too far into the hole that keeps the piston in place. The piston must be easy to release with just a slight, quick pull of the string attached to the pin. If the cart uses a radio-controlled mechanism, be sure students understand how to set the cart and use the control so as to release the piston at the exact desired moment.

2. Have students set up the apparatus by first measuring a distance (Δx) along the lab table. Students should use a meter stick to measure the distance using International System (SI) units, and marking the beginning and end points with tape so that they are easily visible. They will then record the distance in the data table.

3. If photogates are to be used, students must place a support (ring stand or bracket) by each distance marker, and mount a photogate on the support. They should then fix an index card with tape to the side of the ballistic cart, making sure that the front of the card is aligned with the center of the launch tube and piston of the cart. Students also must be sure that the card passes through the photogates without obstruction. If using a timer or stopwatch, students should practice starting the timer when the center of the cart passes the first mark, and stopping the timer when the cart passes the second mark. This will prepare them for when they actually have to make time measurements for the activity.

4. If an electric motor is available for use, have students become familiar with its operation. The motor should have a spindle on which to wrap string at a uniform rate of speed, and so be able to pull the cart along at a constant speed. If a motor is not available, students will need to practice pulling the cart by hand, in which case they must be careful to not to accidentally jerk the string or steadily increase speed, thus causing the cart to accelerate during the trials.

5. Students should measure the average height to which the launched ball rises using International System (SI) units. To do this, they must first measure the distance that the ball rises from the bottom of the piston to the top of the launch barrel. By placing a glass, wood, or metal rod down the empty barrel after the spring for the piston has been set, and marking with a wax pencil the part of the rod that aligns with the top of the barrel, this distance can then be measured in centimeters using a metric ruler.

6. Have students place the meter stick by the side of the barrel, launch the ball, and attempt to measure accurately the maximum height to which the ball rises. They should practice this a few times before recording data. Once they are familiar with the procedure, have students perform five trial measurements of the maximum vertical distance, record each measurement in the first data table, and obtain an average value for (Δy).

7. In each group, one student will hold the string attached to the pin that releases the cart piston, making sure that the point at which the ball is launched coincides with the first distance mark on the table. Another student in the group will either begin pulling the cart at as uniform a speed as possible, or will operate the electric motor that pulls the cart along the table. A third student will either operate the timer and record the times, or operate the computer acquiring data from the photogates.

8. The student pulling the cart should practice several times to determine how fast the cart should be pulled so that it will travel the chosen horizontal distance in the time it takes the ball to complete its trajectory. If an unrealistic horizontal distance has been chosen, it may be necessary to shorten or lengthen this distance until a practical distance is found. Similarly, if an electric motor is used to pull the cart, it may be necessary to adjust the distance and/or the speed of the motor until a large enough horizontal displacement is chosen. If the ball is launched by means of a string-and-pin release, be sure that the student pulling the string need only give the string a slight quick pull to launch the ball, so that this action does not have a large effect on uniform pulling of the cart. As with the pulling of the cart, this process will need to be practiced several times before data is recorded.
9. Once each group has become familiar with the apparatus and their particular tasks, they should perform five trial runs to provide good precision in the data.
10. Have students disassemble the apparatus when finished.

Data Tables:
Sample Data

<table>
<thead>
<tr>
<th>Data for Vertical Motion</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Vertical distance of ball (Δy) (m)</td>
</tr>
<tr>
<td>1</td>
<td>0.38</td>
</tr>
<tr>
<td>2</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>0.38</td>
</tr>
<tr>
<td>4</td>
<td>0.40</td>
</tr>
<tr>
<td>5</td>
<td>0.39</td>
</tr>
<tr>
<td>Average value</td>
<td>0.39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data for Horizontal Motion</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial</td>
<td>Horizontal distance of ball and cart (Δx) (m)</td>
</tr>
<tr>
<td>1</td>
<td>0.52</td>
</tr>
<tr>
<td>2</td>
<td>0.52</td>
</tr>
<tr>
<td>3</td>
<td>0.52</td>
</tr>
<tr>
<td>4</td>
<td>0.52</td>
</tr>
<tr>
<td>5</td>
<td>0.52</td>
</tr>
<tr>
<td>Average value</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Derive the equation for the trajectory of the ball in terms of Δx, Δy, the horizontal speed of the cart (v), and the acceleration of gravity (g), using International System (SI) units. (Hint: Recall that Δy is the distance between the lowest position of the ball in the barrel to the highest point of its vertical displacement, while Δx is the horizontal distance that the cart travels in the time the ball rises and returns to its lowest position (that is 2Δy). The derivation is easier if just the second half of the ball’s trajectory is considered).

\[ Δy = \left(\frac{g}{8}\right)\left(\frac{Δx}{v}\right)^2 \]

2. Using the average value obtained for (Δy), the measured value for (Δx), and \( g = 9.81\ \text{m/s}^2 \), calculate the theoretical speed at which the cart was pulled.

**Sample answer:** For an average vertical distance of 0.39 m and a horizontal distance of 0.52 m, the theoretical (predicted) speed of the cart would be 0.92 m/s.
3. Calculate the horizontal speed of the cart for each of the five trials, and compare the values. How did the values calculated from measured data for the cart’s horizontal motion compare to the theoretical value based only on the measured value of the ball’s vertical path?

**Sample answer:** Measured values for the cart’s speed tended to be slightly less than that predicted by the theoretical value based on calculation.

4. How did the ball’s trajectory compare with the motion of the cart? What was different about their paths? What was the same? Explain why this was the case.

The trajectory of the ball along the horizontal direction followed the horizontal motion of the cart exactly, so that the ball returned to the launching mechanism of the cart. The only significant difference between the paths of the ball and the cart is that the ball moved upward and downward in the vertical direction, while the cart had no vertical component of motion. Both the ball and cart moved along almost identical horizontal paths. This was because the trajectory of the ball was the vector combination of the vertical and horizontal components of the ball’s motion, and the horizontal component was produced by the uniform horizontal velocity of the cart. Thus, the ball and cart had the same horizontal velocities.

5. Look for trends in the measured speed values for the cart. How did they compare with each other? How did they compare with the theoretical value?

**Answer:** The measured speeds should not differ greatly from each other, although they will vary more if the cart is pulled by hand than if the cart is pulled by motor. The measured speeds will tend to be less than the theoretical value.

6. What factors do you think might account for any differences in the theoretical and measured values for the cart’s velocity?

**Sample answers:** The pulling of the pin to launch the ball is a force opposite the motion, and so causes a reduction in the velocity of the cart. Friction in the cart’s wheels is a uniform force that reduces the cart’s velocity. The cart may not be on a truly level surface, so that some forward or backward acceleration by gravity will affect its velocity.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions Design Investigations**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Time
    - Speed
  - Choose appropriate tools to conduct an investigation
    - Meter stick
    - Metric ruler
    - Clock/stopwatch
    - Data acquisition probes (photogates)
    - Ballistic cart
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Comparing results to hypothesis
    - Answering the testable question
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Written report
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Analyzing scientific explanations
    - Analyzing scientific arguments
• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    ▪ Scientific investigation leads to more questions.
  o Scientific Data and Outcomes:
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ It is important in science to keep honest, clear, and accurate records.
Hands-On Activity

Walking About

In this activity, students will gain an appreciation for how everyday motion, such as walking, can be represented through the use of charts, graphs, and equations. Students will first collect data of each other’s positions and times using realtime technology. They will then construct charts of position vs. time, and use these to evaluate and make inferences from the data. Students will then interpret the charts, generate graphs, and use equations to describe the different types of motion in one dimension, including determining walking speed and average velocity.

Suggested Materials
Per Small Group or Pair:

- 15-meter space with a start and finish line labeled on the floor (high schools gyms are appropriate for this activity)
- 1 stopwatch
- 1 dowel rod (0.5–1.0 cm diameter, approximately 0.75–1 m long)
- Optional: 1 video camera

Procedure
1. For each trial, students should pick one person to perform the trial and then assign a second person to record the time with the stopwatch and a third to record the times on paper. If the option to tape the activity with a video camera is made also, then a fourth student will be needed to operate the camera.
2. A student steps up to the starting line once the timekeeper is ready.
3. When the timekeeper says go, the student begins walking in the manner described for the particular trial they are completing. (See the list of trials below.)
   - Important: For all but the “variable walk,” the speed with which students begin should be the speed for the whole walk—in other words students should not speed up or slow down.
   - Remind students that they are studying “one-dimensional motion,” so they should walk straight!
4. Student records the positions and times in the data table below.
5. On the number-line charts provided below the data table, students label the starting and ending points for trials. Students use the charts to evaluate the data, and so determine the distance traveled and the displacement (or “change in position”). They then record the results in their data tables.
6. Students repeat steps 2–5 for each of the four trials below. If the video camera has been used, Students may use time information provided by the camera as data for the activity.
7. Students will use equations for average velocity in one dimension to calculate the average speed and average velocity for each trial, and record the results in the data table. It is important that students note the differences between average speed and average velocity, and between distance traveled and displacement.
8. Later in the unit, as part of the debrief of this activity, students will generate the following graphs of their one-dimensional motion:
   i) Position vs. Time with both the Normal and Fast Walk on the same graph
   ii) Average Velocity vs. Time with both the Normal and Fast Walk on the same graph
   iii) Position vs. Time for the Turnaround Walk
   iv) Position vs. Time for the Variable Walk
   v) Average Velocity vs. Time for the Turnaround Walk
   vi) Average Velocity vs. Time for the Variable Walk

Trials to Conduct*: During this activity, students will perform four trials. Each has a different purpose in the debrief of the activity. The four trials are as follows:

1. **Normal Walk**: Each member of the group will be timed as they walk 15 m straight ahead from an initial position of 0 m to a final position of +15 m. They will walk at their own normal walking speed.
2. **Fast Walk**: This trial is the same as the normal walk except students will walk at what they consider to be a fast pace.
3. **“Turnaround” Walk**: For this walk, students are back to their normal walking speed except that this time, when they reach the final position of +15 m, they will immediately turn around and walk back to the initial position.
4. **“Variable” Walk**: For this walk, students will be trying to balance a dowel rod on their fingertip as they walk 15 m straight ahead from the initial to the final position. If they drop the dowel rod, they should simply pick it up, place it on their finger again, and continue from the point where they dropped it. The dowel rod will ensure that interesting things happen to their speed/velocity as they walk.

*Note: Some of these trials, particularly the variable walk, may be video recorded for analysis during the activity debrief.

Data for Different Walks

<table>
<thead>
<tr>
<th>Trial</th>
<th>Distance Traveled (m)</th>
<th>Displacement-Δx (m)</th>
<th>Time (s)</th>
<th>Average Speed (m/s)</th>
<th>Average Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal Walk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast Walk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Turnaround” Walk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Variable” Walk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Use the chart below to label \( x_i \) and \( x_f \), as well as \( t_i \) and \( t_f \), for the normal walk:

![Normal Walk Chart]

Use the chart below to label \( x_i \) and \( x_f \), as well as \( t_i \) and \( t_f \), for the fast walk:

![Fast Walk Chart]
Use the chart below to label $x_i$ and $x_f$, as well as $t_i$ and $t_f$, for the turnaround walk:

Use the chart below to label $x_i$ and $x_f$, as well as $t_i$ and $t_f$, for the variable walk:
Analysis and Conclusions

1. From the data in the charts, infer which trial had the greatest and smallest average velocities. On what information do you base your inferences?

(*The Fast Walk should have the greatest average velocity, because the displacement is the greatest for the shortest interval of time. The Turnaround Walk should have the smallest average velocity, because the displacement is zero, regardless of the time interval.*)

2. Evaluate the data for changes in position, using your charts of the data to answer the following questions:
   
i) What was the greatest displacement, and in which trial was it made?

   (*The greatest displacement (15 m, forward) will be for the Normal and Fast Walk trials, although if allowed to be completed, the Variable Walk trial should also have the same displacement.*)

   ii) What was the greatest distance traveled, and in which trial was it made? Does this answer differ from that of the previous question? If so, explain why there was a difference.

   (*Sample answer: The distance traveled in the Variable Walk was greatest (26 m). This was greater than the largest displacements, because distance depends on the total change in position, rather than the difference between the final and initial positions, which determines displacement.*)

   iii) What was the smallest displacement, and in which trial was it made?

   (*The smallest displacement (0 m) will be for the Turnaround Walk, although it is possible that the same displacement may occur for the Variable Walk.*)

   iv) What was the distance traveled in the trial with the smallest displacement? How did this distance compare to the distances in other trials? Explain why there is a difference in these values.

   (*The distance traveled in the Turnaround Walk (30 m) was greater than the distance in other trials (15 m), with the possible exception of the Variable Walk. This is because distance depends on the total change in position, rather than the difference between the final and initial positions, which determines displacement. Although the difference in the final and initial positions was zero for the Turnaround Walk, the distance was equal to the sum of the absolute values for the displacements (|+15 m| + |−15 m|), and so was double the distance of the Normal and Fast Walks.*)

3. Interpret the information in the charts and the data table to generate graphs of position vs. time for all four types of walk. Plot the data for the Normal Walk and Fast Walk on the same graph. How does representing the data on the graphs affect your answers to the previous questions?

(*The graph of position vs. time for the Normal and Fast Walks should show two diagonal lines rising from left to right. The Fast Walk line should have a greater slope than the Normal Walk line. The Turnaround Walk graph will show two diagonal lines; the first rising halfway to the right, and the second*
dropping back to the horizontal (time) axis. The graph of the Variable Walk will have many line
segments rising and falling, depending on the results of the walk. There should be no difference in the
answers obtained from the graph or the charts, but the graphs will probably make the evaluations
easier and less inclined to mistakes.)

4. Using the calculated speeds and velocities, generate graphs of average velocity vs. time for all four
types of walk. Plot the data for the Normal Walk and Fast Walk on the same graph. Were there any
significant changes in the speeds of the walkers? Were there changes in their velocities? Explain the
differences, if any, in your two answers.

(The graph of average velocity vs. time for the Normal and Fast Walks should show two horizontal
lines. The Fast Walk line should be above the Normal Walk line. The Turnaround Walk graph will show
two horizontal lines; the first above the horizontal (time) axis, and the second below the horizontal axis.
The graph of the Variable Walk will have many disconnected horizontal segments, depending on the
results of the walk. There should have been no change in the speeds at which the walkers moved,
which would be indicated by the lines being horizontal (no acceleration). The disconnected horizontal
lines at different levels in the graph, such as those in the Turnaround Walk or Variable Walk, indicate
changes in velocity based on changes in direction. Because speed does not depend on direction, no
changes in velocity due to speed should be observed.)
Inquiry and Nature of Science Skills in this Activity:

• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Time
    ▪ Distance
  o Use the appropriate format to record data:
    ▪ Table

• Interpret Data
  o Identifies and interprets patterns:
    ▪ Trends in data
    ▪ Analysis of data collected during an investigation

• Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Using data to determine the cause–effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
    ▪ Extrapolating results beyond the investigation
    ▪ Showing the application of the scientific concept or process being investigated

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

• Scientific Investigation
  o Scientific Data and Outcomes:
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ It is important in science to keep honest, clear, and accurate records.
Hands-On Activity
Conservation of Angular Momentum

In this activity, students will construct and observe spinning toys and investigate how different distributions of weight on the spinning toy affect the angular momentum, angular velocity, and rotational inertia of the spinner.

Materials
Per Student:
- safety goggles

Per Group:
- pencils, sharpened
- rubber bands
- paper plates (circular; small size)
- pennies
- tape
- scissors
- marker (thick-tipped; black or other dark color)
- ruler
- stopwatch or clock with seconds counter

Safety
Remind students to securely tape their pennies to their spinners before testing them; otherwise, pennies will fly off the spinners and create a safety hazard. Remind students to wear their safety goggles.

Introduction
To introduce the activity, review the definitions of the terms angular momentum, angular velocity, and rotational inertia. Discuss with students how each can be observed and calculated for a spinning toy such as a top:
- Angular velocity is how fast the top is spinning. It can be measured in rotations/second.
- Rotational inertia is related to the mass of the spinner and can be calculated by the formula rotational inertia = mass \times radius \times radius. The mass of a single penny is approximately 1.5 grams, and the radius is the distance between the center of the top and its edge. Point out that, in the spinners students will be making, the radius is the distance between the center of the disc and the weights placed on the disc (when weights are placed).
- Angular momentum is conserved because it is the product of angular velocity and rotational inertia.
Procedure

Distribute materials to each group.

1. Review the objective of the activity and the procedure, and answer any questions students may have.
2. Explain that students will construct spinners out of paper plates (edges trimmed off) and sharpened pencils poked through the center (suggest using the ruler to find the exact center of the disc). Rubber bands wound around the pencil above and below the center hole can help the paper disc stay in place. Students may draw a thick, dark line from the center to the edge of each spinner to count the number of rotations per second.
3. Have groups construct four spinners, all of the same size. Allow students to practice spinning their unweighted spinners before making their plan.
4. Have groups decide where on the pencil the disc should sit to produce the most reliable spin. Groups should then adjust all their spinners to have the identical “handle” length, noting the importance of testing only one variable at a time (in this activity, the distribution of weight, not the handle length). When each group is happy with its spinners, it should label them 1–4.
5. Explain that each group will test its four spinners using different arrangements of pennies. Investigations may test even distribution versus uneven distribution of pennies as well as the effect of different diameters (e.g., pennies close to center or close to edge).
6. Have students complete the “Key Question,” “Hypothesis,” and “Plan” sections of their student sheets. Remind students to run several trials for each spinner. You may wish to approve students’ plans to make sure they include finding the angular velocity and rotational inertia of each spinner design.
7. Have students complete the “Data,” “Conclusion,” and “Analysis and Conclusions” sections of the student sheet as they perform their group’s tests. Students should record the angular velocity and rotational inertia of each design in a data table such as the one below:

<table>
<thead>
<tr>
<th>Spinner</th>
<th>Trial 1 Angular velocity</th>
<th>Trial 2 Angular velocity</th>
<th>Trial 3 Angular velocity</th>
<th>Average angular velocity</th>
<th>Rotational inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. When they complete their tests and calculate rotational inertia for each spinner, students should answer the Analysis and Conclusions questions at the end of their student sheets.
Analysis and Conclusions

1. Which design produced the fastest spin? Sketch its design here, and label the direction of the torque.

   Sample Answer: Designs in which the pennies are near the pencil and evenly distributed around the center will produce the fastest spin. Torque of the spinning toy is perpendicular to the pencil.

2. How did friction affect the spin of the spinners? Where were the effects of friction greatest?

   Sample Answer: Friction caused the spinner to slow and eventually stop spinning. It was greatest between the tip of the pencil and the surface (floor, desk, etc.)—i.e., where objects were touching.

3. How was the angular velocity of the spinners related to their rotational inertia?

   Sample Answer: The spinner with the smallest radius had the smallest rotational inertia, and this spinner also had the greatest angular velocity. The spinner with the largest radius had the largest rotational inertia, and this spinner also had the least angular velocity.

4. How does this investigation demonstrate the conservation of angular momentum?

   Sample Answer: Angular momentum was conserved because as the radius decreased, rotational inertia also decreased, but angular velocity increased.

5. A figure skater begins a spin with his arms stretched straight out to the sides. After a few rotations, he pulls his arms in tight to his body.

   A. What do you predict will happen to the velocity of his spin? Explain your prediction.

      Sample Prediction: The skater’s spin will speed up as he pulls his arms toward his body. Decreasing the distance between his body and hands reduces the radius, which decreases his rotational inertia. Because of conservation of angular momentum, the decrease in rotational inertia will cause his angular velocity to increase.

   B. How did your spinning toy help you make your prediction?

      Sample Answer: The toy spun faster when I moved the pennies closer to the center (i.e., decreasing the radius). Similarly, the skater’s spin will be faster when he pulls all of his weight toward the center of his spinning body.

6. Make a mark on the outer edge of one of your spinners with your marker. Determine how many rotations the mark makes in 1 minute. Then, using that number and the radius of the spinner, calculate the mark’s angular velocity.

   Sample Answer: If the mark makes 5 rotations in 1 minute and the radius of the spinner is 10 cm, then according to the formulas, \( \omega = \Theta / t \) and \( \omega = 2\pi r \), the angular velocity would be \((2\pi(5)) / 60 = 0.52 \text{ rad/s}\)
7. How does this experiment demonstrate the difference between translational motion and rotational motion?

Sample answer: This experiment shows that while translational motion involves a body moving from one point in space to another, rotational motion involves a rigid body that remains in the same point in space even as it’s moving. The spinner toys made in this experiment show rotational motion rather than translational motion.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Engineering Solutions: The Egg Drop Challenge

Timing: one 90-minute class session

Objective(s):
Students will design a container for an egg to be dropped from different heights (1 m, 2 m, and 3 m) without cracking.

Safety Precautions:
Remind students to follow all general lab safety rules, wear closed-toe shoes and safety goggles, and not to eat or drink anything in the lab. Students should wear lab coats or aprons to protect their clothing from possible egg splatterings. Students should exercise caution when working with sharp objects, such as knives. Students should follow all instructions for disposal and cleaning of broken eggs and any other materials.

Materials:
Per group:
- cardboard
- cotton balls
- cotton swabs
- polystyrene foam (sheets and "peanuts")
- toy building sticks
- paper clips
- elastic bands
- string
- tape
- glue
- scissors
- knives
- pliers
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- Provide different kinds of materials so that students have sufficient variety for their designs. You may want to include even more items than those already listed.
- Provide research materials or websites to provide students with ideas about previous designs that have been developed. Students may then decide to develop an entirely new design or improve on an existing one.

Procedure

1. As a lab group, research past egg drop challenge designs, both those that have been successful and those that haven’t.
2. Students should select a criteria for what they want their design to do and develop the design as a group. During the development stage, be sure that students plan ahead so that the materials they need are either among those in the list or can be easily obtained.
3. If more or different materials are needed, require students to consult with a teacher for approval to use those materials.
4. Have each group member work on construction of a component of the device, then work as a group to construct the final product.
5. When testing the device, begin by placing the egg in or above the device at a distance of 1 meter above hard ground.
6. Have one group member drop the egg, another notice if it reaches the ground without cracking, and other members observe to see if the speed of the egg is slowed over a sufficient length of time. If the group has four members, assign the fourth person to observe any design flaws in the device and to note them for future improvements. Record all observations.
7. If the egg cracks when dropped from a 1-meter height, the design must be reassessed and improvements made or a new design developed and constructed before further testing is performed.
8. If the egg survives the drop from 1 m, test the device again by dropping the egg from a height of 2 m.
9. Repeat Steps 6–8 for a height of 3 m.
Analysis and Conclusions

1. What types of forces did your design exert on the egg? When the designed device was in use, how did the forces on the egg differ from those acting on an egg dropped from the same height without the device in place? [Sample answer: The design assured that forces were distributed as evenly on the egg as possible so that no one force on any side was large enough to cause the egg to crack. When the egg was dropped, the device exerted an upward force that was opposite the force of gravity and so, effectively, reduced the gravitational force.

2. How did your design affect the momentum of the egg? Did the design reduce the net force acting on the egg during the entire descent, or did it act upon the egg at some point near the ground? [Sample answer: The momentum of the egg was decreased during the descent. The smaller net force acting on the egg during the time of the entire descent was such that, when multiplied by the time during which it acted, it equaled the change in the egg’s momentum.]

3. Based on your answer to question 1, what do you estimate the maximum momentum of the egg to be during its descent? If other groups had designs similar to that of your group, compare your answer to the findings of the other group and draw a conclusion about the comparison. [Sample answer: The mass of the egg was approximately 60 g. If the egg is allowed to fall nearly to the ground without the device, it has a maximum momentum of 0.15 kg•m/s when dropped from 1 m, 0.31 kg•m/s when dropped from 2 m, and 0.46 kg•m/s when dropped from 3 m. The device exerted a force on the egg such that its maximum momentum was never larger than these values. These results were similar to, but not exactly like, those of other groups, suggesting that the most extreme conditions were the same for all groups testing their devices.]

4. At what maximum height did your design allow the egg to fall without cracking? [Sample answer: The egg was not damaged when dropped from heights of 1 m and 2 m. However, instability in the device caused the egg to fall too quickly when dropped from 3 m. This caused it to crack.]

5. What problems arose from your design? Was your group able to find ways to correct these problems? If so, how did the correction affect the maximum height from which the egg could be dropped without damage? [Sample answer: The device was too easily affected during descent by uneven force from the surrounding air, which caused tailspins. Improving the “wings” on the device by making sure they were nearly identical in size and orientation on the device made it more stable so that the egg could be dropped from a greater height without damage.]

6. Develop a mathematical model that explains conservation of momentum after the system you constructed collided with Earth. First, consider what the total momentum of the egg + Earth system is after the collision. Write the mathematical equation that can be used to model the conservation of momentum before and after the collision. Based on your model and your answer to #3 above, what was the maximum momentum of Earth just before the collision when the egg was dropped from 3 m? Given that Earth's mass is estimated to be 5.97 x 10^24 kg, calculate the velocity of Earth just before the impact with the egg. [Sample answer: After the collision, the egg + Earth system had a momentum of 0 kg•m/s, because the objects were not moving. The equation that models the conservation of momentum is: total momentum before = total momentum after Because the maximum momentum of the egg was 0.46 kg•m/s downward, the momentum of Earth just before impact must have been 0.46 kg•m/s upward. Given the mass of Earth, its velocity was 7.7 x 10^-26 m/s.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Recognize and develop testable questions that:
    - Can be answered with a science investigation or observational study
  - Develop:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting out trends and patterns in the data
  - Assessing the conclusion by:
    - Answering the testable question

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating a conclusion

- **Scientific Investigation**
  - Scientific Data and Outcomes:
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - Comparisons of data are not accurate when some of the conditions are not kept the same.
    - When similar investigations give different results, it often takes further studies to decide what is right.

- **Scientific Endeavor**
  - Characteristics of Science:
    - Scientific claims can be substantiated using data and observation.

- **Engineering and Technology**
  - Engineering Design:
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
    - Even a good design may fail even though steps are taken ahead of time to reduce the likelihood of failure.
Hands-On Lab
Marble Collisions

Timing: one 90-minute class session

Objective(s):
Students will investigate conservation of momentum by using a projectile marble to collide with a stationary target marble on a track suspended above the floor, and measuring the distances traveled by both marbles on the floor.

Safety Precautions:
Students should be careful not to let marbles roll away, and should be careful not to slip on marbles on the floor. Students should follow the rules of safe lab behavior previously agreed upon in class.

Materials:
Per group:
- 2—4 marbles of different colors and masses
- 2 plastic rulers with center groove, or a narrow track
- 1–2 books a few centimeters thick
- 1 roll masking tape (can be shared)
- A few large sheets of white paper
- A few sheets of carbon paper
- 1 meter stick
- 1 plumb bob

Per class:
- 1 balance

Teacher Preparation:
None required, except to gather supplies.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Begin by demonstrating the basic marble-collision procedure that students will follow:

1. Secure a ruler or track to the table top with masking tape. Position it so that one short edge of the ruler comes just to the table’s edge. Make sure to keep the tape out of the groove so that the marble can roll freely.
2. Stack books or blocks a few centimeters high on your desk or table.
3. Lay the second ruler down with one end on the stack of books or blocks and one end on the table so that it connects smoothly with the first ruler.
4. Use the tape to secure the second ruler to the table top. This will help fix the ruler with a slight downward flex so that it is nearly flat when it touches the table top.
5. Position one marble (the target marble) in the groove of the ruler at the table edge, so that the marble is as close to the edge as possible. Hold another marble (the projectile marble) in the groove of the inclined ruler at the top edge on the books or blocks.
6. Hang the plum bob from the point where the target marble rolls off the table. This will mark, at floor level, the point of origin for the first momentum vector.
7. Place the large sheet of white paper on the floor below the track, and place sheets of carbon paper (carbon side down) on the paper along the line of the track.
8. Ask for a couple volunteers to catch the marbles. Release the top marble and let it roll down the ramp. Have the volunteers catch the marbles after the first bounce.

Before releasing the marble, ask students to predict what they expect to happen. After the collision, ask the students about what they saw. Do they think that momentum was conserved in this collision?

Ask students the following questions:

- After the projectile marble has rolled down the track and is just about to strike the target marble, what is the direction of the total momentum of the system of two balls? *(It is in the direction of the projectile marble.)*
- What is the expression, in terms of the masses and velocities, for the total momentum of the two marbles just before collision? *(The target marble has no velocity or momentum, so the momentum of the system is the product of the mass and the velocity of the projectile marble.)*
- What is the expression, in terms of the masses and velocities, for the total horizontal momentum of the two marbles just after collision? *(The total momentum of the two marbles is equal to the initial momentum of the projectile marble just before collision.)*
- What happens to the total vertical component of the two marbles’ momentum from the moment...
before the collision to the moment the balls hit the floor? Is the vertical component of the momentum conserved? (The vertical component of the momentum of the two marbles changes from zero to a nonzero quantity. Therefore, vertical momentum is not conserved.)

- How can the momenta after the collision in the horizontal plane be compared without directly measuring the horizontal velocities of the marbles? (The horizontal momentum of each marble is directly proportional to the horizontal distance it travels.)

- Once you have the starting point (the position of the plumb bob) and the end points (the marks left by the carbon paper) for the target and projectile marbles after the collision, how will you find the momentum vectors graphically? (Connect the starting and end point of each marble on the white paper and draw the vector for its momentum. Use the rules for connecting the two momentum vectors to find the resultant. This vector represents the resultant horizontal displacement, velocity, and momentum of each marble, although the magnitude of the quantities differ by degrees of proportionality.)

- How can you find a quantitative value for the momenta of the two marbles? (Use the vectors to find the x- and y- components of each marble after collision, noting the positive and negative directions. Use equations of motion to calculate the horizontal velocities of each marble after collision, the multiply the mass of each marble by its horizontal velocity to calculate its horizontal momentum.)

Have students separate into groups of 3 or 4 to repeat your setup. Before they begin, have them write a summary of the procedure in their lab notebooks, including a labeled sketch of the setup. Ask students to predict what they expect to observe. Will momentum be conserved? If not, why not? Can they anticipate any sources of error?

To record the location of the falling marbles, have them tape the white paper to the floor and the carbon paper on top of the white paper. After each landing, students should mark the location on the white paper. For each trial, students should be careful to track only the location of the initial landing of the marbles.

Students should take measurements of the mass of their marbles and the height of the table top. They will also need to determine the horizontal distance each marble travels from the table edge to the landing spot. They can use a plum bob suspended from the drop point to mark the point of origin of the projectile and target marbles.

Have the students begin by releasing one marble without a second (i.e., without a collision). Have them release the marble 10 times or more.

Encourage students to make efforts to consistently release the first marble from the same spot on the ruler during all trials (with and without the second marble). Also encourage them to try and make sure the marbles are not moving before being released. You may want to encourage them to try and devise
methods for improving the consistency of their techniques, such as using a flat piece of cardboard from a notebook cover to hold the top marble in place at a specific spot on the ruler.

You may wish to have the students stop and analyze the one-marble data before moving on to the two-marble case. Have students analyze the data by first taking an average of the horizontal travel distance. They can then use what they know about two-dimensional projectile motion to relate the vertical and horizontal displacements to the initial horizontal velocity of the marble. They can then use the marble’s mass to calculate its momentum at the end of the ramp.

Next, have students repeat the two-marble collision as you demonstrated, taking 6 or more trials and noting the landing spots of both marbles. They can then repeat the data analysis to determine the average momentum of both marbles. Have them compare the initial momentum of the first marble (as determined in the one-marble trials) with the momenta of the two marbles after the collision.

A sample data chart will look like the following:

<table>
<thead>
<tr>
<th>Mass marble 1 (g)</th>
<th>3.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass marble 2 (g)</td>
<td>2.2</td>
</tr>
<tr>
<td>Table height (m)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial (one marble)</th>
<th>Distance traveled (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.61</td>
</tr>
<tr>
<td>2</td>
<td>0.59</td>
</tr>
<tr>
<td>3</td>
<td>0.65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial (two marbles)</th>
<th>Distance, marble 1 (m)</th>
<th>Distance, marble 2 (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>0.69</td>
</tr>
<tr>
<td>2</td>
<td>0.16</td>
<td>0.72</td>
</tr>
<tr>
<td>3</td>
<td>0.17</td>
<td>0.70</td>
</tr>
</tbody>
</table>

You may choose to give students time to review this procedure on their own or talk through it with them. If time permits, encourage the students to try variations on this procedure. Have them choose an independent variable to adjust. In their notebooks, have them identify constants, independent variables, and dependent variables, and have them write down their hypothesis for what will happen. For example, they can repeat the experiment with more than two marbles having different masses, different ramp heights, or different initial velocities.
Encourage groups to share their results with each other. Have the class discuss their investigations as a group and try and explain any similar patterns or differences in results.

Note that students will almost certainly not see momentum conserved. Along with friction and other systematic errors, a major reason is that the rolling of the marbles (rather than a frictionless sliding) complicates the collision. The final total momentum should be considerably less than the initial momentum. Have the students find the percentage difference between $p_f$ and $p_i$. Talk about friction and rotational energy as causes for the discrepancy. (Your class may not have covered angular momentum yet, but you may wish to guide students toward intuitively understanding that the marble has additional kinetic energy and momentum associated with its rolling.)

**Guided Inquiry**

Students can develop their own procedure and plans for collecting data on the basis of their knowledge of conservation of momentum demonstrations and the materials available. Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- What will be your independent and dependent variables?
- How will you vary the independent variables?
- How will you keep the constants constant?
- What method will you use to determine the velocities of the marbles before the collision?
- What method will you use to determine the velocities of the marbles after the collision?
- How do the horizontal displacements of the marbles relate to the horizontal velocities?
- Will vertical components of velocity matter in your momentum calculations? Why or why not?
- What sources of error do you expect to encounter in the investigation?

Have students separate into groups of 3 or 4. Before they begin, have them write a summary of the procedure in their lab notebooks, including a labeled sketch of their equipment setup. Ask students to summarize what they expect to observe. Will momentum be conserved? If not, why not? Can they anticipate any sources of error? Have students discuss their plans with you before beginning.

Guide students toward using the rulers to construct a track along which they can collide different marbles. Students will also need to develop a method for measuring the momentum of each marble. They may choose a variety of variables to investigate, but a simple procedure involving two marbles is as follows:

1. Secure a ruler or track to the table top with masking tape. Position it so that one short edge of the ruler comes just to the table’s edge. Make sure to keep the tape out of the groove so that the marble can roll freely.
2. Stack books or blocks a few centimeter high on your desk or table.
3. Lay the second ruler down with one end on the stack of books or blocks and one end on the
table so that it connects smoothly with the first ruler.
4. Use the tape to secure the second ruler to the table top. This will help fix the ruler with a slight
downward flex so that it is nearly flat when it touches the table top.
5. Let one marble roll down the ramp and bounce on the floor. Secure a few sheets of white
paper to the floor around that location. Place the carbon paper on top of the white paper.
6. Hang the plum bob from the point where the marble rolls off the track and table. This will
mark, at floor level, the point of origin for the marble’s horizontal displacement.
7. Start with one marble, and release this marble from rest at a chosen spot on the inclined ruler.
Mark the marble’s landing location on the white paper. Repeat this step for 10 trials.
8. Next, position a second marble in the groove of the ruler at the table edge so that the marble
is as close to the edge as possible. Hold the first marble in the groove at the top of the inclined
ruler at the position used in the one-marble trials.
9. Release the top marble and let it roll down the ruler, colliding with the stationary marble. Mark
the landing locations of both marbles. Repeat the previous step and this step for 10 trials.
10. Measure the mass of both marbles and the height of the table top. Determine the vertical
distance the marbles travel on each trial. Use these data to determine the average initial
horizontal momentum of the first marble (using the one-marble data) and the average final
horizontal momenta of the two marbles (using the two-marble data).

A sample data chart will look like the following:

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<td>0.70</td>
</tr>
</tbody>
</table>

If time permits, encourage students to try variations on their first trials. Have them choose an
independent variable to adjust. In their notebooks, have them identify constants, independent variables,
and dependent variables, and have them write down their hypothesis for what will happen. For example, they can repeat the experiment with more than two marbles having different masses, different ramp heights, or different initial velocities.

Encourage groups to share their results with each other. Have the class discuss their investigations as a group and try and explain any similar patterns or differences in results.

Note that students will almost certainly not see momentum conserved. Along with friction and other systematic errors, a major reason is that the rolling of the marbles (rather than a frictionless sliding) complicates the collision. The final total momentum should be considerably less than the initial momentum. Have the students find the percentage difference between $p_f$ and $p_i$. Talk about friction and rotational energy as causes for the discrepancy. (Your class may not have covered angular momentum yet, but you may wish to guide students toward intuitively understanding that the marble has additional kinetic energy and momentum associated with its rolling.)

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Did you find that, on average, momentum was conserved? Did you see an increase or decrease in momentum after the collision? Compare your answer to other groups’ findings and draw a conclusion about the comparison. **No, momentum always decreased.** Other groups saw the same thing, so there must be something about the procedure or the set-up that causes momentum to be “lost” somewhere.

2. Identify some possible sources of error in your experiment. Can you think of ways to improve the experimental technique? **There were lots of error sources. They included 1) not always releasing the marbles from the same spot, 2) the marbles rolling and not sliding, 3) friction between the marbles and the track. Improvements might include using a frictionless track, such as an air track. Also, we could try to construct a device that would hold each marble in place at a specific location.**

3. What were the basic physics relationships and concepts that you used to determine the conservation of momentum in this lab? **The equations describing the motion of a falling object in two dimensions were used to find the initial horizontal velocities of the marbles as they left the edge of the table. These velocity values were then used with the measured masses and the definition of momentum to compute the initial and final momenta of the system.**

4. List another question that your experiment suggested that you would like to test. **I would like to know what happens with three or more marbles on the track. I would like to use a very heavy marble and a very light marble and see what happens. I would like to use rubber balls, ball bearings, or something besides marbles.**
Inquiry and Nature of Science Skills in this Lab:

• Identify Questions
  o Develop a question that:
    ▪ Asks a question about a specific science concept or process

  o Recognize and develop testable questions that:
    ▪ Require the changing of one variable at a time
    ▪ Can be answered with a science investigation or observational study

  o Develop predictions/hypotheses that:
    ▪ State what may happen in an investigation based on prior knowledge or experience (prediction)
    ▪ State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

• Design Investigations
  o Design and conduct investigations using:
    ▪ Fair test—changing only one variable at a time makes comparisons valid
    ▪ Independent variable—the one variable the investigator chooses to change
    ▪ Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    ▪ Constant—identify variables that must remain unchanged
    ▪ Multiple trials—repeated tests with the same variables to check for the variability of results

  o Explain the investigative processes by:
    ▪ Describing the logical sequence that was used to conduct the investigation
    ▪ Properly citing all equipment and materials
    ▪ Describing it so that it can be easily repeated by a fellow scientist

  o Practice lab safety by:
    ▪ Following lab safety procedures
    ▪ Recognizing safety equipment and materials and knowing their proper use
    ▪ Incorporating laboratory safety practices into the investigation design

• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Length/distance/depth
• Mass

  o Choose appropriate tools to conduct an investigation:
    ▪ Ruler/tape measure
    ▪ Meter stick
    ▪ Balance
    ▪ Other laboratory equipment

  o Use senses to observe:
    ▪ Kinesthetic (balance, position)

  o Use the appropriate format to record data:
    ▪ Table
    ▪ Writing (journal, worksheet, electronic text)
    ▪ Sketch
    ▪ Diagram

• Interpret Data

  o Identify and interpret patterns using:
    ▪ Trends in data
    ▪ Repeating physical or data patterns
    ▪ Tables and graphs
    ▪ Analysis of data collected during an investigation

• Evaluate Evidence

  o Draw and support a conclusion by:
    ▪ Using data to determine the cause–effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
    ▪ Comparing results to hypothesis
    ▪ Answering the testable question
    ▪ Extrapolating results beyond the investigation
    ▪ Identifying alternative explanations
    ▪ Examining how investigations can be improved
    ▪ Formulating scientific explanations/arguments
    ▪ Explaining how technology can be used to enhance the investigation

• Communication in Science

  o Report results using:
- Peer presentation
- Written report
- Scientific illustration with proper labeling
- Scientific explanations/arguments
- Table/graph showing data

• Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Identifying alternative explanations
    - Analyzing scientific explanations
    - Analyzing scientific arguments

• Patterns and Systems
  - Patterns and Change:
    - Mathematical patterns help to predict future events and describe change in systems.
  - Systems:
    - A system, such as the human body, is composed of subsystems.
    - No matter how substances within a closed system interact with one another or how they combine or break apart, the total mass of the system remains the same.
    - In some systems, it may not always be possible to predict accurately the result of changing some part or connection.
    - As the complexity of any system increases, gaining an understanding of it depends on summaries, such as averages and ranges, and on descriptions of typical examples of that system.

• Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
    - Scientific investigation results in things we know and things we do not know.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    - Scientific investigation leads to more questions.
Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.

Scientific investigations lead to the development of scientific explanations.

- Scientific Data and Outcomes:
  - Scientific claims are based on data and reliable scientific sources.
  - Collecting and analyzing data is the best way to understand a changing pattern.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data take much longer (e.g., the growth of a tree).
  - Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
  - It is important in science to keep honest, clear, and accurate records.

When similar investigations give different results, it often takes further studies to decide what is right.

- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
    - An important part of science is the critical review and analysis of any idea or conclusion.
    - A law is a description of a specific relationship under given conditions in the natural world.
Hands-On Lab
Atomic Spectroscopy

Timing: one 90-minute class session

Objective(s):
Students will see the spectra of wavelengths of visible light in the output from discharge tubes. Students will use the Rydberg equation to explain the presence of certain wavelengths in those spectra.

Safety Precautions:
Use precautions appropriate to using electrical equipment, and operating in a darkened room.

Materials:
Per group:
• discharge tube (H, He, Ne, Ar) with power supply
• hand-held visible spectrometer

Teacher Preparation:
• Gather materials in advance of students performing the lab.
• Give different teams discharge tubes that contain different gases, and have them repeat their observations by looking at light from other teams’ discharge tubes. Ultimately, all teams should observe the light from discharge tubes containing all gases (i.e., H, He, Ne, Ar) that are available, and sketch all spectra.
• If different discharge tubes use the same gas, teams using either tube should look at the light from each tube, to satisfy themselves that properties of the emitted light arise due to the identity of the gas in the tube.
• If incandescent bulbs, fluorescent tubes, or compact fluorescent bulbs are operating in the room, have students look at these operating lights, to learn their associated visible light spectra.

Procedure
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Instruction**

Students should be familiar with the concepts of the electromagnetic spectrum and the spectrum of visible light. Explain to them why certain gases, when excited, produce visible light photons. Electrons in these gases absorb energy and move between energy levels above the nucleus, releasing a photon when they fall from a high energy level to one with lower energy. These photons produce a visible spectrum that is characteristic to a given element.

**Part 1: Observation**

1. Dim lights in room.
2. Look through hand-held visible spectrometer at area near (inactive) discharge tube, and note any visible light spectrum recorded by the spectrometer.
3. Activate discharge tubes.
4. One member of each team should look at the light from the tube, and describe the light spectrum to other team members, who will sketch the spectrum in their notebooks.
5. Rotate possession of spectrometer, and repeat Step 4 until every team member has looked at light from the discharge tube.
6. If different teams have discharge tubes that contain other gases (i.e., H, He, Ne, Ar), have members of each team observe light from each other team’s discharge tube until all have observed and sketched the visible light spectrum from discharge tubes that contain all available gases.
7. Once all teams have looked at light from discharge tubes containing all available gases, bring lights back up in room.

**Part 2: Analysis**

Explain to students about how electrons in each specific atom absorb only certain wavelengths, so that \( E = h \nu \) will provide enough energy to move an electron between energy levels. The energy of an electron is:

\[
E = \frac{R}{n^2}
\]

where \( R = -13.6 \text{ eV} \) is the ground state energy, \( n = 1 \) is a ground state, and increasing \( n \) moves the electron to higher and higher energy levels. An unbound electron has infinite \( n \) and zero energy, for it has escaped from the potential well of the atom.
If an electron absorbs a photon of frequency $\nu$, it gains energy and moves from one level to another. The amount of energy absorbed is $E = h\nu$. If the electron emits the photon and falls back to the lower level, the photon has the same energy and the same frequency. The energy of the emitted photon is the energy difference between two energy levels. Mathematically, this is:

$$E_{\text{photon}} = R\left(\frac{1}{n_2^2} - \frac{1}{n_1^2}\right)$$

This is the Rydberg equation, and varying values of $n_2$ and $n_1$, with $n_2 > n_1$, give photon wavelengths that may or may not fall in the visible light spectrum.

The figure above shows several wavelengths that come from the excited hydrogen atom. The Lyman series, which has electrons falling to the ground state with $n_1 = 1$, produces ultraviolet photons with high frequencies and short wavelengths. The Paschen series, in which electrons fall to $n_1 = 3$, produces infrared photons with low frequencies and long wavelengths. Only the Balmer series, in which electrons fall to $n_1 = 2$, produces visible light, in the wavelengths that are shown.

If your students have sketched a hydrogen emission spectrum, compare their estimates of the emitted wavelengths to the calculated wavelengths of the Balmer series in Figure 1. If your students sketched emission spectra from helium, compare their wavelength estimates to the wavelengths for each element in Chart 1 below. Neon and argon have very detailed spectra, so discuss colors observed in each and relative brightness of colors, rather than specific wavelengths.
Emission spectrum of the excited helium atom

*Note that the alpha line is the strongest, brightest line in the emission spectrum.*

<table>
<thead>
<tr>
<th>Wavelength, nm</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>439</td>
<td>Weak</td>
</tr>
<tr>
<td>443</td>
<td>Weak</td>
</tr>
<tr>
<td>447</td>
<td>Strong</td>
</tr>
<tr>
<td>471</td>
<td>Medium</td>
</tr>
<tr>
<td>492</td>
<td>Medium</td>
</tr>
<tr>
<td>501</td>
<td>Strong</td>
</tr>
<tr>
<td>505</td>
<td>Weak</td>
</tr>
<tr>
<td>588</td>
<td>Strong</td>
</tr>
<tr>
<td>668</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Guided Instruction

Students can be encouraged to use the visible light spectrometer to look at the output of various lighting systems. The slight differences in output spectra can help students identify the individual gases that are used in these systems. Technical specifications of these systems, if available, can tell students details about these output spectra, and give a point of reference that they may compare against their observations.
Analysis and Conclusions

1. The hydrogen emission spectrum has four lines of visible light. Why is the helium spectrum more complex, with nine lines? Helium has two electrons, to hydrogen’s one. This means more transitions are possible in the helium atom, and photon frequencies from more of them are in the visible light spectrum.

2. Why are the emission spectra of neon and argon so much more complicated than either helium or hydrogen? Neon has ten electrons, and argon has eighteen. More electrons mean more transitions can be made between energy levels, so the emission spectra of either are much more complicated than that of hydrogen or helium.

3. Photons in the visible light spectrum have wavelengths of 380 nm (violet) up to 750 nm (red). Use \( h = 4.136 \times 10^{-15}\) eV \( \cdot \) s in \( E = h\nu \) and \( R = -13.6\) eV in the Rydberg equation to show that an electron falling from \( n = 2 \) to \( n = 1 \) in the hydrogen atom will produce a photon in the ultraviolet region. One nanometer (nm) is \( 10^{-9} \) m.

\[
h\nu = R \left( \frac{1}{2} - \frac{1}{1} \right) = -\frac{3R}{4}
\]

\[
\lambda = \frac{c}{\nu} = \frac{c}{(-3R/4h)} = \frac{-4hc}{3R}
\]

\[
= [-4(4.136 \times 10^{-15} \text{ eV} \cdot \text{s})(3.0 \times 10^8 \text{ m/s}) / (3 \times (-13.6 \text{ eV}))] \times (10^9 \text{ nm/1 m})
\]

\[
= 122 \text{ nm}
\]

This is a shorter wavelength than violet, so it is in the ultraviolet region.

4. Show that an electron falling from \( n = 4 \) to \( n = 3 \) in the hydrogen atom will produce a photon in the infrared region.

\[
h\nu = R \left( \frac{1}{4} - \frac{1}{3} \right) = -\frac{7R}{144}
\]

\[
\lambda = \frac{c}{\nu} = \frac{c}{(-7R/144h)} = \frac{-144hc}{7R}
\]

\[
= [-144(4.136 \times 10^{-15} \text{ eV} \cdot \text{s})(3.0 \times 10^8 \text{ m/s}) / (7(\times (-13.6 \text{ eV})))] \times (10^9 \text{ nm/1 m})
\]

\[
= 1877 \text{ nm}
\]

This is a longer wavelength than red, so it is in the infrared region.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design or conduct field studies using:
    - Survey – collects multiple data points at one point in time.
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable – the one the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable.
  - Practice lab safety by:
    - Following lab safety procedures.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system) to accurately measure:
    - Visible Light Spectra
  - Uses Senses to Observe:
    - Seeing (color, shape, size, texture, motion)
  - Chooses appropriate tools to conduct an investigation
    - Hand-held visual spectrometer
  - Uses the appropriate format to record data:
    - Sketch

- **Interpret Data**
  - Identifies and interprets
    - Analyzes data collected during an investigation

In this lab, students will demonstrate the following Nature of Science Skills:

- **Patterns and Systems**
  - Patterns and Change
    - Patterns in nature may be simple repeating patterns or complex growing and changing patterns

- **Scientific Investigation**
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society
    - It is important in science to keep honest, clear, and accurate records.

- **Scientific Endeavor**
  - Characteristics of Science
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
A Different Shape of Magnet

Timing:
Directed Inquiry – 70–90 minutes
Guided Inquiry – 90 minutes

Objective(s):
Students will learn about the magnetic fields around bar magnets and around horseshoe magnets.

Safety Precautions:
Students should wear closed-toe shoes for all labs. Students should not bring either magnet into close proximity to a credit card or any other card with a magnetized strip.

Materials:
Per group:
- Two bar magnets
- One horseshoe magnet
- Iron filings
- Paper plate or white craft paper
- Flat piece of iron or steel

Teacher Preparation:
Teachers should assemble materials before exercise begins. Note that iron filings may best be put in resealable plastic bags. Teacher should show students how to spread filings thinly on the plate or the white craft paper, and how to use magnets to clean them up and return them to the bags.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students' activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Introduce this exercise by noting that magnets typically have poles, such as the poles marked on the bar magnets. The horseshoe magnets have poles too, although these magnets are bent into a horseshoe shape to produce a strong magnetic field. In today's exercise, students will see the vector fields around each magnet.

**Procedure:**

1. Note that the ends of the bar magnets are either attracted to each other, or repulsed. One end of a magnet is attracted to one end of the other magnet, and repulsed by the end of the other magnet.

2. Repeat Step 1 with the end of one bar magnet and the two ends of the horseshoe magnet. Note results.

3. Open resealable bag with iron filings, and spread filings thinly and evenly on the plate or the white craft paper.

4. Lay bar magnet flat on lab table, and place paper plate or craft paper above magnet. Sketch patterns that are observed in the filings on the plate.

5. Remove bar magnet and even out filings on plate or craft paper.

6. Repeat Step 4 with two bar magnets with like poles pointed together. Depending on how close the magnets are, some team members may have to hold magnets in place.

7. Repeat Step 5.

8. Repeat Step 4 with two bar magnets with unlike poles pointed together. Depending on how close the magnets are, some team members may have to hold magnets in place.

9. Repeat Step 5.

10. Repeat Step 4 with a horseshoe magnet.
11. Lift plate or sheet of white craft paper, and turn horseshoe magnet so ends point up into plate or white craft paper. Sketch patterns that that are observed in the filings on the plate or paper.

12. Even out filings on the plate or paper.

13. Repeat Steps 4 through 7 with flat piece of iron or steel between either magnet on lab table.

**Guided Inquiry**

Your students may wish to repeat Steps 5 through 8 to show the magnetic field interactions between poles of either bar magnet and the horseshoe magnet. Have them devise procedures to do this.

Step 13 illustrates that a flat piece of iron or steel will magnetize, and the magnetic field will not penetrate it. Your students may wish to repeat Step 13 with different flat materials, such as paper, cardboard, or even textbooks. Have them devise procedures whereby they can gauge, qualitatively, if the magnetic field of either magnet will penetrate these (nonmagnetizeable) materials. If either material is thin, the magnetic field will penetrate it and affect the filings. Students may also wish to see how much paper, cardboard, or even textbooks the magnetic field can penetrate. Have them devise procedures whereby they learn what thickness of these materials can block the field.

If flat pieces of nonmagnetizeable metal are available, have students devise procedures to find what thickness of this metal will block the field. This thickness will be thinner than the thickness of paper or cardboard that was required. Explain to your students about how a lesser thickness of more dense material can block the magnetic field as effectively as a larger thickness of less dense material.

Your students may wish to gauge the strength of each magnet by picking up strings of paper clips or other ferromagnetic materials. Have them devise procedures whereby they can learn how much material can be lifted by either design of magnet.

In Steps 4 through 11, your students will see the vector field around each magnet, as shown by the filings when the magnet is beneath the plate. Rotating the horseshoe magnet in Step 11 will produce a strong response in the filings. Explain to your students that horseshoe magnets have the shape they do in order to bring their two poles close together and create a strong magnetic field, stronger than a bar magnet of the same material and size would have.
Analysis and Conclusions:

1. What patterns do you see in the iron filings when you set the plate or craft paper on top of the bar magnet, or on top of the flat horseshoe magnet? What do you see when two magnets are near each other under the plate or craft paper? What do you see when you hold the ends of the horseshoe magnet against the bottom of the plate or craft paper?

   **Sample Response:** For the flat bar magnet, we see magnetic field lines that move from one pole down to the other. For two bar magnets, we see magnetic field lines moving away from each other for like poles, and toward each other for unlike poles. For the horseshoe magnet, we see magnetic field lines that move between its poles. If we tilt the horseshoe magnet up normal to the plate or craft paper, we see these lines displayed even more clearly in the iron filings.

2. Why don’t you see any patterns in the iron filings when the bar magnet is placed under the flat piece of iron or steel under the plate or craft paper? Do you see any patterns when the ends of the horseshoe magnet are placed under the flat piece and under the plate or craft paper?

   **Sample Response:** Iron and steel are ferromagnetic materials that can be magnetized by contact with a magnet. Due to this, we will not see patterns in iron filings on a plate or craft paper placed above a flat piece of iron or steel with either magnet placed beneath it.

3. Why is the same end of a bar magnet attracted to one end of the other bar magnet, and repelled by its other end?

   **Sample Response:** The north or south poles of a magnet are attracted to, or repelled by, the south or north ends of another magnet, respectively.

4. Why is the same end of a bar magnet attracted to one end of the horseshoe magnet, and repelled by the other end?

   **Sample Response:** A horseshoe magnet also has north and south poles, as does a bar magnet. Like poles repel, and unlike poles attract, the same as with bar magnets.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - Asks a question about a specific science concept or process.
  - Recognize and develop testable questions that
    - Can be answered with a science investigation or observational study.

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Survey: compares changes in data points over time.
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Control (control group) - used for comparison in which the independent variable is not changed
  - Make or use models that
    - Function exactly like or similarly to the real thing.
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and Use SI units to accurately measure temperature
  - Uses senses to observe: Seeing
  - Uses a chart and a graph to record data.

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Comparing results to hypothesis
    - Answer the testable question

**Nature of Science questions:**

- **Patterns and Systems**
  - Patterns and Change
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
  - Scientific Data and Outcomes
    - Some data can be collected in a short period of time (e.g. motion of a rolling ball) and some data takes much longer (e.g. the growth of a tree).
    - It is important in science to keep honest, clear, and accurate records.
Hands-On Lab
Fundamental Forces and Radioactivity

Timing: one 90-minute class session

Objective(s):
Students investigate radioactivity of a variety of samples and combinations of samples. Students will ask an experimental question and design a protocol to test a hypothesis that answers the question. They will analyze the data. Students will design investigative procedures, including selecting appropriate equipment, to perform the steps of both the Directed and Guided Inquiry portions of this lab.

Safety Precautions:
Students should not eat or drink in lab, especially the test samples. Note that none of the suggested samples have dangerous levels of radioactivity.

Materials:
Per pair or group:
- 1 Geiger counter (may be shared between groups if needed)
- 1 ruler
- 1 stopwatch or clock
- Variety of small samples of items (may be shared between groups), possibly including:
  - Granite or other rock
  - Lead blocks
  - Brick pieces
  - Bananas and other potassium-rich food items such as kidney beans and potatoes
  - Smoke detector, “ionization” type
  - Potassium chloride
  - Cell phone
  - Old tube television or computer monitor
  - Other assorted objects from daily life
Per class:
- balance

Teacher Preparation:
You may need some time to track down various samples. Note that the selection should include items that are somewhat radioactive, such as bananas or No-Salt, and items that are not at all radioactive, such as lead pieces. (None of the suggested samples have dangerous levels of radioactivity.) Also, prepare copies of the Student Investigation Sheet for each student.

You may want to include extra equipment that is non-essential to completing the lab, so students have the opportunity to consider which equipment they would select and why.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Begin by reminding the class of the connection between the weak nuclear force and radioactivity. Then, explain that students will investigate radioactivity by using a Geiger counter. Demonstrate the use of a Geiger counter by measuring radioactivity from a chosen sample item. (If you wish, you might keep the identity of the sample hidden by placing it in a very large envelope and have students blindly push the Geiger counter into the envelope for a reading—the sample would have to be something that would not spill. An activity for the lab would then be for the students to attempt to determine the material in the sample based on measurements.) Demonstrate briefly how the measurement of the detector can depend on distance from the source and orientation of the source relative to the detector. Discuss with the students what the clicks of the detector signify. (Each radioactive decay of an atom in the source releases particles that the Geiger counter detects; each click of the counter indicates one decay has occurred.)

Explain that students will measure radioactive rates, meaning they will measure the number of clicks in a certain time. Dividing the number of clicks by the time gives a rate. Explain that by measuring for a long period of time, they can calculate an average rate.

Have the students work in groups. Each group will first measure the radioactivity of a variety of samples. You can let the groups choose their samples, or you may wish to give them specific items. Encourage students to measure a collection of different sources. Also instruct them to measure the background levels by letting the detector run with no sources nearby.
Have students record data in a table like this example:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Detector orientation:</td>
<td>Pointed straight at sample, sample at 10 cm distance</td>
</tr>
<tr>
<td>Time of measurement: (s)</td>
<td>120</td>
</tr>
<tr>
<td>Counts:</td>
<td>310</td>
</tr>
<tr>
<td>Rate: (decays/s)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Next, have the students choose an experimental question on the basis their findings so far. You can let them choose freely or provide a list of options. Instruct the students that the dependent variable in their study will be the radioactive rate of a sample. Ask them to choose one independent variable. Sample questions might include:

- Does the size or mass of a sample of material affect the radioactivity?
- How does the radioactivity of combinations of samples relate to the individual radioactivities?
- Do more complicated tech devices, such as television monitors or cell phones, have radioactivity that depends on the location of the counter or on whether the device is operating?
- How does radioactivity depend on distance from a source?
- What sort of nonradioactive materials make good screens? (compare lead and paper for instance)
If time permits, students should investigate multiple questions. Make sure groups discuss their question and their protocol with you before beginning. Sample data might look like the following:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector orientation</td>
<td>Pointed straight at source, 10 cm away</td>
</tr>
<tr>
<td>Time of measurement (s)</td>
<td>120</td>
</tr>
<tr>
<td>Sample 1 mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Sample 2 mass (g)</td>
<td>90</td>
</tr>
<tr>
<td>Sample 1 counts</td>
<td>308</td>
</tr>
<tr>
<td>Sample 2 counts</td>
<td>615</td>
</tr>
<tr>
<td>Sample 1 rate (decay/s)</td>
<td>2.6</td>
</tr>
<tr>
<td>Sample 2 rate (decay/s)</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Have students prepare a presentation of their data by using a graph or bar chart. Each student should prepare a written report of their procedure and findings, including an answer to their testable question. Groups should then present their results to the class. As a class, discuss any discrepancies in measurements between groups. If you have kept your original sample secret, ask the class to try and identify the sample.

**Guided Inquiry**

Students can develop their own plans for collecting data, based on their understanding of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What will be your independent and dependent variables?
- How will you adjust your independent variable, and how many different values will you use?
- Will you perform multiple trials?
- What tools will you use to make your measurements?
You may wish to begin by demonstrating to students how the Geiger counter works, or you may leave it to the students to play with it or possibly research it online. Suggest to students that they should perform two general investigations. One will be a survey of the radioactivity of a wide variety of sample materials. This survey will give them a chance to get familiar with the Geiger counter and how to use it. They may also be surprised to discover that certain items (such as bananas) are more radioactive than they thought, and others (such as cell phones) are not. Have each group set up a data table to record their results.

A data table might look like:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Detector orientation:</td>
<td>Pointed straight at sample, sample at 10 cm distance</td>
</tr>
<tr>
<td>Time of measurement: (s)</td>
<td>120</td>
</tr>
<tr>
<td>Counts:</td>
<td>310</td>
</tr>
<tr>
<td>Rate: (decays/s)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

The other study should be a focused study of a specific question. Suitable questions include

- Does the size or mass of a sample of material affect the radioactivity?
- How does the radioactivity of combinations of samples relate to the individual radioactivities?
- Do more complicated tech devices, such as television monitors or cell phones, have radioactivity that depends on the location of the counter or on whether the device is operating?
- How does radioactivity depend on the distance from a source?
- What sort of nonradioactive materials make good screens? (compare lead and paper for instance)
If time permits, students should investigate multiple questions. Sample data for the question, how does the mass of the sample affect the rate, might look like the following:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector orientation</td>
<td>Pointed straight at source, 10 cm away</td>
</tr>
<tr>
<td>Time of measurement (s)</td>
<td>120</td>
</tr>
<tr>
<td>Sample 1 mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Sample 2 mass (g)</td>
<td>90</td>
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</tr>
<tr>
<td>Sample 1 rate (decays/s)</td>
<td>2.6</td>
</tr>
<tr>
<td>Sample 2 rate (decays/s)</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Have each group decide on a question (or questions) and prepare a protocol for testing. Have them explain their procedure to you before they begin. Make sure students include a procedure for measuring the “noise” or background levels of radiation. Also, ask students to consider how they will present their data (a graph of radioactivity versus sample mass for instance). Each student should prepare a written report of their procedure and findings, including an answer to their testable question. Have each group present their findings to the class.

Have the class discuss any discrepancies in measurements between groups that studied similar questions.
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How do your results compare to the results of another group that made a similar measurement? Can you explain any differences? Our results were similar, but they found more counts. This may be because they had a slightly larger sample, or their counter was closer to the sample.

2. What result would you expect if you placed all the samples together in a small box and measured the radioactivity? Would the arrangement of the samples in the box affect the result? Explain your answer. All the samples together would give a higher count than one sample alone. The result would depend on the arrangement, though. For example, if the lead block ended up on the side of the box nearest to the detector, then the measured radioactivity would be very low.

3. Did you encounter any sources of error in your measurements? What could you do, or what did you do, to account for these errors? How could you improve the experimental procedure to cut down on errors? One error came from the radiation of the bricks in the school walls. We accounted for this by leaving the detector on, with no samples nearby. We measured a value for average clicks per minute and subtracted that from our other measurements. We could cut down on error by surrounding the sample and detector with a screen like a box made of lead.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct investigations using:
    - Fair Test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent Variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
    - Sample (if needed)—a portion of the affected elements in an investigation used to extrapolate what would have happened to a larger set of elements
    - Multiple Trials—repeated tests with the same variables to check for the variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
• Mass
• Time

• Choose appropriate tools to conduct an investigation:
  • Ruler/tape measure
  • Meter stick
  • Clock/stopwatch
  • Scale
  • Other laboratory equipment

• Use senses to observe:
  • Hearing (pitch, volume, reflection, direction)
  • Kinesthetic (balance, position)

• Use the appropriate format to record data:
  • Table
  • Graph
  • Chart
  • Writing (journal, worksheet, electronic text)

• Interpret Data
  • Sort and classify using scientific reasoning by:
    • Sorting objects, substances, and organisms by characteristic
    • Applying a classification scheme to objects, substances, or organisms
    • Developing a classification scheme for objects, substances, or organisms

  • Identify and interpret patterns by using:
    • Trends in data
    • Repeating physical or data patterns
    • Graphed data points
    • Tables and graphs
    • Analysis of data collected during an investigation

• Evaluate Evidence
  • Draw and support a conclusion by:
    • Using data to determine the cause–effect relationship observed in the investigation
    • Reporting trends and patterns in the data
    • Comparing results to hypothesis
    • Answering the testable question
    • Extrapolating results beyond the investigation
    • Identifying alternative explanations
    • Examining how investigations can be improved
    • Formulating scientific explanations/arguments
    • Explaining how technology can be used to enhance the investigation
• Communication in Science
  o Report results by using:
    ▪ Peer presentation
    ▪ Written report
    ▪ Scientific explanations/arguments
    ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

• Patterns and Systems
  o Patterns and Change:
    ▪ Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    ▪ Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    ▪ Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    ▪ Some small changes can be detected by taking measurements.
    ▪ Things that change may do so in steady, repetitive, or irregular ways.

  o Systems:
    ▪ A system, such as the human body, is composed of subsystems.
    ▪ Some systems (such as heating or cooling systems) have feedback mechanisms that serve to keep changes within specified limits.
    ▪ As the complexity of any system increases, gaining an understanding of it depends on summaries, such as averages and ranges, and on descriptions of typical examples of that system.

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ New observations should be made when there is a disagreement among initial observations.
    ▪ When a scientific investigation is repeated, a similar result is expected.
Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.

- **Scientific Data and Outcomes:**
  - Scientific claims are based on data and reliable scientific sources.
  - Collecting and analyzing data are the best way to understand a changing pattern.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data take much longer (e.g., the growth of a tree).
  - Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
  - It is important in science to keep honest, clear, and accurate records.
  - When similar investigations give different results, it often takes further studies to decide what is right.
  - Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

- **Scientific Endeavor**
  - Characteristics of Science:
    - An important part of science is the critical review and analysis of any idea or conclusion.

- **Engineering and Technology**
  - Uses of Technology:
    - Human beings have made tools and machines, such as X rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
Exploration Teacher Guide: Fundamental Forces

Overview

Understanding the nature and interactions of the four fundamental forces is very important to analyze the creation and the behavior of our universe. The four fundamental forces are strong, weak, electromagnetic, and gravitational forces. In this Exploration, students compare and analyze two commonly discussed fundamental forces, which are electric and gravitational forces.

Student Learning Objectives

- Compare the electric and gravitational force between particles like protons, electrons, and neutrons.
- Analyze the effect of the charge of the two bodies on the electric force between them.
- Analyze the effect of the mass of the two bodies on the gravitational force between them.
- Investigate the variation in both electric and gravitational forces based on the distance between them.
- Observe the direction of the electric and gravitational forces acting between the two particles.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, the students compare the electric and gravitational forces between two particles. They can drag two particles from the Select Particle section and drop them to the Particle 1 and Particle 2 sections. The students can select the same particle as both particle 1 and 2 or select two different particles. As soon as a particle is placed, its mass and charge are displayed. The students can select the distance between the two particles using the Select Distance slider.

Once the students click on the Start button, the values of electrostatic and gravitational forces between the two selected particles are displayed. Arrows representing the directions of the two forces are also displayed. They can use the buttons in the Interactive Key section to observe the arrows for individual forces. The students can use the Reset button to undo what they have done and observe electric and gravitational forces between different particles, at different distances.
The Tracker tab displays a summary of the values for all the runs. Mass and charge of the selected particles are displayed. The students can also compare the values of electrostatic and gravitational forces based on the selected distance between them.

**Answers to Questions in the Student Worksheet**

1. Compare the units of the constant of proportionality for gravitational force and electric force.

   **Answer:** Constant of proportionality for gravitational force is G and its unit is m²/N·kg². Constant of proportionality for electric force is k and its unit is m²/N·C². The units for these constants are very similar. Gravitational constant has kg² whereas electric constant has C² present in its denominator.

2. Calculate the distance between the Sun and Jupiter if the mass of the Sun is $1.99 \times 10^{30}$ kg and the mass Jupiter is $1.89 \times 10^{27}$ kg and the gravitational force acting between them is $4.14 \times 10^{23}$ N.

   **Answer:**
   \[
   F_{\text{gravitational}} = \frac{Gm_1m_2}{r^2}
   \]
   \[
   4.14 \times 10^{23} = \frac{(6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 1.89 \times 10^{27})}{(r)^2}
   \]
   \[
   r^2 = \frac{(6.67 \times 10^{-11} \times 1.99 \times 10^{30} \times 1.89 \times 10^{27})}{4.14 \times 10^{23}}
   \]
   \[
   r = 7.78 \times 10^{11} \text{ m}.
   \]

3. State Coulomb’s law of electric forces.

   **Answer:** Coulomb’s Laws states that electric force of attraction or repulsion between two point charges is directly proportional to the magnitude of charge and inversely proportional to the square of the distance between them.

   \[F \propto \frac{q_1q_2}{r^2}\]

   \[q_1\text{ and } q_2\text{ are the magnitudes of the two charges.}\]

   \[r = \text{distance between these charges.}\]

   \[F = k\frac{q_1q_2}{r^2}\]

   In this equation \(k\) is the proportionality constant. The unit of \(k\) is N·m²/C².

4. Two particles have an equal mass and a charge of 1.0 C. Determine the value of mass of these particles if the electric and gravitational force between them is equal. Comment on the result obtained.

   **Answer:**
\[ F_{\text{electric}} = \frac{kq_1q_2}{r^2} \]
\[ F_{\text{gravitational}} = \frac{Gm_1m_2}{r^2} \]

\[ F_{\text{electric}} = F_{\text{gravitational}} \]
\[ \frac{kq_1q_2}{r^2} = \frac{Gm_1m_2}{r^2} \]
\[ kq_1q_2 = Gm_1m_2 \]

Both particles have equal mass and the charge on both particles is 1.0 C.

\[ kq^2 = Gm^2 \]
\[ k(1) = Gm^2 \]
\[ m^2 = k/G \]
\[ m = 1.2 \times 10^{10} \text{ kg}. \]

The gravitational force between two particles will be equal to the electric force acting between these particles, if the charge is 1.0 C and the mass of each particle is \(1.2 \times 10^{10} \text{ kg}. \) This displays that, to produce an effect of force that is equivalent to small charges like 1.0 C, a huge mass of the order of \(10^{10} \text{ kg}. \) is required.

5. List the differences between an electric force and a gravitational force.

**Answer:** The differences between electric and gravitational force are

### Table 1: Comparison between electric and gravitational force

<table>
<thead>
<tr>
<th>Electric Force</th>
<th>Gravitational Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>The constant of proportionality is (9 \times 10^9 \text{ m}^2/N \cdot \text{C}^2. )</td>
<td>The constant of proportionality is (6.67 \times 10^{-11} \text{ m}^2/N \cdot \text{kg}^2. )</td>
</tr>
<tr>
<td>An electric force can be both attractive and repulsive.</td>
<td>A gravitational force is always attractive.</td>
</tr>
<tr>
<td>The electric force acting between two particles depends on the medium.</td>
<td>The gravitational force acting between two particles does not depend on the medium.</td>
</tr>
</tbody>
</table>

6. A particle ‘A’ of mass 2.0 kg has a charge 1.2 \( \mu \text{C} \) deposited on it. Determine the ratio of electric and gravitational forces between ‘A’ and ‘B’, if mass of ‘B’ is 1.5 kg and charge on it is 0.92 \( \mu \text{C} \). The distance between particle ‘A’ and ‘B’ is 4.8 m

**Answer:**
\[ F_{\text{electric}} = k\frac{q_1 q_2}{r^2} \]
\[ F_{\text{electric}} = (9 \times 10^9 \times 1.2 \times 10^{-6} \times 0.92 \times 10^{-6})/(4.8)^2 \]
\[ F_{\text{electric}} = 4.3 \times 10^{-4} \text{ N} \]

\[ F_{\text{gravitational}} = G\frac{m_1 m_2}{r^2} \]
\[ F_{\text{gravitational}} = (6.67 \times 10^{-11} \times 2.0 \times 1.5)/(4.8)^2 \]
\[ F_{\text{gravitational}} = 8.7 \times 10^{-12} \text{ N} \]

To determine ratio of \( F_{\text{electric}} / F_{\text{gravitational}} \)
\[ F_{\text{electric}} / F_{\text{gravitational}} = 4.3 \times 10^{-4} / 8.7 \times 10^{-12} \]
\[ F_{\text{electric}} / F_{\text{gravitational}} = 4.9 \times 10^7 \]

The electric force between the two particles is 49 million times as strong as the gravitational force between them.

7. Determine which of the following statements is true or false. If a statement is false, correct it so that it is true.

a. The electric force between two bodies is directly proportional to distance.

b. The gravitational force between two bodies is inversely proportional to the product of the mass on each body.

c. The unit of gravitational constant is m²/N·kg².

Answer:

a. False. The electric force between two bodies is inversely proportional to the square of the distance between them.

b. The gravitational force between two bodies is directly proportional to the product of the mass of each body.

c. True.

8. A force \( F \) acts between two bodies of mass \( m_1 \) kg and \( m_2 \) kg. The distance between them is \( r \) m. If \( m_1 \) is doubled, \( m_2 \) is quadrupled, and \( r \) is increased to eight times, determine the force acting between them in terms of \( F \).

Answer:

\[ F = Gm_1m_2 / r^2 \]

Now, \( m_1 \) is doubled that is \( 2 \times m_1 \) and \( m_2 \) is quadrupled that is \( 4 \times m_2 \).
Also \( r \) is increased to eight times that is \( 8 \times r \).

Substitute these values in the equation given above to calculate the force acting \( F' \)

\[ F' = G \times 2 \times m_1 \times 4 \times m_2 / (8 \times r)^2 \]
F’ = \( \frac{8Gm_1m_2}{(64)r^2} \).
F’ = \( \frac{Gm_1m_2}{8r^2} \).
F’ = \( \frac{F}{8} \).

The force acting between 2\(m_1\) and 4\(m_2\) when placed 8\(r\) m apart is \(\frac{F}{8}\).

9. Calculate the gravitational force and electric force between the nucleus of a Helium atom and an electron in its orbit. (The atomic mass of Helium is 4.0. Its atomic number is 2.0. The distance between the nucleus and the electron in its orbit is \(0.5 \times 10^{-10}\) m

**Answer:**
The nucleus has two protons so the charge of the nucleus is \(2 \times 1.6 \times 10^{-19} \) C = \(3.2 \times 10^{-19}\) C

The electric force between the nucleus and an electron in the orbit is

\[ F_{\text{electric}} = k\frac{q_1q_2}{r^2} \]
\[ F_{\text{electric}} = (9 \times 10^9 \times 3.2 \times 10^{-19} \times 1.6 \times 10^{-19})/(0.5 \times 10^{-10})^2 \]
\[ F_{\text{electric}} = 1.8 \times 10^{-7} \text{ N.} \]

The atomic mass of Helium is 4.0. Helium has two neutrons and two protons so the mass of the nucleus is \(2 \times \text{mass of proton} + 2 \times \text{mass of neutron} = 2 \times 1.67 \times 10^{-27} + 2 \times 1.67 \times 10^{-27}\)

So, the total mass of the nucleus is \(6.68 \times 10^{-27}\).

The gravitational force between the nucleus and an electron in the orbit is

\[ F_{\text{gravitational}} = \frac{Gm_1m_2}{r^2} \]
\[ F_{\text{gravitational}} = (6.67 \times 10^{-11} \times 6.68 \times 10^{-27} \times 9.11 \times 10^{-31})/(0.5 \times 10^{-10})^2 \]
\[ F_{\text{gravitational}} = 1.62 \times 10^{-46} \text{ N.} \]

10. Use this Exploration to determine the ratio of electric force to gravitational force between two protons and two electrons at a distance of \(5 \times 10^{-15}\) m. Comment on your observation.

**Answer:**
Electric force between two protons is 9.22 N.
Gravitational force between two protons is \(7.44 \times 10^{-36}\) N.
Ratio of electric force to gravitational force = \(9.22 / 7.44 \times 10^{-36} = 1.24 \times 10^{36}\).

Electric force between two electrons is 9.22 N.
Gravitational force between two electrons is \(2.21 \times 10^{-42}\) N.
Ratio of electric force to gravitational force = \(9.22 / 2.21 \times 10^{-42} = 4.17 \times 10^{42}\).

Electric force for both cases is same that is 9.22 N but gravitational force for two protons is greater as the mass of a proton is greater than an electron. So the ratio of electric force to gravitational force is smaller for two protons.
Exploration Teacher Guide: Spectroscopy

Overview

In this Exploration, students will learn about the absorption and emission spectra of various elements. They can also choose two elements to compare their absorption and emission spectra. The wavelength range of the maximum absorption and the maximum emission can also be examined.

Student Learning Objectives

- Examine spectroscopy by observing the absorption and emission spectra of various elements.
- Compare the absorption or emission spectra of two different elements.
- Analyze the maximum absorption and emission range of an element in the visible spectra.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, the experimental setup for recording absorption spectra and for recording emission spectra is displayed. Students can select the element whose absorption and emission spectra they want to examine using options in the Select Element 1 dropdown list.

Students can use the Record button to examine the absorption and emission spectra of the selected element. The absorption and emission spectra are distributed across the visible spectrum of light. Students can observe the maximum absorption and emission wavelength.

Students can use the Compare with Another Element check box to compare the emission or absorption spectra of two different elements. To compare, they can select an element from the Select Element 2 dropdown list and the spectrum they want to compare using the radio button options in the Select Spectra section. When the Record button is clicked, the selected type of spectrum for both the elements can be examined and compared.

The Tracker tab will track the absorption and emission spectra of the elements that the students have examined in all the runs of the Exploration. Students can inspect the number of spectral lines in the emission and absorption spectra of an element. They can also use the images in the column to examine the spectra compared in that run.
Answers to Questions in the Student Worksheet

1. Define and explain spectroscopy.

   **Answer:** Spectroscopy is the study of absorption and emission or scattering of a radiation through matter (solid, liquid or gas) to observe the physical properties of the matter. It is an analysis of the interaction of matter and electromagnetic radiation.

2. Explain the photoelectric effect. Define photoelectrons and photosensitive surfaces.

   **Answer:** The photoelectric effect is the removal of electrons from solid, liquid, or gas when energy is absorbed from visible or ultraviolet radiation. The emission of an electron is possible only when the incident light frequency is more than the cutoff frequency required for that element. The electrons that are emitted from the surface are known as photoelectrons. The surface which exhibits the phenomenon of photoelectric effect is known as a photosensitive surface.

3. Explain the difference between the absorption and emission spectra in spectroscopy.

   **Answer:** When an electron moves to a higher energy level, a photon is absorbed by the electron. The frequency at which the photon is absorbed is recorded in the absorption spectrum. When this electron moves back to a lower energy level, a photon is emitted. The frequency at which the photon is emitted is recorded in the emission spectrum.

4. Use options in the Exploration to compare the number of spectral lines in the absorption spectrum of helium and neon.

   **Answer:** The number of spectral lines in the absorption spectrum of helium is 23 while that in the absorption spectrum of neon is 75.

5. Use options in the Exploration to compare the number of spectral lines in the emission spectrum of nitrogen and hydrogen.

   **Answer:** The number of spectral lines in the emission spectrum of nitrogen is 84 while that in the emission spectrum of hydrogen is 5.

6. Use options in the Exploration to compare the number of spectral lines in the absorption spectrum and emission spectrum of mercury.

   **Answer:** The number of spectral lines in the absorption and emission spectra of mercury is 40.
7. Compare the absorption and emission spectra of any one element. Explain the pattern that can be observed in the two spectra.

   **Answer:** The dark lines in an absorption spectrum appear at exactly the same frequencies as the bright lines in the corresponding emission spectrum.

8. To study the emission spectrum of an element, the gas in the discharge tube is heated before the absorbed ray hits it. Explain why this is important.

   **Answer:** Emission is a phenomenon where electrons drop down to a lower energy level and emit a photon. The heat gives the atoms extra energy using which some electrons jump to higher energy levels. Without the extra energy, only lines corresponding to jumps to and from the ground state would appear.

9. Explain the role of a slit in the experimental set up of spectroscopy.

   **Answer:** The slit helps in making the spectral lines narrow so that the light enters the prism at a single spot and is projected at one spot.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term 'toggle.'

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Fundamental Forces and Radioactivity

Timing: one 90-minute class session

Objective(s):
Students investigate radioactivity of a variety of samples and combinations of samples. Students will ask an experimental question and design a protocol to test a hypothesis that answers the question. They will analyze the data. Students will design investigative procedures, including selecting appropriate equipment, to perform the steps of both the Directed and Guided Inquiry portions of this lab.

Safety Precautions:
Students should not eat or drink in lab, especially the test samples. Note that none of the suggested samples have dangerous levels of radioactivity.

Materials:
Per pair or group:
- 1 Geiger counter (may be shared between groups if needed)
- 1 ruler
- 1 stopwatch or clock
- Variety of small samples of items (may be shared between groups), possibly including:
  - Granite or other rock
  - Lead blocks
  - Brick pieces
  - Bananas and other potassium-rich food items such as kidney beans and potatoes
  - Smoke detector, “ionization” type
  - Potassium chloride
  - Cell phone
  - Old tube television or computer monitor
  - Other assorted objects from daily life
Per class:
- balance

Teacher Preparation:
You may need some time to track down various samples. Note that the selection should include items that are somewhat radioactive, such as bananas or No-Salt, and items that are not at all radioactive, such as lead pieces. (None of the suggested samples have dangerous levels of radioactivity.) Also, prepare copies of the Student Investigation Sheet for each student.

You may want to include extra equipment that is non-essential to completing the lab, so students have the opportunity to consider which equipment they would select and why.
**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Begin by reminding the class of the connection between the weak nuclear force and radioactivity. Then, explain that students will investigate radioactivity by using a Geiger counter. Demonstrate the use of a Geiger counter by measuring radioactivity from a chosen sample item. (If you wish, you might keep the identity of the sample hidden by placing it in a very large envelope and have students blindly push the Geiger counter into the envelope for a reading—the sample would have to be something that would not spill. An activity for the lab would then be for the students to attempt to determine the material in the sample based on measurements.) Demonstrate briefly how the measurement of the detector can depend on distance from the source and orientation of the source relative to the detector. Discuss with the students what the clicks of the detector signify. (Each radioactive decay of an atom in the source releases particles that the Geiger counter detects; each click of the counter indicates one decay has occurred.)

Explain that students will measure radioactive rates, meaning they will measure the number of clicks in a certain time. Dividing the number of clicks by the time gives a rate. Explain that by measuring for a long period of time, they can calculate an average rate.

Have the students work in groups. Each group will first measure the radioactivity of a variety of samples. You can let the groups choose their samples, or you may wish to give them specific items. Encourage students to measure a collection of different sources. Also instruct them to measure the background levels by letting the detector run with no sources nearby.
Have students record data in a table like this example:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Detector orientation:</td>
<td>Pointed straight at sample, sample at 10 cm distance</td>
</tr>
<tr>
<td>Time of measurement: (s)</td>
<td>120</td>
</tr>
<tr>
<td>Counts:</td>
<td>310</td>
</tr>
<tr>
<td>Rate: (decays/s)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Next, have the students choose an experimental question on the basis their findings so far. You can let them choose freely or provide a list of options. Instruct the students that the dependent variable in their study will be the radioactive rate of a sample. Ask them to choose one independent variable. Sample questions might include:

- Does the size or mass of a sample of material affect the radioactivity?
- How does the radioactivity of combinations of samples relate to the individual radioactivities?
- Do more complicated tech devices, such as television monitors or cell phones, have radioactivity that depends on the location of the counter or on whether the device is operating?
- How does radioactivity depend on distance from a source?
- What sort of nonradioactive materials make good screens? (compare lead and paper for instance)
If time permits, students should investigate multiple questions. Make sure groups discuss their question and their protocol with you before beginning. Sample data might look like the following:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector orientation</td>
<td>Pointed straight at source, 10 cm away</td>
</tr>
<tr>
<td>Time of measurement (s)</td>
<td>120</td>
</tr>
<tr>
<td>Sample 1 mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Sample 2 mass (g)</td>
<td>90</td>
</tr>
<tr>
<td>Sample 1 counts</td>
<td>308</td>
</tr>
<tr>
<td>Sample 2 counts</td>
<td>615</td>
</tr>
<tr>
<td>Sample 1 rate (decay/s)</td>
<td>2.6</td>
</tr>
<tr>
<td>Sample 2 rate (decay/s)</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Have students prepare a presentation of their data by using a graph or bar chart. Each student should prepare a written report of their procedure and findings, including an answer to their testable question. Groups should then present their results to the class. As a class, discuss any discrepancies in measurements between groups. If you have kept your original sample secret, ask the class to try and identify the sample.

**Guided Inquiry**

Students can develop their own plans for collecting data, based on their understanding of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What will be your independent and dependent variables?
- How will you adjust your independent variable, and how many different values will you use?
- Will you perform multiple trials?
- What tools will you use to make your measurements?
You may wish to begin by demonstrating to students how the Geiger counter works, or you may leave it to the students to play with it or possibly research it online. Suggest to students that they should perform two general investigations. One will be a survey of the radioactivity of a wide variety of sample materials. This survey will give them a chance to get familiar with the Geiger counter and how to use it. They may also be surprised to discover that certain items (such as bananas) are more radioactive than they thought, and others (such as cell phones) are not. Have each group set up a data table to record their results.

A data table might look like:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Detector orientation:</td>
<td>Pointed straight at sample, sample at 10 cm distance</td>
</tr>
<tr>
<td>Time of measurement: (s)</td>
<td>120</td>
</tr>
<tr>
<td>Counts:</td>
<td>310</td>
</tr>
<tr>
<td>Rate: (decays/s)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

The other study should be a focused study of a specific question. Suitable questions include

- Does the size or mass of a sample of material affect the radioactivity?
- How does the radioactivity of combinations of samples relate to the individual radioactivities?
- Do more complicated tech devices, such as television monitors or cell phones, have radioactivity that depends on the location of the counter or on whether the device is operating?
- How does radioactivity depend on the distance from a source?
- What sort of nonradioactive materials make good screens? (compare lead and paper for instance)
If time permits, students should investigate multiple questions. Sample data for the question, how does the mass of the sample affect the rate, might look like the following:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Banana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector orientation</td>
<td>Pointed straight at source, 10 cm away</td>
</tr>
<tr>
<td>Time of measurement (s)</td>
<td>120</td>
</tr>
<tr>
<td>Sample 1 mass (g)</td>
<td>45</td>
</tr>
<tr>
<td>Sample 2 mass (g)</td>
<td>90</td>
</tr>
<tr>
<td>Sample 1 counts</td>
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</tr>
<tr>
<td>Sample 2 counts</td>
<td>615</td>
</tr>
<tr>
<td>Sample 1 rate (decays/s)</td>
<td>2.6</td>
</tr>
<tr>
<td>Sample 2 rate (decays/s)</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Have each group decide on a question (or questions) and prepare a protocol for testing. Have them explain their procedure to you before they begin. Make sure students include a procedure for measuring the “noise” or background levels of radiation. Also, ask students to consider how they will present their data (a graph of radioactivity versus sample mass for instance). Each student should prepare a written report of their procedure and findings, including an answer to their testable question. Have each group present their findings to the class.

Have the class discuss any discrepancies in measurements between groups that studied similar questions.
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How do your results compare to the results of another group that made a similar measurement? Can you explain any differences? Our results were similar, but they found more counts. This may be because they had a slightly larger sample, or their counter was closer to the sample.

2. What result would you expect if you placed all the samples together in a small box and measured the radioactivity? Would the arrangement of the samples in the box affect the result? Explain your answer. All the samples together would give a higher count than one sample alone. The result would depend on the arrangement, though. For example, if the lead block ended up on the side of the box nearest to the detector, then the measured radioactivity would be very low.

3. Did you encounter any sources of error in your measurements? What could you do, or what did you do, to account for these errors? How could you improve the experimental procedure to cut down on errors? One error came from the radiation of the bricks in the school walls. We accounted for this by leaving the detector on, with no samples nearby. We measured a value for average clicks per minute and subtracted that from our other measurements. We could cut down on error by surrounding the sample and detector with a screen like a box made of lead.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct investigations using:
    - Fair Test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent Variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
    - Sample (if needed)—a portion of the affected elements in an investigation used to extrapolate what would have happened to a larger set of elements
    - Multiple Trials—repeated tests with the same variables to check for the variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
- Mass
- Time

- Choose appropriate tools to conduct an investigation:
  - Ruler/tape measure
  - Meter stick
  - Clock/stopwatch
  - Scale
  - Other laboratory equipment

- Use senses to observe:
  - Hearing (pitch, volume, reflection, direction)
  - Kinesthetic (balance, position)

- Use the appropriate format to record data:
  - Table
  - Graph
  - Chart
  - Writing (journal, worksheet, electronic text)

- Interpret Data
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances, and organisms by characteristic
    - Applying a classification scheme to objects, substances, or organisms
    - Developing a classification scheme for objects, substances, or organisms

  - Identify and interpret patterns by using:
    - Trends in data
    - Repeating physical or data patterns
    - Graphed data points
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Using data to determine the cause–effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Identifying alternative explanations
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Explaining how technology can be used to enhance the investigation
• Showing the application of the scientific concept or process being investigated

• Communication in Science
  o Report results by using:
    ▪ Peer presentation
    ▪ Written report
    ▪ Scientific explanations/arguments
    ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

• Patterns and Systems
  o Patterns and Change:
    ▪ Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    ▪ Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    ▪ Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    ▪ Some small changes can be detected by taking measurements.
    ▪ Things that change may do so in steady, repetitive, or irregular ways.

  o Systems:
    ▪ A system, such as the human body, is composed of subsystems.
    ▪ Some systems (such as heating or cooling systems) have feedback mechanisms that serve to keep changes within specified limits.
    ▪ As the complexity of any system increases, gaining an understanding of it depends on summaries, such as averages and ranges, and on descriptions of typical examples of that system.

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ New observations should be made when there is a disagreement among initial observations.
    ▪ When a scientific investigation is repeated, a similar result is expected.
Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.

- **Scientific Data and Outcomes:**
  - Scientific claims are based on data and reliable scientific sources.
  - Collecting and analyzing data are the best way to understand a changing pattern.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data take much longer (e.g., the growth of a tree).
  - Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
  - It is important in science to keep honest, clear, and accurate records.
  - When similar investigations give different results, it often takes further studies to decide what is right.
  - Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

- **Scientific Endeavor**
  - Characteristics of Science:
    - An important part of science is the critical review and analysis of any idea or conclusion.

- **Engineering and Technology**
  - Uses of Technology:
    - Human beings have made tools and machines, such as X rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
Hands-On Lab
Measuring Radiation in Food

**Timing:** one 90-minute class session

**Objective(s):**
Students will design a protocol to test radiation levels in foods using a simple handheld Geiger counter.

**Safety Precautions:**
All foods are radioactive to some degree; students should not go out of their way to find highly radioactive substances.

**Materials:**
Per group:
- 1 Geiger counter
- Samples of foods, both processed and fresh (e.g., rice, pears, tomatoes, pasta, chicken, and hot dogs; try to include a banana and Brazil nuts), and milk

**Teacher Preparation:**
Prepare one copy of the Student Investigation Sheet for each student. You may separate the class into groups matched to food pyramid distinctions (such as fats, grains, and meats). Since most classrooms will only have one Geiger counter, each group should demonstrate its analysis in front of the class.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’
activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Have a Geiger counter, a glass of tap water, and several types of food on a table or desk at the front of the classroom. Before beginning your demonstration, lead a class discussion addressing the following questions:

- Do you think drinking water contains radiation? *Yes, although the levels are controlled by the FDA to be nontoxic.*
- Is all radiation in food harmful? *No, as long as the radiation amounts do not exceed safe levels.*
- Do you think that the nuclear accident at Fukushima, Japan, in 2011 affected food sources in the United States? How could you find out? *Possibly; some of the dust was carried into the western states, such as California. However, the FDA is closely monitoring radiation levels in foods produced in those states and it is not a source of serious concern at this time.*

Next, turn on the Geiger counter and measure the gamma radiation in the water. In many handheld Geiger counters, gamma radiation is automatically measured when you turn on the machine. The speed of the clicks indicates the intensity of radiation. Most handheld Geiger counters also display a digital readout of the measurement. Then, change the mode to measure alpha radiation and gamma radiation. Record your measurements on a simple chart on a whiteboard or overhead display, indicating item (water) and gamma, alpha, and beta levels. If your Geiger counter does not allow you to measure different types of radiation with a simple switch or button click, you can block alpha particles with a piece of paper, and block beta particles with a 0.4-cm piece of aluminum (folding a piece of aluminum foil repeatedly is fine).

Next, distribute food items to the groups. (For example, the “grains” group may have rye bread, white bread, crackers, pasta, and rice.) Have the first group measure radiation in each food, completing the chart begun with water. Continue testing until all food groups have tested at least 4–5 foods, so that each student has the opportunity to operate the Geiger counter.

After completing the measurements, ask students to identify any trends they may have observed. As a class, discuss whether radiation in foods is a problem in the United States, and what, if any, changes should be made to regulations controlling food safety in terms of radiation exposure.
Guided Inquiry
In groups, students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. For example, some students may choose to investigate radiation levels in particular types of foods. Ask students some guiding questions to help them focus their inquiry:

- What type of food do you want to measure?
- What types of food do you think emit higher-than-average levels of radiation? Why do you think so?
- Do you want to measure foods from a specific geographic location?
- Do you think processed foods have higher radiation levels than organic foods? Why do you think so?

Have students present their protocols to you for approval before allowing them to proceed with their investigation. Make sure students can explain why they chose to investigate the foods and/or locations they did and what they expect to discover from their investigation.

Ask leading questions such as:

- Do you think drinking water contains radiation? Yes, although the levels are controlled by the FDA to be nontoxic.
- Is all radiation in food harmful? No, as long as the radiation amounts do not exceed safe levels.
- Do you think that the nuclear accident at Fukushima, Japan, in 2011 affected food sources in the United States? How could you find out? Possibly; some of the dust was carried into the western states, such as California. However, the FDA is closely monitoring radiation levels in foods produced in those states, and it is not a source of serious concern at this time.
- What types of radiation do Geiger counters measure? Alpha particles—heavy, fast-moving helium nuclei; beta particles—light, faster-moving electrons, and gamma rays, high-energy photons.

Have students complete tables showing each food tested, with its levels of gamma, alpha, and beta radiation. Encourage them to compare their results with those of other groups. Discuss as a class what trends they discovered, and what the rationale for those trends might be. Also, discuss whether radiation in foods is a problem in the United States, and what, if any, changes should be made to regulations controlling food safety in terms of radiation exposure.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What general trends, if any, did you discover about the radiation levels in the foods you analyzed? [Answers will vary: May include information such as "mushrooms have higher radiation levels than other vegetables so that the source of radiation seems to be absorbed by the mushrooms…"]

2. How did the gamma, alpha, and beta radiation levels compare to each other in a single food sample,
and between different food samples? [Answers will vary: Students may notice that the radiation levels are consistent—if beta levels are higher, so usually are gamma and alpha.]

3. Should the FDA tighten regulations on permitted radiation levels in foods? Support your answer with evidence. [Answers will vary: If students suggest that radiation regulations should be relaxed, they might use data from current studies conducted by the EPA to support their position; if students suggest that the regulations should be tightened, they may cite reports that indicate the increased incidence of cancer in living things exposed to radiation.]
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
    - Sample (if needed)—a portion of the affected elements in an investigation used to extrapolate what would have happened to a larger set of elements
    - Multiple trials—repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist

- **Practice lab safety by:**
  - Following lab safety procedures
  - Recognizing safety equipment and materials and knowing their proper use
Incorporating laboratory safety practices into the investigation design

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Radiation
  - Choose appropriate tools to conduct an investigation:
    - Other laboratory equipment
  - Use senses to observe:
    - Hearing (pitch, volume, reflection, direction)
  - Use the appropriate format to record data:
    - Table

- Interpret Data
  - Identify and interpret patterns using:
    - Trends in data
    - Repeating physical or data patterns
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Using data to determine the cause–effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Identifying alternative explanations
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments

- Communication in Science
  - Report results using:
- Peer presentation
- Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating data for accuracy
    - Evaluating a conclusion

- Patterns and Systems
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
    - Science takes place in many locations including labs, offices, fields, and under the ocean.
    - Scientific investigation results in things we know and things we do not know.
    - Scientific investigations generally work the same way in different places.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    - Scientific investigation leads to more questions.
    - Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
What people expect to observe can affect how they perceive what they observe.
Scientific investigations lead to the development of scientific explanations.

Scientific Data and Outcomes:
- Scientific claims are based on data and reliable scientific sources.
- Collecting and analyzing data is the best way to understand a changing pattern.
- Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
- Comparisons of data are not accurate when some of the conditions are not kept the same.
- Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data take much longer (e.g., the growth of a tree).
- Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
- When similar investigations give different results, it often takes further studies to decide what is right.

Scientific Endeavor
- Characteristics of Science:
  - Science is based on factual knowledge.
  - Scientists are curious about wanting to know how things work.
  - One way to make sense of something is to think of how it relates to something more familiar.
  - Scientific claims can be substantiated using data and observation.
Overview

Nuclear forces are those which exist at the subatomic level and hold the protons and neutrons together in the nucleus of an atom. In this Exploration, students examine and analyze the nuclear fission and nuclear fusion processes.

Student Learning Objectives

- Examine the fission of a heavy nucleus into daughter nuclei along with the release of subatomic particles and large amounts of energy.
- Observe the fusion of two light nuclei into a heavier nucleus with the release of large amounts of energy.
- Investigate the mass-energy relation which accounts for mass being converted and released in the form of energy.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion of the Exploration.

Using this Exploration

In the Fission tab, students select the fissionable element provided in the Select Element section. Students use the Bombard button to trigger a hypothetical projectile gun, which fires a projectile, i.e. a neutron or an alpha particle. The animation that follows shows the fission process. The fission reaction is displayed along with a View Data button, which when clicked provides the detailed mass-energy analysis for the reaction. Students use the Replay button to view the fission animation again. Students use the Reset button, to reset the Exploration and select another element for which the fission process is to be investigated.

In the Fusion tab, students select two reactants from the Select Reactants section, by dragging and dropping them in the Reactants section. Each of the reactants, which are isotopes of hydrogen, namely Protium, Deuterium, and Tritium, can be selected twice. Once the two reactants have been selected, the students use the Start button, to initiate the fusion reaction, which occurs inside the fusion reactor called the tokamak. An animation of the fusion reaction is displayed. Using the View Data button, students view a detailed mass-energy analysis for the reaction. The students use the Replay button to view the fusion animation again. They use the Reset button, to reset the Exploration and select a different combination of reactants for which the fusion process is to be investigated.
The Tracker tab is a summary of all the previous runs in the Fission or Fusion tabs. Students select the fission or fusion reactions from the Select Process dropdown options to view the mass and energy analysis for the selected reaction. They also view the animation for the selected process using the View Animation button.

Answers to Questions in the Student Worksheet

1. Nuclear forces are weak forces and hence it is easy to fission a nucleus or to fuse two nuclei. State whether the above statement is true or false. If true, justify. If false, rewrite the sentence in a manner to make it true.

   Answer: False. Nuclear forces are strong forces that bind the nucleons in a nucleus. Fission occurs when a heavy nucleus is raised in energy to make it unstable so that it may break into lighter nuclei along with the release of energy. For fusion to occur, very high temperatures are required to convert the nuclei into their plasma state, so that they may fuse together.

2. State the mass-energy relation. Explain its significance. Calculate the energy equivalent of a body of mass 0.20 kg.

   Answer: The mass-energy relation is given by $E = mc^2$. This relation signifies the equivalence of mass and energy, i.e. mass and energy are not separate entities but different forms of the same thing.

   Solution:

   $m = 0.20 \text{ kg}$

   We know that, $E = mc^2$

   Therefore, $E = 0.20 \times (3.0 \times 10^8)^2 \text{ J}$

   $E = 1.8 \times 10^{16} \text{ J}$
3. Create an analogy representing the differences between nuclear fission and nuclear fusion processes. In your analogy provide a supporting detail for each process.

**Answer:** Nuclear fission is like a couple who is arguing. They release high levels of energy during the fight and end up splitting up in the end. Nuclear fission is the process of a heavy nucleus splitting into fragments, resulting in the release of high amounts of energy.

Uranium-235 is a fissionable element, which may fission along various channels, to form different combinations of daughter products. Consider the fission reaction, $^{235}\text{U} + ^1\text{n} \rightarrow ^{140}\text{Cs} + ^{92}\text{Rb} + 3^1\text{n} + \text{EFission}$. Here, a neutron bombards a uranium-235 nucleus. Cesium and Rubidium are formed as fission products, along with 3 neutrons. A large amount of energy is released in the process.

On the other hand, nuclear fusion is like a couple who is starting a relationship. High amounts of energy are used to stay together. Nuclear fusion is a process in which two light nuclei combine or fuse together to form a heavier nucleus. Consider the fusion of two tritium nuclei, $^3\text{H} + ^3\text{H} \rightarrow ^4\text{He} + 2^1\text{H} + \text{EFusion}$. Here, two tritium nuclei fuse under the condition of very high temperature, to form helium nuclei along with two Protiums. A large amount of energy is released in the process.

4. Determine the role of the projectile in the fission process. Illustrate with an example.

**Answer:** A projectile bombards the fissionable nucleus to raise it to an excited state. This excited state is highly unstable and thus the nucleus splits to form smaller daughter elements along with the release of energy. For example, in the fusion of uranium-235, the uranium nucleus first absorbs the projectile, in this case the neutron, to become uranium-236, which is highly unstable. This unstable nucleus then breaks up into daughter nuclei. Excess neutrons are emitted and energy equivalent of mass defect is released.

5. Explain chain reaction in nuclear fission. Explain how it is controlled in case of fission of thorium.

**Answer:** In nuclear fission, a projectile bombards the parent nucleus to form an unstable nucleus which then fissions into daughter products, along with the release of neutrons and large amounts of energy. In the case of uranium fission, the projectile is a neutron itself. Thus, the emitted neutrons may bombard more uranium nucleus and a chain reaction will occur resulting in the release of tremendous amount of energy.
In the case of fission of thorium, the projectile is an alpha particle. Thus, the emitted neutrons do not trigger further fission of thorium. Hence fission of thorium progresses in a controlled manner that can be regulated by controlling the alpha particle bombardment.

6. One possible fission path of uranium-235 is $^{235}\text{U} + ^1\text{n} \rightarrow ^{136}\text{Xe} + ^{88}\text{Sr} + 12^1\text{n} + \text{EFission}$.

The masses of U-235, Xe-136, Sr-88, and the neutron are 235.043924 a.m.u, 135.90721 a.m.u, 87.905618 a.m.u, and 1.008665 a.m.u respectively. Calculate the value of energy released in the fission reaction. (Use: 1 a.m.u has an energy equivalence of 931.5 MeV).

**Answer:**

**Solution:**

Total mass of reactants = $(235.043924 + 1.008665)$ a.m.u = 236.052589 a.m.u

Total mass of products = $(135.90721 + 87.905618 + 12 \times 1.008665)$ a.m.u

= 235.916808 a.m.u

Therefore, mass defect ($\Delta m$) = Total mass of reactants - Total mass of products

$(236.052589 - 235.916808)$ a.m.u

$0.135781$ a.m.u

Energy released = Energy equivalent of mass defect

$931.5 \times \Delta m = 931.5 \times 0.135781$

$126.480015$ MeV

$126.5$ MeV

7. In this Exploration, determine which of the six possible fusion reactions yields the maximum amount of energy.

**Answer:** The deuterium-tritium fusion yields the maximum amount of energy. The energy released in the fusion reaction is approximately 17.6 MeV.
8. Explain the main difficulty in achieving the fusion reactions artificially. Explain how the difficulties may be overcome.

**Answer:** Fusion reactions require very high temperatures. They are naturally occurring in the hot central parts of stars including the sun. But artificial procurement of fission reactions is very difficult as such temperatures are difficult to achieve and maintain. This difficulty may however be overcome by carrying out the process in the plasma states of matter. For this purpose, a fusion reactor called the tokamak is used. The tokamak is designed to achieve and maintain such high temperatures as is required for the fusion process.

9. Consider the following fusion reaction:

\[ ^{13}\text{C} + ^{4}\text{He} \rightarrow ^{16}\text{O} + ^{1}\text{n} \]

The masses of carbon, helium, oxygen, and neutron in the above equation are 13.003355 a.m.u, 4.0026020 a.m.u, 15.994915 a.m.u, and 1.0086649 a.m.u, respectively. Calculate the energy released in the fusion process. (Use: 1 a.m.u has an energy equivalence of 931.5 MeV).

**Answer:**

Solution:

Total mass of reactants = (13.003355 + 4.0026020) a.m.u = 17.005957 a.m.u

Total mass of products = (15.994915 + 1.0086649) a.m.u

= 17.0035799 a.m.u

Therefore, mass defect (∆m) = Total mass of reactants - Total mass of products

(17.005957 - 17.0035799) a.m.u

0.0023771 a.m.u

Energy released = Energy equivalent of mass defect

931.5 \times ∆m = 931.5 \times 0.0023771

≈ 2.2142687 MeV
10. Calculate the mass (in kilograms) of a substance which, when gets completely converted into energy, releases energy of $4657.5 \times 10^{21}$ MeV. (Use, 1 a.m.u = $1.66053886 \times 10^{-27}$ kg has an energy equivalence of 931.5 MeV).

**Answer:** We know that, 1 a.m.u has an energy equivalence of 931.5 MeV.

So, $4657.5 \times 10^{21}$ MeV energy corresponds to a mass of $(4657.5 \times 10^{21} / 931.5) \text{ a.m.u}$ i.e. $4657.5 \times 10^{21}$ MeV $\Rightarrow (4657.5 \times 10^{21} / 931.5) \text{ a.m.u} = 5 \times 10^{21} \text{ a.m.u}$

Now,

$$1 \text{ a.m.u} = 1.66053886 \times 10^{-27} \text{ kg}$$

Therefore, $5 \times 10^{21} \text{ a.m.u} = 5 \times 10^{21} \times 1.66053886 \times 10^{-27} \text{ kg/a.m.u.}$

$$= 8.3026943 \times 10^{-6} \text{ kg}$$

$$= 8.3027 \times 10^{-6} \text{ kg}$$

Hence, approximately $8.3027 \times 10^{-6}$ kg, i.e. 8.3027 milligrams of the substance was converted into energy.
Hands-On Lab

Charging by Induction

Timing: one 90-minute class session

Objective(s):
In this lab activity, students will charge an object by induction using an electrostatics kit. Students will design and implement investigative procedures, including making observations.

Safety Precautions:
Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for safe use of the electrostatics kit.

Materials:
Per group:
- Electrostatics testing kit, including the following:
  - Metal conducting sphere on insulating stand
  - Conducting wire
  - Metal grounding plane
  - Hard rubber or Ebonite rod
  - Silk fabric or rabbit’s fur
  - Pith ball on insulating string
- Ring stand with clamp

Teacher Preparation:
This lab should be performed on a cool day with low relative humidity. Gather materials in advance of students performing the lab. Divide the class into groups and provide each group with all materials in the list.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Labs, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquire path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students.
using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experienced to the content you are teaching.

**Directed Inquiry**

Give each group its own set of materials for the activity. Place the conducting sphere on the grounding plane. Clip one end of the wire to the grounding plane. Tie the pith ball to the ring or clamp on the ring stand with a piece of non-conducting string. Rub the plastic rod several times with a piece of rabbit fur or silk fabric. Bring the plastic rod close to the conducting sphere (within one centimeter or less). While holding the plastic rod in this position, briefly touch the wire to the surface of the sphere opposite the plastic rod and remove the wire. Rub the plastic rod again with the rabbit fur or silk and touch the pith ball with the rod. Moving the ring stand, bring the pith ball near the conducting sphere. Tell students to observe how the pith ball moves.

Have students in each group repeat this procedure by themselves and record theirs results in their lab notebooks.

After they have completed the procedure, ask the class why the pith ball moved in the direction that it did. *Answer: the conducting sphere and the pith ball both have the same charge.*

Ask students how the conducting sphere acquired an electric charge. *Answer: The charge on the plastic rod repelled the charges of the same sign on the sphere to the opposite side of the sphere, where they followed the conducting wire to the grounding plane.*

**Guided Inquiry**

Give each group its own set of materials for the activity. Provide students the following instructions for charging by induction:

1. Charge the rod by rubbing with silk or rabbit’s fur.
2. Bring the rod close to the conducting sphere but not touching it.
3. Ground the conducting sphere to the grounding plane by momentarily touching the conducting wire to the grounding plane and the conducting sphere at the same time.
4. Charge the rod again and touch the rod to the pith ball on its string.
5. Bring the pith ball near the metal conducting sphere, but not touching the sphere. Observe the behavior of the pith ball.
6. Write the results of the experiment in your laboratory notebook.

Once the students in each group have successfully completed this part of the laboratory, ask students these questions:

What would happen if you varied the distance between the plastic rod and the sphere? *Answer: If the rod is farther away from the conducting sphere when the wire touches it, the pith ball will not move as far away from the sphere.*

What would happen if you touched the metal part of the wire while grounding the conducting sphere? *Answer: There would be no effect. The plastic rod is an insulator, and charges do not move easily on the rod, even if it is grounded.*
What would happen if you did not charge the pith ball before bringing it near the conducting sphere? Answer: You would still see some attraction between the sphere and the pith ball (but not as much) because the charge on the conducting sphere will induce a small opposite charge in the pith ball.

Let each group design additional experiments to find the answers to each of these questions. Have students come up with questions of their own and design experiments to test those questions. Have the students write their questions, hypotheses, results and conclusions in their individual laboratory notebooks.

Analysis and Conclusions

1. What new information did you learn about relocating electric charges on the metal conducting sphere?
   Sample Response: It is possible for charges to move on the surface of a conducting sphere.

2. What did you notice about the movement of the pith ball when you brought it near the metal conducting sphere?
   Sample Response: The pith ball moved toward the charged sphere.

3. What did the movement of the pith ball tell you about the relationship of the charge on the pith ball to the charge on the metal conducting sphere?
   Sample Response: The pith ball was attracted to the charged sphere and thus had a charge opposite that of the sphere.

4. How do you think the results of this experiment would change if you used a non-conducting sphere instead of a metal conducting sphere?
   Sample Response: Electrons could not move as easily on the non-conducting sphere. The induced charge on the sphere would be very small or absent.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Recognize and develop testable questions that:
    - specify a cause-effect relationship.
    - can be answered with a science investigation or observational study.

- **Design Investigations**
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing.

- **Gather Data**
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)

In this lab, students will demonstrate the following Nature of Science Skills:

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
  - Scientific Data and Outcomes
    - It is important in science to keep honest, clear, and accurate records.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Overview

Charles Augustin de Coulomb measured electric force acting on charged bodies using a torsion balance. Using this setup, he formulated the law of electric forces. In this Exploration, students examine the parameters affecting the electric force between two charged objects.

Student Learning Objectives

- Analyze Coulomb’s law of electric forces.
- Examine the magnitude of force acting between two charged objects.
- Observe the force interaction between two objects depending on their charge and polarity.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, the setup of Coulomb’s torsion balance is displayed on the screen. Using the suspended sphere section, students select the polarity and magnitude of the charge on the suspended sphere. Students select polarity using the Positive and Negative radio buttons. Students select the magnitude of the charge using options in the Magnitude dropdown list. Students select polarity and magnitude of the charge on the brass disc using options in the Brass Disc section. Using the Distance between Suspended Sphere and Brass Disc dropdown, students select the distance between them.

Once the students click on the Start button, a zoomed-in view shows the deflection of the brass disc. Depending on the selected polarity, the brass disc will deflect away or toward the suspended sphere. The values of the angle of deflection, magnitude of force, and force interaction are displayed. The Force Representation section shows a magnified view of the force interaction between the suspended sphere and the brass disc.

The Reset button can be used to observe the values for a different selection.

The Graph tab displays graphs of force versus distance and force versus 1/distance$^2$, for the current run. Students can use these options in the Select Graph dropdown list to select from one of the two graphs. These graphs can be used to analyze the variation in the values of electric force between two charged bodies as the distance between them is changed.

The Tracker tab displays a summary of the values for all the runs. Students can observe the values of the angle, force, and force interaction for the selected values.
Answers to questions in student worksheet

1. Using the Exploration, determine the effect of charge on the magnitude of force and force interaction between the suspended sphere and the brass disc if the distance between them is kept constant. Record your findings here.

   **Answer:** If the magnitude of charge is increased, the magnitude of force increases. Force interaction depends on the polarity of individual charge. If both charges have the same polarity, repulsive force is observed and, if both charges have opposite polarity, attractive force is observed.

2. Using the Exploration, determine the effect of the distance (between the suspended sphere and brass disc) on the magnitude of force and on the magnitude of force interaction. Assume that the magnitude and polarity of their charge is constant. Record your findings here.

   **Answer:** If the distance is increased, the magnitude of force decreases. Force interaction does not depend on the distance between suspended sphere and brass disc.

3. Explain Coulomb’s law of electric forces.

   **Answer:** Coulomb’s law states that “The electrostatic force between two charged objects is directly proportional to the product of the magnitude of their charges and inversely proportional to the square of the distance between them.

   \[ F_e \propto \frac{q_1 q_2}{r^2} \]

   \[ F_e = \frac{k q_1 q_2}{r^2} \]

   k is the constant of proportionality.  

   F_e is attractive if q_1 and q_2 have opposite polarity.  

   F_e is repulsive if q_1 and q_2 have similar polarity.

4. Determine the unit of the constant of proportionality used in the law of electric forces.

   **Answer:** \[ F_e = \frac{k q_1 q_2}{r^2} \]

   The unit of force is N (Newton).  

   The unit of charge is C (Coulomb).  

   The unit of distance is m (meter).

   \[ k = \frac{F_e r^2}{q_1 q_2} \]

   \[ k = \text{Nm}^2 / \text{C}^2 \text{ (in the form of units).} \]

   So the unit of k is Nm^2/C^2.
5. A proton is placed at a distance of $5.3 \times 10^{-11}$ m. from an electron. Calculate the electrostatic force between them and determine the polarity. (Proton charge = $1.6 \times 10^{-19}$ C. Electron charge = $-1.6 \times 10^{-19}$ C.)

**Answer:**
- Charge of a proton ($q_1$) = $1.6 \times 10^{-19}$ C.
- Charge of an electron ($q_2$) = $-1.6 \times 10^{-19}$ C.
- Distance between them ($r$) = $5.3 \times 10^{-11}$ m.

According to Coulomb's law $F_e = kq_1q_2/r^2$

$$F_e = (9 \times 10^9 \times 1.6 \times 10^{-19} \times -1.6 \times 10^{-19}) / (5.3 \times 10^{-11})^2$$

$F_e = -8.2 \times 10^{-8}$ C (negative sign indicates that the force is attractive).

6. Determine if the following statements are true or false. If a statement is false correct it so that it is true.
   a. Coulomb’s law is valid only for point charges.
   b. A neutral object has a different number of positive and negative charges.

**Answer:**
   - a. True.
   - b. False. Positive and negative charges are equal in a neutral object.

7. The charge of particle A is $2 \mu$C and the charge of particle B is $4 \mu$C. If they repel each other with a force of 1.8 N, calculate the distance between them.

**Answer:**
- Charge of A ($q_1$) = $2 \mu$C.
- Charge of B ($q_2$) = $4 \mu$C.
- Electrostatic force ($F_e$) = 1.8 N.

According to Coulomb's law $F_e = kq_1q_2/r^2$

$$1.8 = (9 \times 10^9 \times 2 \times 10^{-6} \times 4 \times 10^{-6}) / (r)^2$$

$r^2 = 0.04$.

$r = 0.2$ m.

8. The force between two particles with charge $Q_1$ and $Q_2$ is $F$ and the distance between them is $R$. Determine the change in magnitude of force between them in the following cases:
   a. $Q_1$ is doubled.
   b. $R$ is halved.
   c. Both $Q_1$ and $Q_2$ are doubled.
   d. $Q_1$ is doubled and $Q_2$ is halved.
   e. $R$ is tripled.

**Answer:**
   - a. If $Q_1$ is doubled, $F$ is also doubled.
   - b. If $R$ is halved, $F$ is quadrupled.
   - c. If both $Q_1$ and $Q_2$ are doubled, $F$ is quadrupled.
   - d. If $Q_1$ is doubled and $Q_2$ is halved, $F$ remains unchanged.
   - e. If $R$ is tripled, $F$ becomes $F/9$. 

Teacher Guide: Electric Forces

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9. Describe the similarities and differences between Newton’s law of gravitation and Coulomb’s law of electric forces.

**Answer:**

**Similarities:**
- a. The form of equations, for both laws is similar.
- b. Both laws are governed by the inverse square law.
- c. Both have constants.

**Differences:**
- a. Mass in the gravitational law is replaced by charge in the law of electric forces.
- b. The constant used in both equations are different.

10. The charge of particle A is 3\(\mu\)C and the charge of particle B, placed at a distance of 2 m from A, is -6\(\mu\)C. If \(F_A\) is the force exerted by A on B and \(F_B\) is the force exerted by B on A, determine which of the following statements is correct. Justify your answer.

   a. \(F_A > F_B\).
   b. \(F_A < F_B\).
   c. \(F_A = F_B\).
   d. Cannot be determined.

**Answer:** Option C is the correct option. According to Coulomb’s law \(F_e = k|q_1q_2| / r^2\). The value of force calculated is equal as the charges and distance involved remain constant.
Student Investigation Sheet
Electrostatic Forces at Work

Introduction

In this investigation you will explore the forces produced by electrically charged objects. You will rotate through several stations making observations about charged objects such as acrylic rods, clear adhesive tape and aluminum pie shells. As you record observations at these stations, try to explain the behavior of the objects using what you know about electric charge and electric force.

Safety Precautions:
Wear closed-toe shoes. If you have a pacemaker or use another electronic medical device, do not go near Van de Graaff generators. Electric fields may interfere with the operation of these devices. People with known heart problems should also avoid Van de Graaff generators.

Objective(s):
In this activity, you will investigate the relationship between electric charge and electric force.

Materials:
- 1 rolls of clear adhesive tape (Station #1)
- 1 bag of balloons (Station #2)
- 3 acrylic rods (one each for Stations #3, #4 and #5)
- 3 pieces of wool or silk (one each for Stations #2, #3, #4 and #5)
• 1 set of pith balls (Station #5)
• Optional: 1 Van De Graaff generator (Station #6)
• Optional: 3 aluminum pie shells (Station #6)

Student Data Table:

<table>
<thead>
<tr>
<th>Station:</th>
<th>Observations</th>
<th>Possible Explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
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<td>4</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Key Question

**What is the question you want to answer?**

*Directions: Write the question for the investigation. The question should be specific and investigable.*

**Key Components**
- Specific (one general thought, does not combine two or more questions)
- Is able to be investigated

### Hypothesis

**What do you predict will be the result of the investigation?**

*Directions: Develop a claim about what you think is going to happen.*

**Key Components**
- Expresses a cause-and-effect relationship
- Is testable
- Incorporates prior knowledge
### How will you investigate the question?

**Directions:** Describe the plan that you will use to study your question and analyze your hypothesis.

**Key Components**
- Plan is easily repeatable by others
- Plan describes the use of materials
- Plan is in a logical order
### Data

<table>
<thead>
<tr>
<th>What evidence was gathered during the investigation?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Directions:</strong> Record all of the evidence that has been collected. Use graphic organizers, tables, and graphs when appropriate.</td>
</tr>
</tbody>
</table>

**Key Components**

- Data (from an investigation and/or other sources, such as observations, reading material, archived date, etc.)
- Appropriate (data applies directly to the question)
- Sufficient (uses enough data to completely answer the question and determine a finding on the hypothesis)
### Conclusion

**What did you learn from this investigation?**

<table>
<thead>
<tr>
<th>Directions: Develop a conclusion for your investigation. The conclusion should contain clear thoughts and proper vocabulary. This section focuses on the answer to your question. It should prove or refute the hypothesis by using logical reasoning to link the hypothesis to the data.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Key Components</strong></td>
</tr>
<tr>
<td>• Use precise and accurate language</td>
</tr>
<tr>
<td>• Use scientific vocabulary</td>
</tr>
<tr>
<td>• Provide clear logical thoughts</td>
</tr>
<tr>
<td>• Use evidence and reasoning to support or refute the hypothesis</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. What caused the initial behavior of the clear adhesive tape? After the tape was adhered together and pulled apart, what caused the change in behavior?

2. What caused the observed behavior of the balloon?

3. What caused the observed behavior of the stream of water when it was brought near the acrylic?

4. What caused the observed behavior of the polystyrene foam bits when the rod was brought near it?

5. How do the pith balls respond when the charged acrylic rod is brought near them? What happens when the rod makes contact with the pith balls? Why does this change the behavior of the pith balls?

6. (Optional) What caused the observed behavior of the aluminum pie shells at Station #6?
Hands-On Lab
Testing Methods for Charging Objects

Timing: one 90-minute class sessions

Objective(s):
Students will develop a procedure to test which substances provide the greatest charge by friction. The procedure will involve making some non-quantitative observations by charging pith balls by conduction with the rod.

Then, students will be shown a force diagram for a charged pith ball that is being deflected by another equally and similarly charged pith ball and challenged to identify ways to adjust their procedure to provide a quantitative comparison of the amount of charge provided by the different substances.

Safety Precautions:
- Follow all lab safety guidelines.
- Be careful when handling glass rods.
- Notify the instructor immediately if you see any broken glass. Do not try to clean it up yourself.
- Tie back long hair.
- Do not eat or drink anything in the lab.

Materials:
Per group:
- thread, 2 pieces of fine silk or cotton each approximately 50 cm long
- pith ball, 2 identical small
- mass scale
- ring stand
- clamp
- support rod, metal
- rod, plastic
- rod, glass
- rod, metal
- fur
- silk
- support rod, nonmetal (preferably wood or glass)
- light source
- vertical screen on base or piece of white paper taped to vertical surface, such as the side of a box
- paper
- ruler
- scotch tape

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- If possible, experiment should not be performed on a humid day, as charges will dissipate more quickly.
- If pith balls cannot be obtained, small polystyrene spheres covered in aluminum foil can also be used.
- Remind students that they must work quickly when making measurements, as the charge on the pith balls will dissipate in a short period of time.
- In order to allow students to focus solely on the experimental investigations, the pith balls can be attached to the supports before the start of the lab.
Teacher’s Note
The procedure for this lab is fairly complex. You may want to demonstrate some of the techniques, such as charging the rod by friction, touching the pith balls with the rod to charge them by conduction, and using the screen to mark the deflection of the hanging ball in Part 2. The students’ role will be to apply these techniques to testing which combination of substances provides the greatest charge by friction.

Procedure:

Part 1 Non-Quantitative Observation
1. Measure the mass of one of the pith balls.
2. Use a clamp to attach the metal support rod to one end of the ring stand. The support rod should be positioned horizontally approximately two feet above the table.
3. Tie one end of each of the thin threads to the polystyrene ball whose mass you measured. Attach the opposite end of both threads to the support rod so that the pith ball is only free to swing in one plane. This pith ball is the "hanging pith ball."
4. Attach the other pith ball to one end of the nonmetal support rod. It should not swing freely. This is the "attached pith ball."
5. Touch both pith balls with your hand to make them electrically neutral.
6. Choose one of the test rods and rub it with either the fur or silk.
7. Touch the test rod to both pith balls. Set the test rod out of the way and then move the attached pith ball close to, but not touching, the hanging pith ball. Observe the movement of the hanging pith ball and record the observations in a data table similar to the one that follows.
Table 1: Sample student data table.

<table>
<thead>
<tr>
<th>Rod</th>
<th>Material</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>plastic</td>
<td>fur</td>
<td></td>
</tr>
<tr>
<td>plastic</td>
<td>silk</td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>fur</td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td>silk</td>
<td></td>
</tr>
<tr>
<td>metal</td>
<td>fur</td>
<td></td>
</tr>
<tr>
<td>metal</td>
<td>silk</td>
<td></td>
</tr>
</tbody>
</table>

8. Repeat steps 5–7 with all of the other possible combinations of test rod and material.
9. Use the observations in the data table to determine which combination of rod and material transfers the greatest amount of charge onto or off of the pith balls. Write a brief description of the procedure that you have determined will transfer the greatest number of electrons onto or off of the pith balls. What evidence was there that this procedure was more effective?

Part 2 Quantitative Data

Before they begin work, ask students to consider how they might determine how much charge was transferred by the different combinations. Listen to their suggestions. Ask them to consider the forces acting on a deflected charged pith ball. Consider showing them a force diagram such as the one shown below. In this diagram, $T$ represents the tension of the strings, $F_g$ represents the force of gravity on the pith ball, and $F_e$ represents the electrical force on the pith ball. The angle of the deflection of the string from the vertical is $\theta$. 

![Force diagram](image)
Guide students to see that they can use the apparatus from Part 1 but make measurements, and they can easily calculate some of these quantities. The weight, \( F_w \), can be calculated as mass times free-fall acceleration. The tangent of the angle of displacement, \( \theta \), can be determined from the distance the ball is deflected divided by the length of the pendulum. With those values determined, students can find the tension, \( T \), and solve for the electrostatic force, \( F_e \).

Below is an example procedure that applies this approach.

10. Attach a piece of paper with tape to the screen (or other vertical surface) behind the apparatus.
11. Shine the light source from in front of the apparatus so that the shadow of both pith balls can be clearly seen on the piece of paper. Draw the shadow of the undeflected position of the hanging pith ball on the paper.

![Diagram of apparatus with shadow and measurements]

12. Measure the distance between the lamp and the pith ball. Record this value in the data table as \( a \). Measure the distance between the lamp and the screen and record this value in the data table as \( b \).

### Table 2: Sample Student Data Table.

<table>
<thead>
<tr>
<th>Charging materials</th>
<th>( a ) (m)</th>
<th>( b ) (m)</th>
<th>( L ) (m)</th>
<th>( d ) (m)</th>
<th>( r ) (m)</th>
</tr>
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<tbody>
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</table>

13. Measure the length between the ring stand and the center of the undeflected hanging pith ball. Record this value in the data table as \( L \). The same value should be used for \( L \) for all trials.
14. For the remainder of the experiment, be careful not to move the ring stand supporting the hanging pith ball, the paper, or the lamp. (If the apparatus remains unmoved, the same values of \( a \) and \( b \) can be used for all trials.)
15. Touch both pith balls with your hand in order to ground them and make them electrically neutral.

16. Use the chosen rod and material to charge the attached pith ball. Then briefly touch the hanging pith ball with the attached pith ball by moving the non-conducting rod closer. Then, separate the balls.

17. Move the pith ball attached to the nonmetal support rod far enough away so that the hanging pith ball remains undeflected.

18. Slowly move the ring stand with the clamp holding the non-conducting rod and the attached pith ball closer to the system until the hanging pith ball just begins to move. Be sure to adjust the height of the non-conducting rod and the attached pith ball so that both pith balls remain at the same height.

19. Trace the shadow made by the two pith balls on the paper. Be careful not to touch either pith ball while labeling the location.

20. Attach a new piece of paper to the screen. Ground the pith balls by touching them. Repeat this process for the different combinations of rods and materials used to rub the rods. All data points must be taken quickly in order to avoid dissipation of the charge.

21. Once all the data is collected, make measurements of the shadows you marked on the papers for each trial. For each of the data points, measure the distance \( d \) between the centers of the undeflected position of the hanging pith ball and its deflected position. Also measure the distance \( r \) between the centers of the two pith balls. Place these quantities in the data table.

22. The distances \( d \) and \( r \) describe the relationship among the shadows. To convert these to distances that involved the actual pith balls, multiply each of them by the factor of \( a/b \). Record the results of your calculations in the table that follows.
Table 3: Sample Student Calculation Table.

<table>
<thead>
<tr>
<th>$d' = d \times (a/b) \text{ (m)}$</th>
<th>$r' = r \times (a/b) \text{ (m)}$</th>
<th>$1/(r')^2 \text{ (1/m}^2\text{)}$</th>
<th>$F_e \text{ (N)}$</th>
<th>$q \text{ (C)}$</th>
</tr>
</thead>
<tbody>
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</table>

23. Use the quantities in your calculation table to calculate the electric force on the pith ball and record it in the calculation table. In the following calculations: $T = \text{tension}$, $\theta = \text{angle string makes with the vertical}$, $m = \text{mass of pith ball}$.

\[
\tan \theta = \frac{d'}{L}
\]

\[
T \cos \theta = mg
\]

\[
T = \frac{mg}{\cos \theta}
\]

\[
F_e = T \sin \theta = \left( \frac{mg}{\cos \theta} \right) \sin \theta
\]

\[
F_e = mg \tan \theta
\]

\[
F_e = mg \left( \frac{d'}{L} \right)
\]

24. Based on Coulomb's law, the electric force, $F_e$, is also given by the equation below, which can be rearranged to solve for the charge, $q$, on each of the pith balls. Use the value of $8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$ for $k$, the electrostatic constant.

\[
F_e = k \left( \frac{q^2}{(r')^2} \right)
\]

\[
q^2 = \frac{F_e (r')^2}{k}
\]

\[
q = \sqrt{\frac{F_e (r')^2}{k}}
\]
25. As an extension, lab groups may be challenged to identify ways to further improve the charging method. Some possible variables to adjust might include: to measure the time spent rubbing the rod with material, to determine whether multiple rounds of charging the pith balls before moving them together allows more charge to accumulate, and/or to determine whether the lengths of the threads have any effect on the amount of charge placed on the pith balls.

Analysis and Conclusions

1. What is occurring on an atomic/molecular level as a net charge created on the rod?
   [Electrons are being transferred between materials. This happens because the atoms of some materials have extra electrons in their outermost shell while others are missing.
   A pith ball is coated with a material that allows excess charge to move freely. When a neutral pith ball is touched by a positively charged rod, electrons flow off the pith ball onto the rod, leaving the pith ball positively charged. When touched by a negatively charged rod, electrons flow off of the rod onto the pith ball, leaving the pith ball negatively charged. In both cases, the pith ball acquires the charge of the rod.]

2. How does the attached pith ball cause the hanging pith ball to move?
   [Because both pith balls are touched by the same rod, they acquire the same type of charge. Because like charges repel, the two pith balls exert repulsive forces on each other.]

3. What happens when you rub your hand over a charged pith ball?
   [Rubbing your hand over the charged pith ball removes excess charge by grounding it, allowing the excess charge to flow into the earth, making the ball electrically neutral.]

4. Which combinations of rod and material resulted in the largest amount of charge transfer? Why?
   Were your results from the non-quantitative part of the investigation the same as the results when you took quantitative measurements?
   [A glass rod rubbed with silk will transfer the greatest amount of positive charge onto the rod. A plastic rod rubbed with fur will transfer the greatest amount of negative charge onto the rod.]

5. Why didn’t the metal test rod result in any significant movement of the hanging pith ball?
   [Rubbing the materials over the metal rod will transfer electrons onto or off of the rod. However, the metal rod is a conductor, so the charge will quickly dissipate through your hand and be grounded.]

6. Why was it important to support both pith balls with non-conducting material?
   [In order to maintain the charge on the pith balls, neither one should be grounded. Otherwise, the charge would escape out of the system.]
7. Did any charge leak off of the pith balls? Explain what evidence you have for your answer.
   [The pith balls gradually got closer together, so this is a sign that charge was leaking off of them into
   the surroundings.]

8. How would you improve the design of the investigation and the apparatus to get better results? If
   you have time and your instructor's permission, test your proposed improvements.
   [Answer will vary. Sample answer: Instead of measuring the shadows, we clamped a meter stick to the
   ring stand for the hanging ball. We took a cell phone picture of the undeflected hanging pith ball. When
   it deflected, we took another cell phone picture of it and the attached pith ball with the meter stick
   visible. Later, we took our data off of the pictures. This was a much faster and simpler way to record
   data than drawing the shadows.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Develop predictions/hypotheses that state what may happen in an investigation based on prior knowledge or experience (prediction).

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
  - Explain the investigative processes by:
    - describing the logical sequence that was used to conduct the investigation.
    - describing it so that it can be easily repeated by a fellow scientist.
    - Function exactly like or similarly to the real thing.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Mass
    - Length/distance/depth
  - Choose appropriate tools to conduct an investigation
    - Ruler/tape Measure
    - Scale or balance
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
    - Kinesthetic (balance, position)
  - Uses the appropriate format to record data:
    - Table

- **Interpret Data**
  - Sorts and classifies using scientific reasoning:
    - Objects, substances, and organisms by characteristic
  - Identifies and interprets patterns
    - Trends in data
    - Tables and graphs
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Comparing results to hypothesis
    - Identifying alternative explanations

- **Communication in Science**
  - Report results using:
    - Peer presentation
    - Table/graph showing data
Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Gravity

Overview

The law of gravitation states that the gravitational force acting between two bodies is directly proportional to their masses and inversely proportional to the square of the distance between them. In this Exploration, students observe the gravitational force acting between two bodies of different masses separated by varying distances.

Student Learning Objectives

- Investigate the effect of mass and distance on the gravitational force between two bodies.
- Observe the orbit followed by the smaller body around the larger body based on the imparted initial velocity.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, options for selecting the larger and the smaller bodies are available. Based on the selection of the larger body, three different options for the smaller body are provided. The initial distance between the two bodies can be selected using the Distance slider. The Velocity slider can be used to select an initial velocity imparted to the smaller body.

Once the students click on the Observe button, the orbit of the smaller body around the larger body is displayed. The smaller body follows a circular or elliptical path depending on the selected values. If the imparted velocity is large enough, the smaller body escapes the gravitational field of the larger body.

Students may use the Reset button to reset the Exploration and observe the gravitational force and the shape of the orbit for different selection.

The Tracker tab displays a summary of the values for all the runs. Students observe the effect of mass of the bodies, distance between them, and the initial velocity of smaller body on the shape of the orbit and the minimum and maximum force of gravitation.

Answers to Questions in the Student Worksheet

1. Write the SI unit for gravitational constant, G.

   Answer: The unit for gravitational constant G is Nm² / kg².
2. If the force of gravity acts on all bodies proportional to their masses, then explain why a heavy body does not fall to the Earth faster than a light body.

**Answer:** Even though the force of gravity is proportional to the masses of bodies the gravitational field of Earth around the surface of the Earth is constant. So if the objects of different masses are dropped from the same height then they will hit the surface of the Earth at the same time.

3. Explain why the law of gravitation \( F = \frac{G m_1 m_2}{r^2} \) is classified as an inverse square law.

**Answer:** According to the law of gravitation, every particle in the universe attracts every other particle with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

\[ F = \frac{G m_1 m_2}{r^2}. \]

As distance \( r \) increases, the magnitude of the force decreases by a factor of \( \frac{1}{r^2} \). This is the inverse square law.

4. Determine the acceleration due to gravity on Earth's surface, if its density is doubled while keeping its radius constant (acceleration due to gravity \( g = \frac{GM}{R^2} \) where \( G \) is the gravitational constant, \( M \) is the mass of the Earth, and \( R \) is Earth's radius).

**Answer:**

\[ g = \frac{GM}{R^2}. \]

If the density of Earth is doubled while keeping the radius constant.

Density \( (\rho) = \frac{M}{V} \).

That is \( M = \rho \times V \).

\[ V = \frac{4}{3} \pi R^3. \]

\[ M = \rho \times \frac{4}{3} \pi R^3. \]

If the density of Earth is doubled, keeping the radius constant, then the new mass of Earth will be,

\[ M' = 2 \rho \times \frac{4}{3} \pi R^3. \]

\[ M' = 2 \times (M). \]

Since \( g = \frac{GM}{R^2} \),

Substituting \( M' \) in the equation mentioned above.

\[ g' = \frac{GM'}{R^2}. \]

\[ g' = \frac{G2M}{R^2}. \]

\[ g' = 2g. \]

The acceleration due to gravity will be doubled.
5. Determine the mass of the moon if you are given the following data (Given: Mass of Earth, Force acting on the Moon due to Earth and the distance between the centers of Earth and the Moon).

**Answer:** Assume that the mass of Earth (M), force acting on the Moon due to Earth and the distance between the centers (F<sub>e</sub>), and distance between the centers of Earth and the Moon (d)
Consider Mass of the Moon to be m

\[ F_e = \frac{GMm}{d^2}. \]
So, \( m = \frac{F_ed^2}{GM} \).

Since the values of mass of Earth, force acting on the Moon due to Earth, and the distance between the centers of Earth and the Moon are known, we can determine the value of mass of the Moon.

6. It is known that acceleration due to gravity at the surface of the Earth is \( \frac{GM}{R^2} \), where M and R are the mass and radius of the Earth. Show that on a hypothetical planet having half the diameter of the Earth and twice its density, the acceleration due to gravity will be same as that of the Earth.

**Answer:** \( g = \frac{GM}{R^2} \).
If the density of the planet is twice the density of Earth and the radius is reduced by half.

- Density \( (\rho) = \frac{M}{V} \).
- That is \( M = \rho \times V \).
- \( V = \frac{4}{3} \pi R^3 \).
- \( M = \rho \times \left(\frac{4}{3} \pi R^3\right) \).

If the density of the planet is twice the density of Earth and the radius is reduced to half

- \( M' = 2\rho \times \left(\frac{4}{3} \pi \left(\frac{R}{2}\right)^3\right) \).
- \( M' = 2\rho \times \left(\frac{4}{3} \pi R^3 / 8\right) \).
- \( M' = \rho \times \left(\frac{4}{3} \pi R^3 / 4\right) \).
- \( M' = \frac{M}{4} \).

Since \( g = \frac{GM}{R^2} \)
Substituting \( M' \) and \( R' \) in the equation mentioned above.

- \( g' = \frac{GM'}{R'^2} \).
- \( g' = G(M / 4) / (R / 2)^2 \).
- \( g' = g \).

The acceleration due to gravity will be the same.

7. The magnitude of the force of gravity between two identical objects is given to be \( F_0 \). Calculate the new force of gravity between the objects if the mass of each object and the distance between them is doubled.

**Answer:** According to the law of gravitation, \( F = \frac{Gm_1m_2}{r^2} \).
It is given that the two objects are identical. So their masses are equal.
\[ F_0 = \frac{Gmm}{r^2} = \frac{Gm^2}{r^2}. \]

Now, if the masses and the distance between the two objects is doubled

New mass \((m') = 2m\)

New distance \((r') = 2r\)

Substituting in the above equation.

\[ F = \frac{G (m')^2}{(r')^2} = \frac{G (2m)^2}{(2r)^2}. \]

\[ F = G \times 4 \times m^2 / 4 \times r^2. \]

\[ F = Gm^2 / r^2 \]

So \( F = F_0. \)

8. Determine the value of the gravitational field at the surface of Earth if the gravitational field around an object of mass \( m \) is given by \( F_g / m \) (\( F_g \) is the gravitational force on the object due to Earth).

**Answer:** \( F_g = GMm / R^2. \)

\( R \) is the radius of the Earth since the object is placed on the surface of the Earth. 

Gravitational field = \( F_g / m. \)

Gravitational field = \( (GMm / R^2) / m. \)

Gravitational field = \( GM / R^2. \)

9. State whether nature of gravitational force is attractive or repulsive.

**Answer:** Force of gravitation is always attractive.

10. State whether the gravitational force between two bodies is affected by the following factors.

   a. Distance between the two objects.

   b. Mass of the two objects.

   c. Medium in which they are placed.

   d. Density of the two objects.

**Answer:**

   a. Yes.

   b. Yes.

   c. No.

   d. Yes.
Hands-On Lab
Gravity

Timing: one 90-minute class session

Objectives: In this lab, students will make observations and implement investigative procedures, including formulating testable hypotheses about how the law of universal gravitation applies to objects near Earth's surface.

Safety Precautions:
The students will need to drop a variety of objects from different heights. Instruct them to be careful not to drop objects that might break, and not to drop objects on their feet. It is best to require students to wear closed-toe shoes. Also, they should try to control the dropped items after they hit the floor, and should be careful not to trip on items on the floor.

Materials:
Per class
• 1 balance or mass scale
Per group of 3 or more:
• 1 meter stick
• 1–3 small objects, such as a penny, a tennis ball, and a baseball (or other objects of varying mass, size, or shape)
• 1 stopwatch
• motion-sensing probe and data-logging software (optional)

Teacher Preparation:
The materials list suggests that you provide each group with 1 penny, 1 tennis ball, and 1 baseball, but the important point is that each group will need objects of varying mass, size, or shape. Assemble a collection of objects for the students to use. Use objects that will not break or damage the floor when students drop them from heights of 2 meters or more. Smaller, compact objects will help the students obtain consistent results. Other examples include a standardized mass set, small stones, or balls from various sports such as golf or racquetball.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Hold up a tennis ball and a baseball and ask the students what will happen if you drop them from similar heights. Drop them and ask the students to describe what they saw. Repeat this step using other objects along with the tennis ball and baseball, and ask the students to describe what they saw. You can direct the discussion using leading questions such as

- Did all objects fall at the same average speed? *(Yes, when they fell from the same height.)*
- What factors had an effect on the speed, if any? *(The height affected the final speed.)*
- Did the same object seem to fall at the same speed each time? *(Yes, when it fell from the same height.)*

Ask students what kind of hypothesis they could formulate that would be testable in an investigative procedure. What kind of observations would be necessary to gather evidence to either support or reject the hypothesis?

Review the basic concepts of \( g \), acceleration due to gravity near Earth's surface, with the students. Demonstrate for students a basic method of measuring the acceleration of an object:

1. Measure the mass of the object using the scale and record the result on the board.
2. Use the meter stick to measure the distance from the floor to the table or desk top and record the result on the board.
3. Recruit three volunteers. Assign one to be "dropper", one to be "spotter", and one to be "timer". The dropper will hold the object at the table top height, and the spotter will verify that the object is at the correct height. The timer will control the stopwatch and will focus on the floor where the object will land. The spotter will count down and say "drop", and the dropper will let go of the object. The timer will start the watch when the spotter says "drop" and will stop it when the object hits the ground.
4. Repeat Step 3 ten times for each object, and record the times on the board.
5. Calculate the average drop time using your data, and then use the equation for free fall to determine the average acceleration of the object.
An alternative method is to use a motion sensor and data-logging software to record the fall of the object.

Lead the students in brainstorming properties that might affect the acceleration of an object due to gravity. Ideas that might come up include an object's mass, its shape, and the height of the drop.

Have each group choose one variable to alter. Have them record in their notebooks a testable hypothesis of what will happen to \( g \) when they alter this variable. Have them choose a selection of objects that allow them to perform the test, and then have them implement an investigative procedure to test the hypothesis, following the procedure you demonstrated.

Have the students record the steps of their investigative procedure in their lab books, including an identification of the equipment and material to be used, observations to be made, the dependent and independent variables, constants, and controls. Have the students record their measurements in data tables, using SI units and the correct number of significant figures.

A portion of a data table for one of the objects might look like the following:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Time of drop in seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>0.42</td>
</tr>
<tr>
<td>3</td>
<td>0.43</td>
</tr>
<tr>
<td>4</td>
<td>0.53</td>
</tr>
<tr>
<td>5</td>
<td>0.43</td>
</tr>
<tr>
<td>6</td>
<td>etc.</td>
</tr>
</tbody>
</table>

Students should analyze their data to determine an average value of acceleration for each object and each choice of variable. Have them plot the average values on a graph of \( g \) versus the independent variable.

Encourage students to compare their results with other groups. Discuss as a class what factors could be altered without affecting the outcome of the experiment, and what factors had to be kept constant and why.
Guided Inquiry

Hold up a tennis ball and a baseball and ask the students what will happen if you drop them from similar heights. Drop them and ask the students to describe what they saw. Repeat this step using other objects along with the tennis ball and baseball, and ask the students to describe what they saw.

You can direct the discussion using leading questions such as:

- Did all objects fall at the same average speed? (Yes, when they fell from the same height.)
- What factors had an affect on the speed, if any? (The height affected the final speed.)
- Did the same object seem to fall at the same speed each time? (Yes, when it fell from the same height.)

Ask students what kind of hypothesis they could formulate that would be testable in an investigative procedure. What kind of observations would be necessary to gather evidence to either support or reject the hypothesis?

Lead the students in brainstorming properties that might affect the fall of an object due to gravity. Ideas that might come up include an object's mass, its shape, the angle of the drop, and the height of the drop.

Have each group choose one variable to alter. Have them record in their notebooks a testable hypothesis of what will happen to \( g \), the acceleration due to gravity, when they alter this variable. Have them choose a selection of objects that allow them to implement an investigative procedure to test the hypothesis. Have them present their procedure to you before they begin the experiment.

To guide them in designing the procedure, ask leading questions such as:

- What objects will you drop, and how will you determine their mass(es)? (They will drop one object, or several objects, and they will measure the mass on the scale.)
- How will you determine the height of the drop? (They can use a meter stick to measure the height.)
- What variables are involved in the equations of projectile motion, and how do they help you determine acceleration? (Projectile motion equations relate the gravitational acceleration to the distance an object falls and the time it has fallen. You can measure the distance and time to determine the acceleration.)
- What method will give better accuracy and precision: letting each group member perform the entire experiment, or assigning specific tasks to the members? (It will probably be best to have members focus on small parts of the experiment.)

Have the students record the steps of their investigative procedure in their lab books, including an identification of the equipment and material to be used, observations to be made, the dependent and
independent variables, constants, and controls. Have the students record their measurements in data tables, using metric units and the correct number of significant figures.

As an example, a group may choose to test whether mass affects an object’s acceleration due to gravity. Their procedure might be as follows:
1. Use the meter stick to measure the distance from the floor to the table top.
2. Choose three objects with different masses, and measure the mass of each on the scale.
4. Assign one group member to be "dropper", one to be "spotter", and one to be "timer". The dropper will hold one object at the table top height, and the spotter will verify that the object is at the correct height. The timer will control the stopwatch and will focus on the floor where the object will land. The spotter will count down and say "drop", and the dropper will let go of the object. The timer will start the watch when the spotter says "drop" and will stop it when the object hits the ground.
5. Repeat Step 4 ten times for each object.

A portion of a data table for one of the objects might look like the following:

**Falling Object Data Table**

<table>
<thead>
<tr>
<th>Object 1: Tennis ball</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong> 57.2 g</td>
</tr>
<tr>
<td><strong>Height</strong> 1.13 m</td>
</tr>
<tr>
<td><strong>Trial</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Students should analyze their data to determine an average value of acceleration for each object and each choice of variables. Have them plot the average values on a graph of \( g \) versus the independent variable.

Encourage students to compare their procedures and results with other groups. Discuss as a class what factors could be altered without affecting the outcome of the experiment, and what factors had to be kept constant and why.
Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What new questions did your results suggest to you? How could you extend this lab to answer these questions?
   **Sample Response:** The results made us wonder what the acceleration would be if we dropped the tennis ball from the school roof. We could extend the lab by testing a wider range of heights.

2. How do you explain variations between your results for each drop, for each object, or each variable? How do you explain variations between the results of different groups? What are the sources of the errors in drop times?
   **Sample Response:** Variations and errors result because we cannot do the exact same procedure each time. The dropper and spotter might not synchronize exactly, and the timer may not always time precisely. These variations might also cause differences between our results and other groups’ results.

3. Describe a situation where you could use what you have learned in this lab.
   **Sample Response:** If I am learning archery, I know that an arrow will drop the same amount every time it travels the same distance from bow to target, so I should learn to aim high.

4. What results would you expect if you could drop your objects from the school roof, or if you could drop a very heavy object like a school bus?
   **Sample Response:** It might be hard to conduct multiple trials in a consistent way with a school bus, and small objects dropped from the roof might be affected strongly by the wind. Therefore, actual results might vary. The average value of acceleration should be similar to our results, though.

5. Evaluate your investigative design. If you had enough time and resources, how could you change your investigation to improve the consistency and accuracy of your results? What other sort of creative or innovative methods could you use to test your hypothesis?
   **Sample Response:** We had a lot of variation in our results, so the design could be improved. We could design and build an automated timing device that would make more careful measurements.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.
    - can be answered with a science investigation or observational study.
  - Develop predictions/hypotheses that
    - state what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials - repeated tests with the same variables to check for variability of results.
  - Explain the investigative process by:
    - describing the logical sequence that was used to conduct the investigation
    - properly citing all equipment and materials.
    - describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and use the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Mass
    - Time
  - Choose appropriate tools to conduct an investigation
    - Choose appropriate tools to conduct an investigation
    - Clock/stopwatch
  - Use the appropriate format to record data:
    - Table
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns
    - Trends in data
    - Tables and graphs
    - Based on an analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - reporting trends and patterns in the data.
  - Assess the conclusion by:
    - Comparing results to hypothesis
    - Extrapolating results beyond the investigation
• Communication in Science
  o Report results using:
    ▪ Peer presentation
    ▪ Written report
    ▪ Table/graph showing data
• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
Hands-On Lab
Gravity

Timing: one 90-minute class session

Objectives: In this lab, students will make observations and implement investigative procedures, including formulating testable hypotheses about how the law of universal gravitation applies to objects near Earth’s surface. Students will use data in order to verify a mathematical representation of the Newton’s Law of Universal Gravitation and identify patterns to support this law.

Safety Precautions:
The students will need to drop a variety of objects from different heights. Instruct them to be careful not to drop objects that might break, and not to drop objects on their feet. It is best to require students to wear closed-toe shoes. Also, they should try to control the dropped items after they hit the floor, and should be careful not to trip on items on the floor.

Materials:
Per class:
- balance or mass scale, 1
- other objects of varying mass, size or shape
Per group of 3 or more:
- meter stick, 1
- stopwatch, 1
- small objects, 1–3 (such as a penny, a tennis ball, a marble, and a baseball, or motion-sensing probe and data-logging software (optional)

Teacher Preparation:
The materials list suggests that you provide each group with 1 penny, 1 tennis ball, 1 marble, and 1 baseball, but the important point is that each group will need objects of varying mass, size, or shape that are heavy and dense enough that air resistance is not an issue.

Assemble a collection of objects for the students to use. Use objects that will not break or damage the floor when students drop them from heights of 2 meters or more. Smaller, compact objects will help the students obtain consistent results. Other examples include a standardized mass set, small stones, or balls from various sports, such as golf or racquetball.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process also will be included. In some cases, students then may be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It also will be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Hold up a tennis ball and a baseball, and ask the students what will happen if you drop them from the same height. Drop them, and ask students to describe what they saw. Repeat this step using other objects along with the tennis ball and baseball, and ask students to describe what they saw. You can direct the discussion using leading questions such as

- Did all objects fall at the same average speed? Explain why you can be sure. *(Yes, when they fell from the same height, because they spent the same time in the air.)*
- What factors that you changed had an effect on the speed, if any? *(The height affected the final speed.)*
- Did the same object seem to fall at the same speed during all of the trials? *(No, it only fell with the same speed when it fell from the same height.)*

Ask students what hypothesis they could formulate that would be testable in an investigative procedure. What kind of observations would be necessary to gather evidence to either support or reject the hypothesis?

Review the basic concepts of \( g \), acceleration due to gravity near Earth's surface, with the students. Demonstrate for students a basic method of measuring the acceleration of an object:

1. Measure the mass of the object using the scale, and record the result on the board.
2. Use the meter stick to measure the distance from the floor to the table or desk top, and record the result on the board.
3. Recruit three volunteers. Assign one to be "dropper," one to be "spotter," and one to be "timer." The dropper will hold the object at the table-top height, and the spotter will verify that the object is at the correct height. The timer will control the stopwatch and will focus on the floor where the object will land. The spotter will count down and say, "drop", and the dropper will let go of the object. The timer will start the watch when the spotter says, "drop," and will stop it when the object hits the ground.
4. Repeat Step 3 ten times for each object, and record the times on the board.
5. Calculate the average drop time using your data, and then use the equation for free fall to determine the average acceleration of the object.

An alternative method is to use a motion sensor and data-logging software to record the fall of the object.

Lead the students in brainstorming properties that might affect the acceleration of an object due to gravity. Ideas that might come up include an object's mass, its shape, and the height of the drop.

Have each group choose one variable to alter. Have them record in their notebooks a testable hypothesis of what will happen to \( g \) when they alter this variable. Have them choose a selection of objects that allow them to
perform the test, and then have them implement an investigative procedure to test the hypothesis, following the procedure you demonstrated.

Have the students record the steps of their investigative procedure in their lab books, including an identification of the equipment and material to be used, observations to be made, the dependent and independent variables, constants, and controls. Have the students record their measurements in data tables, using SI units and the correct number of significant figures.

A portion of a data table for one of the objects might look like the following:

<table>
<thead>
<tr>
<th>Object 1: Tennis ball</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td>Trial</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Students should analyze their data to determine an average value of acceleration for each object and each choice of variable. They can use the equation \( d = \frac{1}{2} gt^2 \), and rearrange to solve for \( g \) (that is, \( g = 2d/t^2 \)). Have them plot the average values on a graph of \( g \) versus the independent variable.

Encourage students to compare their results with other groups. Discuss as a class what factors could be altered without affecting the outcome of the experiment, and what factors had to be kept constant and why.

Once student have discussed their results and concluded that the acceleration of all their objects was close to 9.8 m/s\(^2\), show them the following set of data:

| Acceleration due to Earth’s gravitational field at heights above sea level |
|-----------------------------|-----------------|
| Distance from sea level (km) | Acceleration due to gravity (m/s\(^2\)) |
| 0 (this is sea level)        | 9.81            |
| 3.1                         | 9.76            |
| 11                          | 9.74            |
| 160                         | 9.30            |
| 1600                        | 6.24            |
| 16000                       | 0.79            |
| 36000                       | 0.23            |
| 385000                      | 0.003           |
Ask the students as a group to calculate the distance from the center of Earth to each of the heights by adding 6400 km (the radius of Earth) to each distance.

In small groups or as a whole class, have the students make a graph of distance from the center of Earth versus acceleration due to gravity. Sketch the curve of best fit on the graph.

Ask students to reflect upon what kind of pattern the data forms, and lead them in a discussion about the significance of this inverse-squared relationship. Prompt them to understand the while Newton proposed his law, it took over 100 years to be verified by Cavendish.

**Guided Inquiry**

Hold up a tennis ball and a baseball, and ask students what will happen if they drop them from similar heights. Drop them, and ask students to describe what they saw. Repeat this step using other objects along with the tennis ball and baseball, and ask students to describe what they saw. You can direct the discussion using leading questions, such as

- Did all objects fall at the same average speed? Explain why you can be sure. *(Yes, when they fell from the same height, because they spent the same time in the air.)*
- What factors that you changed had an effect on the speed, if any? *(The height affected the final speed.)*
- Did the same object seem to fall at the same speed during all of the trials? *(No, it only fell with the same speed when it fell from the same height.)*

Ask students what hypothesis they could formulate that would be testable in an investigative procedure. What kind of observations would be necessary to gather evidence to either support or reject the hypothesis?

Lead the students in brainstorming properties that might affect the fall of an object due to gravity. Ideas that might come up include an object's mass, its shape, the angle of the drop, and the height of the drop.

Have each group choose one variable to alter. Have them record in their notebooks a testable hypothesis of what will happen to the acceleration of the object when they alter this variable. Have them choose a selection of objects that allow them to implement an investigative procedure to test the hypothesis. Have them present their procedure to you before they begin the experiment.

To guide them in designing the procedure, ask leading questions, such as

- What objects will you drop, and how will you determine their mass(es)? *(They will drop one object, or several objects, and they will measure the mass on the scale.)*
- How will you determine the height of the drop? *(They can use a meter stick to measure the height.)*
- What variables are involved in the equations of projectile motion, and how do they help you determine acceleration? *(Projectile motion equations relate the gravitational acceleration to the distance an object falls and the time it has fallen. You can measure the distance and time to determine the acceleration.)*
• What method will give better accuracy and precision: letting each group member perform the entire experiment, or assigning specific tasks to the members? *(It will probably be best to have members focus on small parts of the experiment.)*

Have the students record the steps of their investigative procedure in their lab books, including an identification of the equipment and material to be used, observations to be made, the dependent and independent variables, constants, and controls. Have the students record their measurements in data tables, using metric units and the correct number of significant figures.

As an example, a group may choose to test whether mass affects an object's acceleration due to gravity. Their procedure might be as follows:
1. Use the meter stick to measure the distance from the floor to the table top.
2. Choose three objects with different masses, and measure the mass of each on the scale.
3. Assign one group member to be "dropper," one to be "spotter," and one to be "timer." The dropper will hold one object at the table-top height, and the spotter will verify that the object is at the correct height. The timer will control the stopwatch and will focus on the floor where the object will land. The spotter will count down and say, "drop," and the dropper will let go of the object. The timer will start the watch when the spotter says, "drop," and will stop it when the object hits the ground.
4. Repeat Step 3 ten times for each object.

A portion of a data table for one of the objects might look like the following:

<table>
<thead>
<tr>
<th>Falling Object Data Table</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Object 1: Tennis ball</strong></td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Height</td>
</tr>
<tr>
<td><strong>Trial</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

Students should analyze their data to determine an average value of acceleration for each object and each choice of variables. Have them plot the average values on a graph of g versus the independent variable. *(Note that the type of graph will depend upon what variables students chose to investigate. If they varied mass, a line graph should be constructed of acceleration versus mass. If students varied the shape of the object while keeping the mass and surface area the same, the appropriate type of graph would be a bar graph or histogram.)*
Encourage students to compare their procedures and results with other groups. Discuss as a class what factors could be altered without affecting the outcome of the experiment, and what factors had to be kept constant and why.

Once students have discussed their results and concluded that the acceleration of all their objects was close to 9.8 m/s², show them the following set of data:

<table>
<thead>
<tr>
<th>Distance from sea level (km)</th>
<th>Acceleration due to gravity (m/s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (this is sea level)</td>
<td>9.81</td>
</tr>
<tr>
<td>3.1</td>
<td>9.76</td>
</tr>
<tr>
<td>11</td>
<td>9.74</td>
</tr>
<tr>
<td>160</td>
<td>9.30</td>
</tr>
<tr>
<td>1600</td>
<td>6.24</td>
</tr>
<tr>
<td>16000</td>
<td>0.79</td>
</tr>
<tr>
<td>36000 (satellite distance)</td>
<td>0.23</td>
</tr>
<tr>
<td>385000 (moon distance)</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Ask the students as a group to calculate the distance from the center of Earth to each of the heights by adding 6400 km (the radius of Earth) to each distance.

In small groups or as a whole class, have the students make a graph of distance from the center of Earth versus acceleration due to gravity. Sketch the curve of best fit on the graph.

Ask the students to reflect upon what kind of pattern the data forms, and lead them in a discussion about the significance of this inverse-squared relationship. Prompt them to understand the while Newton proposed his law in the late 1600s, it took over 100 years to be verified by Cavendish.
Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What new questions did your results suggest to you? How could you extend this lab to answer these questions?

   **Sample Response:** The results made us wonder what the acceleration would be if we dropped the tennis ball from the school roof. We could extend the lab by testing a wider range of heights.

2. How do you explain variations between your results for each drop, for each object, or each variable? How do you explain variations between the results of different groups? What are the sources of the errors in drop times?

   **Sample Response:** Variations and errors result because we cannot do the exact same procedure each time. The dropper and spotter might not synchronize exactly, and the timer may not always time precisely. These variations also might cause differences between our results and other groups’ results.

3. How do patterns in the data you collected support the Law of Universal Gravitation? How does the data provided to you support the lab?

   Note: If students chose to investigate a different variable, this answer will be very different. **Sample Response for students who varied mass:** In general, all the objects dropped from the same height reached the floor at the same time. This shows that acceleration due to gravity is independent of mass. In contrast, the data provided shows that acceleration does vary with height, although at heights close to Earth’s surface it is still very close to 9.8 m/s². However, the inverse-squared relationship results in rather low acceleration at distances as far away as a satellite in orbit around Earth.

4. Describe a situation where you could use what you have learned in this lab.

   **Sample Response:** If I am learning archery, I know that an arrow will drop the same amount every time it travels the same distance from bow to target, so I should learn to aim high to compensate for the fall of the arrow as it travels to the target.

5. What results would you expect if you could drop your objects from the school roof, or if you could drop a very heavy object like a school bus?

   **Sample Response:** It might be hard to conduct multiple trials in a consistent way with a school bus, and small objects dropped from the roof might be affected strongly by the wind. Therefore, actual results might vary. The average value of acceleration should be similar to our results, though.
6. Evaluate your investigative design. If you had enough time and resources, how could you change your investigation to improve the consistency and accuracy of your results? What other sort of creative or innovative methods could you use to test your hypothesis?

**Sample Response:** *We had a lot of variation in our results, so the design could be improved. We could design and build an automated timing device that would make more careful measurements.*

7. Express Newton’s Law of Universal Gravitation in words and as a mathematical equation. Why is this idea considered a scientific law and not a theory?

**Sample Response:** *In words, all objects with mass have a gravitational attraction to other objects with mass. The force between the objects is equal and opposite. It decreases as the square of the distances between the objects. The equation is \( F_g = (Gm_1m_2)/d^2 \), where \( G \) is the a constant equal to \( 6.673 \times 10^{-11} \) N m\(^2\)/kg\(^2\). The idea is considered a law because Newton proposed that gravity is universal, and repeated observations have confirmed that this equation for gravity consistently describes the magnitude of the force due to gravity.*
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time
    - can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that
    - state what may happen in an investigation based on prior knowledge or experience (prediction)

- Design Investigations
  - Design and conduct investigations using:
    - Fair test–changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials–repeated tests with the same variables to check for variability of results.
  - Explain the investigative process by:
    - describing the logical sequence that was used to conduct the investigation
    - properly citing all equipment and materials
    - describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - following lab safety procedures

- Gather Data
  - Use Tools and use the SI (metric) system) to accurately measure:
    - length/distance/depth
    - mass
    - time
  - Choose appropriate tools to conduct an investigation
    - Choose appropriate tools to conduct an investigation.
    - clock/stopwatch
  - Use the appropriate format to record data:
    - table
    - writing (journal, worksheet, electronic text)

- Interpret Data
  - Identify and interpret patterns
    - trends in data
    - tables and graphs
    - based on an analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - reporting trends and patterns in the data.
  - Assess the conclusion by:
    - comparing results to hypothesis
    - extrapolating results beyond the investigation

- Communication in Science
  - Report results using:
    - peer presentation
    - written report
- table/graph showing data
- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - evaluating an investigative design
    - evaluating data for accuracy
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Movements in Space

Overview

Johannes Kepler, a German mathematician, developed the three laws of planetary motion in the early 1600s. Along with the law of gravity, these laws describe the revolution of a planet around the Sun. In this Exploration, students observe the effects of Kepler’s first and second laws of planetary motion. Students also use Kepler’s third law of planetary motion to calculate the orbital period of the planet.

Student Learning Objectives

• Examine Kepler’s first and second law of planetary motion.
• Calculate the orbital period of the planet using Kepler’s third law of planetary motion.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion. Some questions require critical thinking and application of concepts and math skills that students may or may not have covered. These questions are best completed as a class than as individual assessments.

Using this Exploration

In the Explore tab, students select a planet that they want to examine to observe Kepler’s laws of planetary motion in action. After selection, students use the Proceed button to go to the next step of the Exploration.

In the second step of the Explore tab, students select the correct semi-major axis of the selected planet using the options in the Select Semi-major Axis dropdown list. Students then select the time lap for which they want to observe the area swept out by the planet using the options in the Select Time Lap dropdown list. Students use the Observe button to examine how the selected planet follows the Kepler’s first (planets move in elliptical orbits with the Sun at one focus of the ellipse) and second law (a line that connects a planet to the Sun sweeps out equal areas in equal times as the planet orbits the Sun) of planetary motion. If the selected semi-major axis is incorrect, students are prompted to try again. If the correct axis is selected, the selected planet revolves around the Sun in an elliptical orbit following Kepler’s first law of planetary motion. The selected planet also sweeps equal areas of its elliptical orbit for the selected time lap following Kepler’s second law of planetary motion.

Students then use the Proceed button to analyze the graph of the cube of the semi-major axis \(a^3\) versus the square of the orbital period \(T^2\). Based on the cube of the semi-major axis plotted on the \(y\)-axis, students select the correct position of the planet on the graph. The correct position reveals the value of the square of the orbital period plotted on the \(x\)-axis. Students use the Proceed button to identify the orbital period of the selected planet using the radio button options. (Note: If students have trouble with this, remind them that the graph is not a vs. \(P\), but
$a^3 \text{ vs. } T^2$. They will need to take the square root of the $x$-value to determine the orbital period, $T$.)

Students may use the Reset button to undo what they have done and select another semi-major axis and time lap for the selected planet. They may also use the Select Another Planet button to observe Kepler’s laws of planetary motion for another planet.

In the Tracker tab, students track the semi-major axis, orbital period, selected time lap, and area swept by planets for which they have observed Kepler’s laws of planetary motion.

**Answers to Questions in the Student Worksheet**

1. State the following Kepler’s laws of planetary motion:
   
   a. Law of Orbits (Kepler’s First Law)
   
   b. Law of Areas (Kepler’s Second Law)

   **Answer:**
   
   a. Kepler’s first law of planetary motion, also known as the law of orbits, states that “*All planets move in elliptical orbits, with the Sun at one focus.*”

   b. Kepler’s second law of planetary motion, also known as the law of areas, states that “*An imaginary line that connects a planet to the Sun sweeps out equal areas in equal times.*”

2. Explain the term eccentricity of an orbit. What is the eccentricity of an elliptical orbit as opposed to a perfectly circular orbit?

   **Answer:** The eccentricity of the orbit describes the amount by which the orbit deviates from a perfect circle. The eccentricity of an elliptical orbit is greater than 0 but less than 1, whereas the eccentricity of a perfect circle is 0.

3. Define the terms perihelion and aphelion. Identify the perihelion and aphelion of Earth’s orbit around the Sun.

   **Answer:** The point in the orbit when a planet is closest to the Sun is called the perihelion while the point in the orbit when a planet is farthest from the Sun is called the aphelion. Earth’s perihelion is 0.9833 AU and its aphelion is 1.017 AU.

4. Identify the parameters that define an elliptical orbit.

   **Answer:** An elliptical orbit of a planet is defined by its semi-major axis ($a$), its eccentricity, and the position of its two foci. It can also be defined in terms of the perihelion, aphelion, and semi-minor axis.
5. Use the exploration to compare how the planets move when they are close to perihelion versus how they move when they are close to aphelion.

**Answer:** The planet moves faster around the Sun at perihelion than at aphelion. The acceleration of a planet in an orbit around the Sun is inversely proportional to the square of the planet’s distance from the Sun. The distance of the planet from the Sun at the perihelion is lesser than the aphelion. Therefore, the acceleration of the planet around the Sun at perihelion is greater than the acceleration at the aphelion.

6. The perihelion \((R_p)\) of Mars’ orbit is 1.381 AU while its aphelion \((R_a)\) is 1.666 AU. Using the relation \(R_p = a(1 - e)\) and \(R_a = a(1 + e)\), where \(a\) is the length of the semi-major axis and \(e\) is the eccentricity of the orbit, calculate \(a\) and \(e\) for Mars’ orbit around the Sun. Show all of your work.

**Answer:**

\[
a = 1.524 \text{ AU}
\]

\[R_p = a(1 - e) \quad \text{---- eq. (1)}\]
\[R_a = a(1 + e) \quad \text{---- eq. (2)}\]

For Mars,
\[R_p = 1.381 \text{ AU}\]
\[R_a = 1.666 \text{ AU}\]

Substituting the values, \(R_p\) and \(R_a\) in eq. (1) and eq. (2)
\[
1.381 \text{ AU} = a(1 - e) \quad \text{---- eq. (3)}
\]
\[
1.666 \text{ AU} = a(1 + e) \quad \text{---- eq. (4)}
\]

Adding eq. (3) and eq. (4)
\[
1.361 \text{ AU} + 1.666 \text{ AU} = a - ae + a + ae
\]
\[
3.047 \text{ AU} = 2a
\]
\[
a = 3.047 \text{ AU} / 2 = 1.524 \text{ AU}
\]

Substituting the value of \(a\) in eq. (3)
\[
1.381 \text{ AU} = a(1 - e) = 1.524 \text{ AU} (1 - e) = 1.524 \text{ AU} - 1.524 \text{ AU} \cdot e
\]
\[
1.524 \text{ AU} \cdot e = 1.524 \text{ AU} - 1.381 \text{ AU} = 0.143 \text{ AU}
\]
\[
e = 0.143 \text{ AU} / 1.524 \text{ AU} = 0.094
\]
7. Calculate the mass of the Sun using Kepler’s third law of planetary motion for the planet Venus. Show all of your work.

**Answer:** According to Kepler’s third law of planetary motion,

\[ T^3 = \frac{4\pi^2}{GM}a^3 \]

where \( T \) is the orbital period, \( a \) is the semimajor axis, \( G \) is the gravitational constant and \( M \) is the mass of the star (in this case, the Sun).

For Venus,

\( T = 0.615 \) Earth year

\[ = \left( \frac{0.615 \text{ years}}{\text{orbit}} \times \frac{365.25 \text{ days}}{\text{year}} \times \frac{24 \text{ hours}}{\text{day}} \times \frac{60 \text{ minutes}}{\text{hour}} \times \frac{60 \text{ seconds}}{\text{minute}} \right) \]

\[ = 1.94 \times 10^7 \text{ s} = 19,400,000 \text{ seconds} \]

\( a = 1.08 \times 10^{11} \text{ m} \)

\( G = 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \)

(recall that 1 N = 1 kg m/s²)

\[ M = \frac{4\pi^2a^3}{GT^2} \]

\[ = 4\pi^2(1.08 \times 10^{11} \text{ m})^3 / 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \times (1.94 \times 10^7 \text{ s})^2 \]

\[ = 4\pi^2(1.26 \times 10^{33} \text{ m}^3) / 6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2 \times (3.76 \times 10^{14} \text{ s}^2) \]

\[ = 4\pi^2(1.26 \times 10^{33} \text{ m}^3) / 25.10 \times 10^3 \text{ kg} \cdot \text{m}^2/\text{s}^2/\text{kg}^2 \]

\[ = (49.74 \times 10^{33} \text{ m}^3) / 25.10 \times 10^3 \text{ kg} \cdot \text{m}^2/\text{s}^2/\text{kg}^2 \]

\[ = (49.74 \times 10^{33}) / 25.10 \times 10^3 / \text{kg} \]

\[ = 1.98 \times 10^{30} \text{ kg} \]

The mass of the Sun is 1.98 \times 10^{30} \text{ kg}.

8. One AU is about 150,000,000 kilometers. What is the semi-major axis of Venus in meters?

**Answer:**

Semi-major axis of Venus = 0.723 AU

1 AU = 150,000,000 kilometers = 150,000,000,000 meters

Hence, the semi-major axis of Venus is

\[ 0.723 \text{ AU} \times 150,000,000,000 \text{ m/AU} = 108,450,000,000 \text{ meters}. \]
9. Examine the graph of $T^2$ vs. $a^3$. Explain the importance of using units AU for distance and Earth years for orbital period. What would the graph be like if length were plotted in meters or time were in seconds?

**Answer:** The units of length are in AU and of time are in Earth years in order to compare the distances from Sun and orbital periods of planets to those of Earth. The units that are used should not affect the shape of the trend line, but will affect the slope of the line.

10. Use the exploration to identify the planet whose orbit around the Sun is closest to a perfect circle. Identify the planet whose orbit around the Sun is the most elliptical. Explain your answer.

**Answer:** The eccentricity of a circle is 0 while the eccentricity of an ellipse is greater than 0 but less than 1. The planet whose orbit has an eccentricity closest to 0 has the orbit that is closest to a perfect circle. The planet whose orbital eccentricity is closest to 0 has the most elliptical orbit.

Venus has the most circular orbit (eccentricity of Venus’ orbit is 0.0068) while Mercury has the most elliptical orbit (the eccentricity of Mercury’s orbit is 0.206).
Use the simplified version of Kepler’s Third Law \( T^2 = a^3 \) to solve the problems below.

1. Suppose an asteroid orbits the Sun with a mean radius 11 times that of Earth. What is the period of the asteroid?  [answer: about 36 Earth years]

2. We know that the orbital period of Haley’s Comet is about 75 years. What is its mean radius from the Sun as compared to Earth?  [answer: about 18 times that of Earth]

3. A student is celebrating her 17\(^{th}\) birthday today. Mars is 1.52 times farther from the Sun than Earth. How old would she be in "Martian years" if she had lived her entire life in a space colony on Mars?  
   [answer: In "Martian years," she is about nine years old.]

4. Neptune’s orbit period is 164.8 Earth years. What is its orbital radius compared to Earth’s?  [answer: about 30.06 times greater]

5. Why is Kepler’s Third Law considered a law instead of a theory?  [answer: A theory attempts to provide a scientific explanation for a given phenomenon. A theory can be proven incorrect with any evidence to the contrary. A law, on the other hand, is a phenomenon that has been repeatedly observed and for which there are no exceptions. Kepler’s observations quantify celestial relationships that are known to exist without exception.]
Hands-On Lab
Calorimetry and the Energy of Food

Timing: one 90-minute class session

Objective(s):
Students will investigate the amount of energy stored in food items by using calorimetry. Students will develop a question and design an investigation to test it. They will then gather data, and evaluate and analyze their results. They will also have a chance to practice lab safety when using the calorimeter.

Safety Precautions:
You may wish to verify whether any students have any food allergies that affect your choice of food samples. Students should not eat or drink in lab, especially the food samples. Students should wear safety goggles and glasses when igniting the food samples and when handling the burnt samples. Students should be careful around open flames. Encourage students not to blow out burning samples, since the samples could easily blow away without going out; students should simply wait for any ignited samples to burn out on their own.

Materials:
Per pair or group:
- 1 ring stand with 1 ring support and 1 test-tube holder
- 1 empty soda can
- 3 paper clips or 10-cm pieces of stiff wire
- 1 graduated cylinder (100 mL)
- 1 thermometer
- 1 lighter or supply of matches
- Assorted food items, preferably dry, high-calorie (food calorie) items that can be broken into small pieces. Some ideas are nuts, potato chips, popcorn (popped), marshmallows, and energy bars
- Safety glasses
- Safety gloves

Per class:
- Water supply
- Pan balance

Teacher Preparation:
You may wish to punch holes in the soda cans (as described below) before class by using a pair of scissors or small nail, etc. You may wish to compile nutritional information of the different food samples onto an easy-to-read sheet and make copies to distribute to students. Prepare a copy of the Student Investigation Sheet for each student.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
You will really “grab” students’ attention by igniting the food sample in a demonstration. Start class by setting up and using the calorimeter as follows. (The following procedure is just one of several ways you can build a simple calorimeter.)

- Set up a ring stand with a ring support clamped 10—20 cm above the surface of the table.
- Take an empty soda can, and punch four evenly spaced holes around the can 2 to 3 cm from the can top. Run a stiff wire or straightened paper clip through two opposite holes, then run a second piece of wire or straightened paper clip through the other pair of opposite holes. Hang the can from the ring support by using these pieces of wire that stick out from the can. The can will be the water container of the calorimeter.
- Attach a test-tube holder to the ring stand below the soda can, a few centimeters above the table top.
- Straighten one end of a paper clip and hold it with the test-tube holder. Shape the other end of the paper clip as needed so that the clip will hold your food sample.
- Finally, adjust the height of the soda can so that it is suspended 10 cm above the food sample.
- Measure 100 g (100 mL) of water into the graduated cylinder, and then pour the water into the soda can. Insert the thermometer through the hole in the can top.
- Measure the mass of your food sample and then set it on the paper-clip holder.
- Observe and record the temperature of the water in the can.
- Ignite the sample by using the matches or lighter, repeating as necessary until it stays lit.
- When it is burnt out, observe the final temperature of the water. When the food sample is cooled, remove it and measure the final mass.
Lead the class in a discussion of what they have observed, and how it relates to transformations of energy. You may wish to ask leading questions such as:

- What type of energy is stored in the food? Into what other types of energy can it transform in the body? Into what kind of energy did the energy stored in the food transform when the food was burned? (Energy is chemical potential energy. It can transform into other forms of chemical energy that become mechanical or electrical energy in the body. Burning the food in the demonstration transformed the chemical potential energy into thermal energy.)
- How can you measure the amount of thermal energy released by the burning food? (The released thermal energy can be measured by using it to heat water and by measuring the change in the water’s temperature.)
- What do you predict will happen if you change the amount of food or the type of food? (Increasing the amount of food should cause a bigger change in temperature. Different types of food may have different amounts of stored energy, so the change in temperature may be harder to predict.)
- What properties of each food may relate to the amount of stored energy? How can you find out these properties? (The amount of fat or carbohydrate in the food may affect the amount of stored energy. This information can be found on the nutritional label of the food’s packaging, or on the Internet.)

You may need to review or explain to the class about calories and Calories. One calorie is the amount of energy needed to raise the temperature of 1 g of water by 1°C. Therefore, if the temperature of the 100 g of water in the calorimeter changed by 4°C, the water absorbed 400 cal of energy. One Calorie (or “1 fcal” or “1 food calorie” or 1 kcal) is 1,000 calories.

Have students sketch and label the setup of the calorimeter in their lab notebooks. Next, have each group choose variables to investigate. On the basis of their knowledge of transformations of energy, they should predict how altering independent variables, such as the mass of the water or the mass of the food sample to be tested, will change the outcome of dependent variables. Make sure the students explain their procedure in their notebooks.

Encourage students to discuss their procedures and results with other groups. Have the class discuss their results together and see if they can draw conclusions from the collected information. Ask if any groups studied similar variables, and then have those groups compare their results. Ask them if they can explain any differences in the outcomes of their tests.
Guided Inquiry

Students can develop their own plans for collecting data on the basis of their knowledge of energy stored in food and transformations between energy types. Ask students some guiding questions to help them focus their inquiry:

- What variables do you want to study?
- Which variables are the dependent variables?
- What variables can be the independent variables?
- What will be your constants?
- What type of data will you collect?
- What sort of connection do you expect to see between the dependent and independent variables?
- What is your hypothesis?

Have students work in groups, and ask students to design a procedure using calorimetry to investigate the amount of energy stored in food samples. Have them present their designs to you before they proceed. Make sure they can explain each element of the calorimeter design and each step in the investigative procedure. You may wish to summarize the connection between energy, calories, and Calories.

Make sure the students sketch and label their setup in their lab notebooks. They should also summarize the procedure they will follow, as well as their hypothesis or prediction.

A sample procedure for constructing a calorimeter is the following:

- Set up a ring stand with a ring support clamped 10—20 cm above the surface of the table.
- Take an empty soda can, and punch four evenly spaced holes around the can 2 to 3 cm from the can top. Run a stiff wire or straightened paper clip through two opposite holes, then run a second piece of wire or straightened paper clip through the other pair of opposite holes. Hang the can from the ring support by using these pieces of wire that stick out from the can.
- Attach a test-tube holder to the ring stand below the soda can, a few centimeters above the table top.
- Straighten one end of a paper clip and hold it with the test-tube holder. Shape the other end of the paper clip as needed so that the clip will hold your food sample.
- Finally, adjust the height of the soda can so that it is suspended 10 cm above the food sample.
- Measure 100 g (100 mL) of water into the graduated cylinder, and then pour the water into the soda can. Insert the thermometer through the hole in the can top.
- Measure the mass of your food sample and then set it on the paper-clip holder.
- Observe and record the temperature of the water in the can.
- Ignite the sample by using the matches or lighter, repeating as necessary until it stays lit.
• When it is burnt out, observe the final temperature of the water. When the food sample is cooled, remove it and measure the final mass.

Once students have designed their procedure, have them choose variables to investigate. The students will also have to develop a procedure for organizing and analyzing their data. Make sure they can explain how they will do this.

Students can choose between several different variables, such as the fat content and carbohydrate content in different food types. Another simple choice would be to choose one food type and to vary the mass of the sample. For this choice, sample data might look like this:

<table>
<thead>
<tr>
<th>Amount Water</th>
<th>100 mL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potato Chip</td>
<td>Sample 1</td>
</tr>
<tr>
<td>Mass before (g)</td>
<td>1.5</td>
</tr>
<tr>
<td>Mass after (g)</td>
<td>0.11</td>
</tr>
<tr>
<td>Change in mass (g)</td>
<td>0.39</td>
</tr>
<tr>
<td>Water temperature before (°C)</td>
<td>21</td>
</tr>
<tr>
<td>Water temperature after (°C)</td>
<td>41</td>
</tr>
<tr>
<td>Change in temperature (°C)</td>
<td>2.0 x10¹</td>
</tr>
<tr>
<td>Energy released (cal)</td>
<td>2.0 x10³</td>
</tr>
<tr>
<td>Energy released (Cal)</td>
<td>2.0</td>
</tr>
<tr>
<td>Energy per mass change (cal/g)</td>
<td>5.1</td>
</tr>
</tbody>
</table>

To help students in the process, you may wish to ask leading questions such as:
• What type of energy is stored in the food? Into what other types of energy can it transform in the body? Into what kind of energy will the energy stored in the food transform when the food is burned? (Energy is chemical potential energy. It can transform into other forms of chemical energy that become mechanical or electrical energy in the body. Burning the food will transform that energy into thermal energy.)
• How can you measure the amount of thermal energy released by the burning food? (The released thermal energy can be measured by using it to heat water and by measuring the change in the water’s temperature.)
• What do you predict will happen if you change the amount of food or the type of food? (Increasing the amount of food should cause a bigger change in temperature. Different types of food may have different amounts of stored energy, so the change in temperature may be harder to predict.)
• What properties of each food may relate to the amount of stored energy? How can you find out these properties? (The amount of fat or carbohydrate in the food may affect the amount of stored energy. This information can be found on the nutritional label of the food’s packaging, or on the Internet.)

Encourage students to discuss their procedures and results with other groups. Have the class discuss their results together and see if they can draw conclusions from the collected information. Ask if any groups studied similar variables, and then have those groups compare their results. Ask them if they can explain any differences in outcomes of their tests.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Compare your results to your prediction or hypothesis. Do the results support your expectations? We expected that increasing the amount of fat in the sample would cause a greater change in the water temperature. This is what we observed.

2. Did you notice any sources of error, such as lost heat or inaccurate measurements? Can you suggest improvements to your design or procedure to lessen these errors? Some thermal energy from the burning food may have been lost. We could improve the design by surrounding the sample on all sides with a container of water.

3. Did you observe any trends in your data as you varied the independent variables? How do you explain this trend? We saw that as we increased the initial mass of the food sample, the change in temperature of the water was greater. That is because the greater amount of food contained a greater amount of chemical potential energy.

4. Did your investigation lead you to other questions about the food samples? We wondered whether food high in carbohydrates contained more chemical potential energy per gram than food high in fat.

5. How might researchers use this procedure in real-world applications? This procedure can be used to determine the calorie content of different foods.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
• Temperature

○ Choose appropriate tools to conduct an investigation:
  ▪ Glassware (beakers, flasks, watch glass, etc.)
  ▪ Thermometer
  ▪ Scale
  ▪ Graduated cylinder
  ▪ Other Laboratory equipment

○ Use the appropriate format to record data:
  ▪ Table
  ▪ Writing (journal, worksheet, electronic text)
  ▪ Sketch
  ▪ Diagram

• Interpret Data
  ○ Identify and interpret patterns using:
    ▪ Trends in data
    ▪ Repeating physical or data patterns
    ▪ Tables and graphs
    ▪ Analysis of data collected during an investigation

• Evaluate Evidence
  ○ Draw and support a conclusion by:
    ▪ Using data to determine the cause–effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
    ▪ Comparing results to hypothesis
    ▪ Answering the testable question
    ▪ Extrapolating results beyond the investigation
    ▪ Examining how investigations can be improved
    ▪ Explaining how technology can be used to enhance the investigation
    ▪ Showing the application of the scientific concept or process being investigated

• Communication in Science
  ○ Report results using:
    ▪ Peer presentation
    ▪ Written report
    ▪ Scientific illustration with proper labeling
- Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy

- Patterns and Systems
  - Patterns and Change:
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.
  - Systems:
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
    - In some systems, it may not always be possible to predict accurately the result of changing some part or connection.

- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - Scientific investigation results in things we know and things we don’t know.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    - Scientific investigation leads to more questions.
  - Scientific Data and Outcomes:
    - Scientific claims are based on data and reliable scientific sources.
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - Comparisons of data are not accurate when some of the conditions are not kept the same.
    - Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data take much longer (e.g., the growth of a tree).
    - Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
• It is important in science to keep honest, clear, and accurate records.
• When similar investigations give different results, it often takes further studies to decide what is right.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientific claims can be substantiated using data and observation.
    ▪ Scientific theories are based on accumulated evidence.
    ▪ An important part of science is the critical review and analysis of any idea or conclusion.

• Engineering and Technology
  o Uses of Technology:
    ▪ Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
    ▪ Even a good design may fail, even though steps are taken ahead of time to reduce the likelihood of failure.
  o Societal Issues:
    ▪ Scientific discoveries have benefitted people in many ways.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:

- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen. 

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Designing Solutions: Wind Energy

Timing: one 90-minute class session

Objective(s):
First, students will design and build a model of a wind turbine that they will use to convert wind energy into electrical energy. Next, they will use their model to determine the propeller blade angle that results in the production of the maximum amount of electrical energy for their system. Then, they will have an opportunity to improve on their design and test the improved design, if time allows.

Safety Precautions:
- Follow all lab safety guidelines.
- Be careful when handling all electrical equipment.
- Do not touch the metal contacts on the electrical wires when current is flowing through the circuit.
- Tie back long hair.
- Do not eat or drink anything in the lab.

Materials:
Per group:
- motor, 1.5 V DC
- voltmeter
- cork, cylindrical with 1–2 cm length
- toothpicks
- glue
- needle
- cardboard
- wires, 2 insulated
- alligator clips, 4
- tube, cardboard with wide diameter
- hair dryer
- protractor

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- If students are not aware of basic circuitry including the proper operation of a voltmeter, a brief introduction should be given before the start of the lab.
- If a hair dryer is not available for each student group, one wind tunnel (as described in the first step of the Procedure) can be set up for the entire class and groups can take turns collecting data.
Procedure

1. Construct the wind tunnel by placing the hair dryer at one end of the cardboard tube. Place a small mark at the opposite end of the tunnel where the model wind turbine will be placed.
2. Cut six rectangles from the cardboard. Each should be 1.5 cm x 4.0 cm.
3. Glue a toothpick to one end of each of the cardboard rectangles. Be sure each toothpick is positioned similarly with respect to the cardboard rectangle to which it is glued. Allow the glue to fully dry before continuing.
4. Insert the toothpicks into the cork. Make sure that they are equally spaced around the circumference of the cork. Adjust the position of the propeller blades so that they are edge on in the direction of the hair dryer, which would be perpendicular to the axis of the cork. This is the reference position of the blades (0°).
5. Use a needle to make a small hole in the center of the base of the cork that is farthest away from the propeller blades.
6. Place the cork on the shaft of the motor. Make sure that the hole in the cork is just wide enough to fit snugly over the shaft. The cork and the shaft should turn as one unit without slipping. The shaft must be centered exactly in the middle of the cork and run vertically along its axis.
7. Attach alligator clips to both ends of the two insulated electrical wires. Clip one end of both wires to the motor terminals. Attach the other ends to the voltmeter.
8. Turn on the voltmeter. Spin the propeller blades by hand to check that the voltmeter registers a voltage.
9. Place the model wind turbine on the marked test position of the wind tunnel. The base may have to be held in place. Turn on the hair dryer at the low-temperature setting (for blowing air without heating it). Record the voltage value on the voltmeter in a data table. Also record observations on the rotational motion of the propeller.
10. Tilt the propeller blades so that they make an angle of 10° with the direction of the hair dryer and the vertical axis of the cylindrical cork. Repeat the voltage measurements.
11. Continue taking data in 10° increments until the blades can't be rotated any farther.
12. Graph the voltage versus the angle of the propeller blades. The angle of the propeller blades is the independent variable and should be placed on the horizontal axis. The voltage is the dependent variable and should be placed on the vertical axis.
13. Lab groups should use their graphs to identify the propeller blade angle that resulted in the largest amount of electrical energy produced.
14. The experiment involved a six-bladed propeller with measurements taken at only increments of 10°. Challenge students to improve their designs. If time allows, have them test their improved designs.
Analysis and Conclusions

1. What forces act on the wind turbine while it is in motion? [The oncoming wind pushes against the blades creating a lift force that causes the turbine to spin. As the blades spin, they also experience a drag force due to air resistance that opposes the rotational motion of the turbine.]

2. Why did a 0° blade angle produce little or no rotational motion? [A 0° blade angle does not expose any surface area against which the oncoming wind can exert a push.]

3. Which blade angle produced the largest amount of electrical energy? Suggest a possible explanation for this result. [Answers will vary depending on individual results, but the optimal angle is expected to be around 30°. At this angle, there is a fairly large amount of blade surface area exposed to the oncoming wind, so there will be a large lift force while still keeping the drag force small.]

4. What other variable could be adjusted in order to maximize the amount of electrical energy generated by the wind turbine? [The shape of the blades, size of the blades, weight of the blades, construction material, wind speed, and length of wind tunnel will all affect the amount of electrical energy generated.]

5. Was all of the energy supplied by the hair dryer converted into electrical energy by the system? If not, where did the extra energy go? [The wind turbine is not 100% efficient because there are many losses in the system. Not all of the oncoming wind was used to push the blades. There were loses due to friction in the coupling of the propeller to the motor. There were also losses in the motor itself.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Develop questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing

- **Gather Data**
  - Uses the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns
    - Trends in data
    - Graphed data points
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting out trends and patterns in the data.
  - Assessing the conclusion by:
    - Answering the testable question
    - Extrapolating results beyond the investigation
Hands-On Activity
Bouncing Balls

Objective:
Students will use a variety of balls to demonstrate how kinetic energy can be transferred from one object to another.

Estimated time to complete: 25 minutes

Materials:
For each small group of three:
• Basketball
• Soccer ball
• Volley ball
• Compressed rubber ball (bouncy ball)
• Tennis ball
• Lacrosse ball
• Meter stick or metric tape measure
• Safety goggles

Procedure:
Have students make a prediction about which ball will have the greatest bounce height. Students can base this prediction the size of the ball and/or the material that the ball is made of.

Divide students into groups of three and distribute the materials to each group. Instruct students to wear their safety goggles throughout the entire activity. Have student groups decide which of the three possible variables that they would like to investigate. Student groups will share data for each of the topics below later in the activity.

Topics include:
1. Test the effect of the size of the ball on the bounce height, by using three different balls of the same material.
2. Test the effect of the material of the ball on the bounce height, by using three balls of the same size, but of different materials.
3. Test the effect of elasticity on the bounce height, by using three different size balls or different materials.
Instruct each student in the group to drop each ball from the same height, noting the number of times each ball bounces and the approximate height of each bounce. Students should record their data in a table such as the following, adding columns as needed:

<table>
<thead>
<tr>
<th></th>
<th>Height of First Bounce</th>
<th>Height of Second Bounce</th>
<th>Height of Third Bounce</th>
<th>Height of Fourth Bounce</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ball 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

While students are recording their data in the table above, have them draw a diagram for each ball drop and bounce and label the maximum and minimum KE and PE for each. Students should note the height of the drop, height of the bounce, the location of the maximum kinetic energy for each bounce, and the location of the maximum potential energy for each bounce on their diagrams.

Next, have students use the data that they have collected to develop a conclusion about how their factor effected the bounce height. Student groups should then create a two minute summary of their findings and report these out to the class. As groups report out their data, students should be encourage to write the summaries of each group in their journal. Finally, students should check their original predictions and be asked to determine which combination of factors create the greatest kinetic energy and require the least potential energy for each ball on their diagrams.

Extension

After students have tested each ball separately, have students predict what will happen to the balls if they place the compressed rubber ball on top of the tennis ball and drop them together, so that they are touching when they hit the ground. Students should make similar predictions about the compressed rubber ball on top of the basketball and the basketball on top of the tennis ball. After students have recorded their predictions in new rows of their data tables, they should perform each drop and compare the results to their predictions. (Students should note that the larger balls on the bottom don’t bounce as high, while the smaller balls on top bounce significantly higher.)

Finally, ask students to explain the data they gathered, using the law of conservation of energy.
Inquiry and Nature of Science Skills in this Activity:

• Identify Questions
  o Develop predictions/hypotheses that
    ▪ State what may happen in an investigation based on prior knowledge or experience (prediction)

• Design Investigations
  o Practice lab safety by:
    ▪ Following lab safety procedures

• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Length/distance/depth
  o Choose appropriate tools to conduct an investigation:
    ▪ Ruler/Tape measure
    ▪ Meter stick
  o Use senses to observe:
    ▪ Seeing (color, shape, size, texture, motion)
  o Use the appropriate format to record data:
    ▪ Table

• Interpret Data
  o Identify and interpret patterns using:
    ▪ Trends in data
    ▪ Tables and graphs
    ▪ Analysis of data collected during an investigation
Overview

In a roller coaster ride, energy transforms from one form to another. Kinetic energy of the roller-coaster depends on its mass and velocity and the potential energy depends on its mass and distance above the ground. In this Exploration, students observe the relationship between these energies and also the total energy of the system. They analyze the effect when friction is accounted for and use these observations to understand the law of conservation of energy.

Student Learning Objectives

- Understand that the total amount of energy in the universe is constant and can be changed from one form to another.
- Investigate that the sum of kinetic energy and potential energy is constant when no friction is present.
- Inspect the dependence of kinetic energy on the mass and velocity of the object.
- Examine the changes in potential energy with mass and distance of the object above the ground.
- Investigate the effect of friction on energy.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, two different track profiles of the roller coaster are available. Students select the initial velocity and mass of the cart using the Select Starting Velocity and Select Cart Mass dropdown lists. Students include friction using the Add Friction checkbox.

Students select the Line Graph, Pie Chart, or Bar Graph radio button option to select the view of the graph. After selecting the Start button, the cart starts moving along the selected track profile. As the cart moves, the different forms of energy with time are plotted on the graph. The changes in the different forms of energies are displayed in the graph area. Students select and observe the individual graphs for Potential Energy, Kinetic Energy, Friction Loss (available only if friction is accounted for), and Total Energy using buttons provided next to the graphical representation.

Students may use the Pause button to pause the cart when it is in motion and the Continue button to resume the cart movement. The Reset button can be used to reset the Exploration and try a different set of values.
The *Data* tab shows the cart’s height above the ground, its velocity, potential energy, kinetic energy, energy lost due to friction, and the total energy after every 0.10 seconds for the selected values of the current run. The corresponding *View Graphs* icons are also available. Students use these icons to observe a motion snapshot and graphs after the corresponding time.

The *Tracker* tab is a summary of the values for all the run. Students use these to analyze the dependence of kinetic energy, potential energy, and total energy on selected parameters like initial velocity, mass, and the effect of mass on the loss of energy due to friction.

**Answers to Questions in the Student Worksheet**

1. Select a track. Select the initial velocity as 12 m/s and the cart mass as 300 kg. At what point in time is the kinetic energy of the roller coaster cart maximum? Explain.

   **Answer:** Kinetic energy of the cart is maximum when its distance from the ground is minimum. Potential energy of the cart is maximum when its distance from the ground is maximum. As the cart moves its potential energy gets converted to kinetic energy. So the potential energy decreases and kinetic energy increases until kinetic energy is maximum when the cart is at the lowest point.

2. Select a track and cart mass. Run the roller coaster cart two times with different starting velocities selected. Describe the impact of the starting velocities on the energies.

   **Answer:** If the starting velocity increases, then the kinetic energy of the cart also increases. This increases the total energy of the cart. Variation in velocity does not affect the potential energy.

3. Analyze the relationship between the distance of the cart from the ground and its potential energy.

   **Answer:** As the distance of the cart from the ground increases, its potential energy also increases. Since the relationship is linear, potential energy is directly proportional to the distance of the cart from the ground.

4. Investigate how adding friction affects the potential energy, kinetic energy, and total energy.

   **Answer:** Adding friction does not affect the potential energy or the total energy of the system. The kinetic energy of the system is reduced because friction reduces the velocity of the cart.
5. Based on your observations, discuss the relationship between the mass and energy lost to friction.

**Answer:** As the mass of the cart is increased, energy lost due to friction increases.

6. When the cart reaches the highest point, determine which out of potential, kinetic, and total energy is minimum, maximum, or stays constant.

**Answer:** When the cart reaches the highest point, its potential energy becomes maximum, its kinetic energy becomes minimum, and its total energy stays constant.

7. Run the roller coaster cart along a selected track a few times to analyze at what points in time is the kinetic energy maximum and minimum.

**Answer:** Kinetic energy is maximum when the distance of the cart from the ground is minimum and minimum when its distance from the ground is maximum.

8. Run the roller coaster cart along a selected track a few times to analyze at what points in time is the potential energy maximum and minimum.

**Answer:** Potential energy is maximum when the distance of the cart from the ground is maximum and minimum when its distance from the ground is minimum.

9. State and explain the law of conservation of energy using an example of compressed spring.

**Answer:** When the spring is compressed, elastic potential energy is stored in the spring. This potential energy is converted to kinetic energy when the spring is released. The potential energy of the spring in the compressed state is equal to the kinetic energy of the spring in the uncompressed state.

10. Describe what happens to the kinetic energy, potential energy, and total energy of a falling object just before it touches the ground.

**Answer:** Just before a falling object touches the ground, its kinetic energy is maximum, its potential energy is zero and its total energy is equal to its kinetic energy.
Exploration Teacher Guide: Conservation of Energy

Overview

In a roller coaster ride, energy transforms from one form to another. Kinetic energy of the roller-coaster depends on its mass and velocity and the potential energy depends on its mass and distance above the ground. In this Exploration, students observe the relationship between these energies and also the total energy of the system. They analyze the effect when friction is accounted for and use these observations to understand the law of conservation of energy.

Student Learning Objectives

- Understand that the total amount of energy in the universe is constant and can be changed from one form to another.
- Investigate that the sum of kinetic energy and potential energy is constant when no friction is present.
- Inspect the dependence of kinetic energy on the mass and velocity of the object.
- Examine the changes in potential energy with mass and distance of the object above the ground.
- Investigate the effect of friction on energy.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, two different track profiles of the roller coaster are available. Students select the initial velocity and mass of the cart using the Select Starting Velocity and Select Cart Mass dropdown lists. Students include friction using the Add Friction checkbox.

Students select the Line Graph, Pie Chart, or Bar Graph radio button option to select the view of the graph. After selecting the Start button, the cart starts moving along the selected track profile. As the cart moves, the different forms of energy with time are plotted on the graph. The changes in the different forms of energies are displayed in the graph area. Students select and observe the individual graphs for Potential Energy, Kinetic Energy, Friction Loss (available only if friction is accounted for), and Total Energy using buttons provided next to the graphical representation.

Students may use the Pause button to pause the cart when it is in motion and the Continue button to resume the cart movement. The Reset button can be used to reset the Exploration and try a different set of values.
The Data tab shows the cart’s height above the ground, its velocity, potential energy, kinetic energy, energy lost due to friction, and the total energy after every 0.10 seconds for the selected values of the current run. The corresponding View Graphs icons are also available. Students use these icons to observe a motion snapshot and graphs after the corresponding time.

The Tracker tab is a summary of the values for all the run. Students use these to analyze the dependence of kinetic energy, potential energy, and total energy on selected parameters like initial velocity, mass, and the effect of mass on the loss of energy due to friction.

**Answers to Questions in the Student Worksheet**

1. Select a track. Select the initial velocity as 12 m/s and the cart mass as 300 kg. At what point in time is the kinetic energy of the roller coaster cart maximum? Explain.

   **Answer:** Kinetic energy of the cart is maximum when its distance from the ground is minimum. Potential energy of the cart is maximum when its distance from the ground is maximum. As the cart moves its potential energy gets converted to kinetic energy. So the potential energy decreases and kinetic energy increases until kinetic energy is maximum when the cart is at the lowest point.

2. Select a track and cart mass. Run the roller coaster cart two times with different starting velocities selected. Describe the impact of the starting velocities on the energies.

   **Answer:** If the starting velocity increases, then the kinetic energy of the cart also increases. This increases the total energy of the cart. Variation in velocity does not affect the potential energy.

3. Analyze the relationship between the distance of the cart from the ground and its potential energy.

   **Answer:** As the distance of the cart from the ground increases, its potential energy also increases. Since the relationship is linear, potential energy is directly proportional to the distance of the cart from the ground.

4. Investigate how adding friction affects the potential energy, kinetic energy, and total energy.

   **Answer:** Adding friction does not affect the potential energy or the total energy of the system. The kinetic energy of the system is reduced because friction reduces the velocity of the cart.
5. Based on your observations, discuss the relationship between the mass and energy lost to friction.

**Answer:** As the mass of the cart is increased, energy lost due to friction increases.

6. When the cart reaches the highest point, determine which out of potential, kinetic, and total energy is minimum, maximum, or stays constant.

**Answer:** When the cart reaches the highest point, its potential energy becomes maximum, its kinetic energy becomes minimum, and its total energy stays constant.

7. Run the roller coaster cart along a selected track a few times to analyze at what points in time is the kinetic energy maximum and minimum.

**Answer:** Kinetic energy is maximum when the distance of the cart from the ground is minimum and minimum when its distance from the ground is maximum.

8. Run the roller coaster cart along a selected track a few times to analyze at what points in time is the potential energy maximum and minimum.

**Answer:** Potential energy is maximum when the distance of the cart from the ground is maximum and minimum when its distance from the ground is minimum.

9. State and explain the law of conservation of energy using an example of compressed spring.

**Answer:** When the spring is compressed, elastic potential energy is stored in the spring. This potential energy is converted to kinetic energy when the spring is released. The potential energy of the spring in the compressed state is equal to the kinetic energy of the spring in the uncompressed state.

10. Describe what happens to the kinetic energy, potential energy, and total energy of a falling object just before it touches the ground.

**Answer:** Just before a falling object touches the ground, its kinetic energy is maximum, its potential energy is zero and its total energy is equal to its kinetic energy.
Hands-On Lab
Conservation of Energy

Timing: one 90-minute class session

Objectives:
Students will design a protocol to test conservation of energy and to examine transformations of energy between different forms.

Safety Precautions:
Warn students that stretched springs can pinch fingers or fabric, and compressed springs can fly off or shoot projectiles at high speeds when released. Students using a spring to launch a projectile should stay clear of the launch direction, and you should inspect the students’ setups before allowing them to proceed. Students using a hanging mass or pendulum should be careful not to drop the weight on their feet.

Materials:
Per group:
- 1 marble or lightweight mass cart
- 1 or more springs of varying stiffness, with known spring tension
- 1 inclined plane or ramp
- 1 large bowl for rolling a marble, 30 cm in diameter or larger
- 1 stand for hanging pendulum or spring
- 1 pendulum bob with string for hanging
- 1 mass with hanger, 250–500 g
- 1 stopwatch
- 1 meter stick
- 2 racquetballs (one prepared as explained below; per class)
- 1 mass scale (per class)
- motion or velocity sensor and software (optional)

Teacher Preparation:
- Gather materials in advance of students preforming the lab.
- Each group will use only a subset of the listed materials, so it may not be necessary to have all supplies for each group. Also, you may have other ideas of ways for the students to examine conservation of energy, so feel free to include additional materials.
- The initial discussion involves a standard racquetball and a specially prepared half-racquetball. For this second ball, cut a standard racquetball in half and trim down the edges of one half a little until you can easily flip it "inside out."
Procedure

Directed Inquiry

To introduce this lab, begin the discussion with a review of conservation of energy, using a normal racquetball and the prepared racquetball half.

1. A standard racquetball dropped from a given height will return almost to that height. Demonstrate this, and ask the students about the transformations of energy during the drop and bounce, including the energy lost during the bounce. Next, turn the half-ball inside-out and drop it with the ball’s original outer side facing downwards. It will bounce much higher than the original height. Ask about the transformations of energy and where the extra energy came from. (There was elastic potential energy stored in the deformed ball.)

2. Lead the class in a discussion of different forms of energy and how we can observe and measure them. Ask them leading questions such as:
   - What kind of energy does the half-ball have when it is in "pre-pop" shape? (elastic potential energy and gravitational potential energy)
   - Can we measure this energy directly? (possibly with the right technical measuring tools, but it is very hard to measure the elastic potential energy of the ball directly)
   - How else can we measure the initial energy indirectly? (by measuring the final potential energy)
   - Will all the initial energy become final potential energy? (No, some is lost in sound or heat or deformations of the ball.)
   - Can we measure this missing energy somehow? (It is difficult to do, but it is possible with clever experiments or accurate measuring devices.)

3. Explain to the students that in this lab they will design an investigation about energy conservation, similar to the demonstration with the racquetball. With the class, go through the materials you have assembled, leading the students in a discussion of how each might be used in this investigation. Have students break into 2- or 3-person groups. You may wish to assign materials for each group to use, or you guide groups in choosing their own.

4. Instruct students to spend a few minutes experimenting with the materials as they brainstorm ideas for their investigation. Then, have each group create their investigation procedure. Depending on the time you have available, you may want to have a few groups share their procedures. This gives you and other students the opportunity to provide feedback. Be sure to approve all procedures before any groups begin their investigation. An example procedure using a spring and the inclined plane is the following:
a. Set up a ramp so that one end is at an incline. At the bottom of the ramp, 10–20 cm from the bottom, attach the spring to a base so that the spring lies horizontally.
b. Use the scale to measure the mass of a marble (or mass cart), and record the result.
c. Push the marble against the spring, compressing the spring. Use the meter stick to measure the compression and record the result.
d. Let go of the spring and let it project the marble towards the ramp. Note the maximum height up the ramp reached by the marble. Use the meter stick to measure the height above the table top.
e. Calculate the initial elastic potential energy using the measured compression and the stated spring constant of the spring. Calculate the final gravitational potential energy relative to the table top using the marble's mass, the height reached, and gravitational acceleration $g$. Compare the two answers, which should be similar.
f. Repeat steps 4–8 several times to reduce errors, and calculate average values for the initial and final energies. Students will most likely observe that the final energy is less than the initial.

5. Now challenge students to extend their procedures to investigate whether energy in a cyclic or repeating system is lost over time. For example, the above procedure could be extended in this way:

a. Using the setup above, use the spring to project the marble up the ramp. Let the marble return down the ramp, rebound off the spring, and continue back up the ramp.
b. Let the marble bounce this way until it comes to a stop. With each bounce, note how far up the ramp the marble goes.
c. Use the series of maximum height values to calculate the change in potential energy over time.

Other examples can use a procedure similar to above and include the following:

- Pendulum bob: Hang a bob from a stand, and set it in motion. Measure the change in maximum height with each swing, or use a motion sensor to measure velocity (and therefore kinetic energy) at the low point of the swing.
- Marble and bowl: Let the marble roll back and forth inside the bowl and measure the change in maximum height.
- Mass hanging from a spring: Let the spring and mass oscillate vertically. Measure the change in maximum height, or use a motion detector to measure the maximum speed.

6. Instruct students to describe their setup and procedure in their lab notebooks, including a sketch of the equipment with proper labeling. Instruct them to also record all data in their notebooks. For the example procedure above, a sample set of data might look like this:
Marble Mass | 4.5 g
---|---
Spring Constant | 25 N/m

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Initial compression</th>
<th>Initial elastic potential energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.0 cm</td>
<td>0.005 J</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bounce #</th>
<th>Height (cm)</th>
<th>Gravitational potential energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10.5</td>
<td>0.0046</td>
</tr>
<tr>
<td>2</td>
<td>6.5</td>
<td>0.0029</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>0.0015</td>
</tr>
<tr>
<td>4</td>
<td>1.0</td>
<td>0.00044</td>
</tr>
</tbody>
</table>

7. Ask students to describe the different forms of energy present in their investigation and the transformations between different forms. Have students sketch graphs of the different types of energy over time, and ask them to describe and comment on trends in the data.

Procedure

Guided Inquiry
To introduce this lab, begin the discussion with a review of conservation of energy, using a normal racquetball and the prepared racquetball half.

1. A standard racquetball dropped from a given height will return almost to that height. Demonstrate this, and ask the students about the transformations of energy during the drop and bounce, including the energy lost during the bounce. Next, turn the half-ball inside-out and drop it with the ball’s original outer side facing downwards. It will bounce much higher than the original height. Ask about the transformations of energy and where the extra energy came from. (There was elastic potential energy stored in the deformed ball.)

2. Lead the class into a discussion of different forms of energy and how we can observe and measure them. Ask them leading questions such as:
   - *What kind of energy does the half-ball have when it is in "pre-pop" shape?* [elastic potential energy and gravitational potential energy]
   - *Can we measure this energy directly?* (possibly with the right technical measuring tools, but it is very hard to measure the elastic potential energy of the ball directly)
   - *How else can we measure the initial energy indirectly?* (by measuring the final potential energy)
   - *Will all the initial energy become final potential energy?* (No, some is lost in sound or heat or deformations of the ball.)
• Can we measure this missing energy somehow? (It is difficult to do, but possibly it can be
done with clever experiments or accurate measuring devices.)

3. Explain to students that in this lab they will design an investigation about energy conservation,
similar to the demonstration with the racquetball. Emphasize that they should explore one-time
events as well as cyclical or repeating events. Have students break into 2- or 3-person groups,
and allow them a few minutes to discuss what materials they would like to use and what their
procedure might look like. Then invite one group at a time to select their materials. Depending
on the materials you have available, you may have to limit the number of items each group
chooses, or you might have to put the items in “sets” and have each group choose one set.

4. Instruct students to design their investigations and have you approve their procedures before
they take any further steps. You may wish to ask leading questions to help the students design
their investigation, such as:
• Do certain objects (springs, inclined plane) allow you to demonstrate different types of
potential energy?
• How could you combine these objects to investigate additional transformations of energy?
• How could you measure the amount of energy in the system?

5. Have groups complete their investigations and record the data they collected, emphasizing that
they may have to refine their procedures after the first few trials. Remind students to describe
their setup and procedure in their lab notebooks, including a sketch of the equipment setup
with proper labeling, and to record all data in their notebooks. A data-collection table might look
like this:

<table>
<thead>
<tr>
<th>Marble Mass</th>
<th>4.5 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring Constant</td>
<td>25 N/m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trial #</th>
<th>Initial compression</th>
<th>initial elastic potential energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<th>Bounce #</th>
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<td>4</td>
<td>1.0</td>
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</tr>
</tbody>
</table>

6. Ask students to describe the different forms of energy present in their investigation and the
transformations between different forms. Have students sketch graphs of the different types of
energy over time, and ask them to describe and comment on trends in the data.

7. Once they have finished, each group should select a method for sharing their results, and
should prepare a short presentation for the class.
Analysis and Conclusions

1. Sketch the path of the falling racquetball from the demonstration at the beginning of this lab. Label different locations where energy transformations take place.
   
   **Sample response:**

   1. Maximum potential energy  
   2. Potential energy becomes kinetic energy  
   3. Maximum kinetic energy  
   4. Kinetic energy becomes thermal and sound energy  
   5. Kinetic energy becomes potential energy

2. How much work is done to lift the ball from the ground to the point where it is released? How is work related to the energy that the ball has at this location?
   
   **Sample response:** Due to the work-energy theorem, the work done on the ball to lift it to its highest point is equal to the potential energy that the ball has at that point. The potential energy of the ball at that location is equal to the mass of the ball, times the acceleration due to gravity, times the height at which the ball is dropped.

3. Why is it important to conduct multiple trials?
   
   **Sample response:** Every trial will include errors. Multiple trials help reduce the effects of random errors.

4. Why do you see a decrease in the amount of energy? Can you think of a more direct way to measure the lost energy? Do you think energy is really conserved?
   
   **Sample response:** Energy was lost to friction, sound, and kinetic energy of the spring. I don't know how to measure the lost energy more directly, so I don't know for sure if energy is conserved.

5. Use the work-energy theorem to calculate the maximum kinetic energy of the mass. Where in the mass's path will this occur?
   
   **Sample response:** The mass will have maximum kinetic energy immediately after it launches from the spring. By the work-energy theorem, this kinetic energy will be equal to the work done on the mass, which in turn will be equal to the potential energy stored in the compressed spring, or:
   
   \[ KE = \frac{1}{2}k\Delta x^2 \]
   
   \[ KE = \frac{1}{2}(25 \text{ N/m})(0.02 \text{ m})^2 \]
   
   \[ KE = 12.5 \text{ N/m} \times 0.004 \text{ m}^2 \]
   
   \[ KE = 0.05 \text{ J} \]
6. Use the conservation of energy to calculate the gravitational and kinetic energy of the marble at the bottom and at the top of your ramp. Also use the conservation of energy and the kinetic energy of your marble to calculate how high the marble will go in its path.

   In the last problem, we calculated that the marble will have 0.05 J of kinetic energy. Ignoring energy lost to friction, this will be its kinetic energy at the base of the ramp. At the base of the ramp, the marble will have 0 J of potential energy because its height is zero. The height of our ramp was 5 cm, so the marble’s gravitational potential energy is calculated as follows:

   \[ PE = mgh \]

   \[ PE = (0.0045 \text{ kg})(9.8 \text{ m/s}^2)(0.05 \text{ m}) \]

   \[ PE = 0.002 \text{ J} \]

   As the marble travels up the ramp, kinetic energy becomes gravitational potential energy, so at the top of the ramp, kinetic energy will be given by:

   \[ KE_{\text{top}} = KE_{\text{bottom}} - PE \]

   \[ KE_{\text{top}} = 0.05 \text{ J} - 0.002 \text{ J} \]

   \[ KE_{\text{top}} = 0.048 \text{ J} \]

   Finally, by conservation of energy, the marble will have 0.05 J of potential energy at its highest, so we can find how high the marble should go with the equation:

   \[ 0.05 \text{ J} = (0.0045 \text{ kg})(9.8 \text{ m/s}^2)h \]

   \[ h = (0.05 \text{ J})/(0.0045 \text{ kg})(9.8 \text{ m/s}^2) \]

   \[ h = 1.1 \text{ m} \]

7. Compare your results with those of another group that used a similar method. Did you see more or less lost energy? How do you account for the differences?

   Sample response: The other group also saw that energy was lost, but on average they saw less lost energy. The difference may be because they did a better job of measuring where the marble reached on the ramp.

8. Consider a setup where a spring of spring constant 25 N/m is compressed 2 cm to send a 4.5 g marble up to a height of 10.5 cm above the floor. If no energy was lost, how high could the marble go above the floor?

   Sample response: In such a system, initial mechanical energy is equal to final mechanical energy. The potential energy in the compressed spring would be used to push the marble up the ramp to a height given by:

   \[ \frac{1}{2}k\Delta x^2 = mgh \]

   so the height would be calculated as follows:

   \[ h = \frac{k\Delta x^2}{2mg} \]

   \[ h = \frac{25 \text{ N/m} \times (0.02 \text{ m})^2}{2(0.0045 \text{ kg})(9.8 \text{ m/s}^2)} = 0.113 \text{ m} \]

   \[ h = 11.3 \text{ cm} \]

9. If you had unlimited resources, what experiment would you design to better test conservation of energy?

   Sample response: I would do an experiment like Joule did, using a wheel in a big container of water, using a very accurate thermometer.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that
    - can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - state the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - describing the logical sequence that was used to conduct the investigation
    - properly citing all equipment and materials
    - describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Mass
    - Time
    - Speed
  - Choose appropriate tools to conduct an investigation:
    - meter stick
    - Clock/stopwatch
    - scale
    - Other Laboratory equipment
    - Probes (computer based)
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Writing (journal, worksheet, electronic text)
    - Sketch
    - Diagram

- **Interpret Data**
  - Identifies and interprets patterns:
    - Trends in data
    - Repeating physical or data pattern
    - Tables and graphs
    - Based on an analysis of data collected during an investigation
• Evaluate Evidence
  o Drawing and supporting a conclusion by:
    ▪ reporting trends and patterns in the data
    ▪ Comparing results to hypothesis
    ▪ Answer the testable question
    ▪ Examining how investigations can be improved
    ▪ Formulating scientific explanations/arguments
    ▪ Explain how technology can be used to enhance the investigation

• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Scientific illustration with proper labeling
    ▪ Formulating scientific explanations/arguments
    ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating a conclusion
    ▪ Evaluating an investigative design
    ▪ Analyze scientific explanation
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

![Create a graph](image)

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

![Graph details](image)

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Evaluating Systems: Stearic Acid as a Heating Fluid

Timing: one 90-minute class session

Objective(s):
Students will collect data on the cooling rate of stearic acid as a function of time, and they will use their results to create a graphical model of the system. Then, they will use their graphical model to make predictions of how the system will respond in different situations. Finally, they will use their results to evaluate whether molten stearic acid is likely to be effective in applications involving heat.

Safety Precautions:
- Wear closed-toe shoes.
- Do not eat or drink anything in the lab.
- Wear safety equipment including goggles, gloves, and lab aprons.
- Students should report any broken glass immediately and should not try to clean it up by themselves.
- Use care when handling the Bunsen burner.

Materials:
Per pair:
- stearic acid, 20 g
- test tube
- test tube clamp
- ring stand
- wire gauze
- beaker, 500 mL
- Bunsen burner
- striker
- thermometer
- test tube rack
- tongs
- timer

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Place stearic acid samples inside of the test tubes before the start of lab. Remind students to return the test tubes at the end of lab because the samples can be reused.
- Depending on the purity of the samples, the freezing point of stearic acid can be anywhere from 55°C–70°C. This lab procedure is designed for a pure sample with a freezing point of approximately 70°C. You may wish to determine the freezing point for your samples ahead of time and adjust the beginning and ending temperatures for the experiment accordingly. Additionally, if the melt time for your sample is not long enough, you may wish to increase the mass of the sample.
**Procedure**
1. Use the thermometer to measure the air temperature of the room.
2. Place the wire gauze on the ring stand above the unlit burner. Fill the beaker two-thirds full with tap water and place it on the wire gauze.
3. Clamp a test tube containing the stearic acid sample to the ring stand so that the entire sample is below the level of the water. Make sure that water doesn't enter the test tube.
4. Light the burner and slowly heat the water bath and sample. Once the sample fully melts, place the thermometer inside of the test tube.
5. When the water just begins to boil, remove the test tube and place it in the test tube rack.
6. Record the starting temperature of your sample in a data table similar to the one shown below. Also include observations on the physical appearance of the sample including comments on its physical state.
7. Continue to record the temperature of the sample and observations on its appearance every 30 seconds. Don't try to move the thermometer after the sample has solidified.
8. Once the temperature of the sample has reach 45°C, stop taking data. Melt the sample to remove the thermometer. Wipe the thermometer clean and return the test tube and sample.
9. Graph the temperature of the sample as a function of time.
10. Identify whether the graph is of one shape or if it seems to have multiple regions. Divide the graph as appropriate by identifying the temperature and time limits for different parts of the graph. What observations were made about the stearic acid at these temperatures and during these times?
11. Identify whether a line or a curve best approaches the shape of your graph and any parts it has.

**Table 1: Sample student data table**

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Temperature (°C)</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>180.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>210.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240.0</td>
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<td>270.0</td>
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<tr>
<td>300.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>330.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. Use the graphical model to determine the temperature and phase of the sample at 45 s, 140 s, and 320 s.
   [Although actual values will vary, students should locate each time on their graphical model and determine the temperature value that corresponds to that time value by interpolating between the measurements they took at 30 s and 60 s for the 45 s point, between 120 s and 150 s for the 140 s point, and between 300 s and 330 s for the 320 s point. At 45 s, the sample is likely to still be in liquid form, at 140 s it will be on or near the phase transition, and at 320 s it should be entirely in solid form.]

2. Use the graphical model to predict how long it will take for the stearic acid sample to reach room temperature. Can the temperature of the sample ever go below room temperature?
   [In order to determine the time it will take for the sample to reach room temperature, students must locate room temperature on the graph and extrapolate from the graph to determine the time value associated with this temperature value. Once the sample reaches room temperature, it is in thermal equilibrium with the room, therefore, its temperature will never be below this value unless the temperature of the room is raised.]

3. How long would it take to heat the sample from 100°C to 120°C?
   [Since the cooling curve is reversible, students can find the time it would take to cool the sample from 120°C to 100°C. Although actual values will vary, students should locate 120°C on the temperature axis and determine the time value of the extrapolated curve that corresponds to the value. They should also determine the time at which the temperature of the sample was 100°C. Subtracting these two values will give the time it takes to heat the sample from 100°C to 120°C.]

4. How would doubling the mass of the sample affect the time and temperature limits of the liquid to solid phase transition?
   [Changing the mass of the sample will not change its melting temperature. However, the amount of thermal energy that leaves the sample during the phase transition from liquid to solid is directly proportional to the mass of the sample. If the mass of the sample doubles, the amount of heat released and, therefore, the amount of time it takes for the phase transition to occur will also double.]

5. Assume that the sample was allowed to cool in an ice water bath rather than in room temperature air. Qualitatively describe how the graphical model would change.
   [If the sample is cooled in an ice water bath rather than in room temperature air, the qualitative shape of the cooling curve and the freezing temperature will remain the same. However, the cooling process will occur at a faster rate, and the final temperature of the sample will be the temperature of the ice bath rather than room temperature.]
6. What type of energy is the sample losing in regions that are shaped like diagonal lines? What observations indicate this loss?

[The kinetic energy of the molecules in the sample is decreasing. This loss can be observed as a decreasing temperature of the sample.]

7. The temperature of the sample in one part of the graph doesn’t change. Is the sample still losing thermal energy?

[Yes, the sample still loses thermal energy during a phase change because it loses potential energy.]

8. How is the graphical model useful for making predictions?

Graphical models are useful for making predictions because they allow one to create a visual model of a system from a limited number of data points. The model can then be used to extrapolate information outside of the original observation range and interpolate between recorded data points.

9. Is the graphical model viable for all temperatures and times? Describe any limitations of the model.

[No, there are limitations to the graphical model. It cannot be extended to temperatures greater than the boiling point (361°C). The cooling rate (the slope of the curve at any point) is dependent on the properties of the sample including its mass, purity, and surface area. Therefore, a graphical model created for one sample can’t be used to accurately make predictions for a different sample. Additionally, the model doesn’t account for any unexpected changes in experimental conditions such as a sudden gust of cold air in the room.]

10. An inventor has proposed that instead of heating a building by sending steam through pipes and radiators in each room, a system that uses molten stearic acid should be used instead. Based on your results and your observations of what was happening in your graph, identify a challenge to overcome in such a system.

[One problem with using such a system is that stearic acid undergoes a phase change at temperatures close to room temperature, so it may become solid and clog the pipes. Steam, as a gas, can move through pipes more easily. And if the steam cools enough to condense to form liquid water, it will still move through the pipes.]

11. Another inventor proposes using molten stearic acid in a series of sealed pouches surrounding food that needs to be kept warm. Evaluate whether this system is likely to be better than simply insulating the food with padding or air. Does the data in your graph suggest an advantage or disadvantage to this approach?

[Because stearic acid goes through a phase change in region B of the graph, its temperature doesn’t change, even though it is releasing energy to the surroundings. As such, it could keep food at a consistent temperature as long as the phase change was occurring. This should work better than insulating the food with padding or air because with those approaches, as energy is lost to the surroundings, their temperature will decrease.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process.
    - specifies a cause-effect relationship.
    - requires the changing of one variable at a time.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
  - Make or use models that:
    - function exactly like or similarly to the real thing.
    - allow the testing of a hypothesis with results that can be extrapolated to the real thing.
  - Practice lab safety by:
    - following lab safety procedures.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Temperature
    - Time
  - Uses the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns
    - Trends in data
    - Repeating physical or data pattern
    - Graphed data points
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - extrapolating results beyond the investigation.

- **Patterns and Systems**
  - Patterns and change:
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Some changes are very slow and some are very fast, and some of these changes may be hard to see and/or record.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive, or irregular ways.
  - Systems
- Physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.

- **Scientific Investigation**
  - **Scientific Data and Outcomes**
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - Comparisons of data are not accurate when some of the conditions are not kept the same.
Hands-On Activity
Pendulum

Objective:
Students will investigate the effect of mass on the energy and velocity of a simple pendulum.

Estimated time to complete: 45 minutes

Materials:
For each student pair:
- A simple pendulum attached to a table or a ringstand
- Masses of different sizes (100 g, 200 g, 300 g, etc.)
- A table and ruler, or ringstand, from which to hang the pendulum
- A heavy weight, such as a textbook (if using a table)
- Meter stick or metric tape measure
- Pan balance

Procedure:
If necessary, show students how to set up the apparatus. Tie one end of the string to the ruler or ringstand, and then tie the other end of the string to the mass. If using a table, place the ruler on the edge of the table, and place a heavy weight, such as a book, on top of the ruler to hold it in place. Make sure the pendulum can swing freely.

Ask students to explain how the pendulum experiences both kinetic and potential energy as it moves through its arc. Ask them when the potential energy is greatest and least. Ask them about the transformation to kinetic energy. (The pendulum’s potential energy is greatest when the pendulum is at its highest point, in the instant when it pauses before swinging back down; as the pendulum swings, its kinetic energy increases, then as the pendulum rises again, its kinetic energy decreases as gravity pulls the pendulum toward Earth and causes it to slow down.) Students should also know that the sum of potential energy (maximum when the pendulum is at rest) and kinetic energy (maximum when the pendulum is moving) is a constant, and that $TE$ (total energy) = $PE$ (potential energy) + $KE$ (kinetic energy).

Ask students how they could calculate the velocity of the pendulum at the bottom of its swing. (They can use the relationship: $\frac{1}{2}mv^2 = mgh$, which simplifies to $v = (2gh)^{1/2}$.) Have them write a prediction in their lab report on the effect of mass on the velocity of the pendulum bob.

After reviewing these concepts with students, instruct them to work with a partner to use five masses
and calculate $PE$, $KE$, and velocity for each mass. Emphasize that students are changing only one variable for each trial of this investigation: the mass. The pendulum must be set in motion at the same point for each swing, thus keeping the amplitude the same. This ensures that comparisons between trials are valid.

Students should record their data in a table similar to the following:

Data Table: Energy and velocity of pendulum system

<table>
<thead>
<tr>
<th>Energy and Velocity</th>
<th>Mass of Pendulum Bob</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 g</td>
</tr>
<tr>
<td>$PE = mgh$ (J)</td>
<td></td>
</tr>
<tr>
<td>$KE = \frac{1}{2}mv^2$ (J)</td>
<td></td>
</tr>
<tr>
<td>$TE = PE + KE$ (J)</td>
<td></td>
</tr>
<tr>
<td>$\text{Velocity} = \sqrt{2gh}$ (m/s)</td>
<td></td>
</tr>
</tbody>
</table>

Have student share their data tables and use them to answer the following questions in complete sentences:

- Which pendulum bob had the most potential and kinetic energy? (See data table.)
- What is the relationship between mass, and kinetic and potential energy? (See data table.)
- Which pendulum bob had the greatest velocity? (See data table.)
- What is the relationship between mass, velocity, kinetic energy, potential energy, and total energy? (See data table.)
- What assumptions about energy did you make in calculating the velocity of the pendulum bob? How could you test these assumptions? (The assumption was that no energy was transformed into heat due to friction between the pendulum and its supporting surface. A temperature gauge could be used to test any heat produced.)
- How could you measure the actual velocity of the bob? (Use photogates or a motion detector.)
- What other factors might have an impact on the pendulum’s energy, and could be tested? (The amplitude of swing and the length of the string)
- Have students write a final paragraph about their initial predictions, the data they collected, and their conclusions based on the evidence from their data.
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Ruler/Tape measure
    - Meter stick
    - Pan balance
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
Hands-On Activity
Roller Coaster

In this activity, students will use marbles and a simple “roller coaster” to demonstrate how potential energy transforms into kinetic energy. Specifically, students will determine the effect of a marble’s mass and initial height on the marble’s potential and kinetic energy.

Suggested Materials
Per Group:
- two 183-cm (6-ft) lengths of foam pipe insulation cut in half lengthwise and taped together, (or track of similar length made from any suitable material)
- marbles of different masses (at least three per each group)
- meter stick or metric tape measure
- pan balance

Procedure

1. Separate students into groups of 3 or 4 and distribute the materials to each group. Explain to students that they are to use the materials to demonstrate the law of conservation of energy. (If necessary, show how the track can be raised to different angles and manipulated at one end to form a loop or a second rise.)
2. Before they begin working with the materials, have student groups work to devise a plan for their roller coaster design, which should also include a step-by-step procedure, a means for recording data, and a sketch of the set-up. Have students submit their plans for your approval before they begin the activity. Here is one possible plan:

Students find and record the mass of the marble that they are using. One student raises the track to a height of 100 centimeters (1 meter); a second student confirms this height by measuring with the meter stick and calculates the slope of the roller coaster (“rise” over “run,” or height divided by length). A third student forms a small loop at the lower end of the pipe. As the first and third students hold the pipe in place, the second student drops the marble down the roller coaster and notes whether the marble completes the loop.

Students then raise the height of the roller coaster to 110 cm, 120 cm, 130 cm, 140 cm, and 150 cm; calculate the new slopes for each height, and determine whether the marble completes the loop for each new height. They may then repeat the procedure, using the other marbles that they have been given.
Another plan might involve adding a second rise in the roller coaster for each given height. Students then release the same, previously used marble. They might then experiment with changing the height of the second rise to determine the maximum height that the marble can reach when the initial height is 110 cm.

3. After students have gotten approval for their plans, have them begin their investigation. Make sure that students draw a diagram for each configuration and label the maximum potential energy (PE) and kinetic energy (KE) for the coaster at each configuration. Also have students show their calculations for PE and KE at various points along the roller coaster track, starting with the equation for conservation of energy. For example, they should first calculate, using \( PE = mgh \), the marble’s potential energy at the top of the track. Then, they should calculate the potential energy at the bottom of the track (before the loop) and equate this change in potential energy to kinetic energy, using \( KE = \frac{1}{2}mv^2 \).

4. Have students design a data table for recording their data, such as the example below:

<table>
<thead>
<tr>
<th>Mass of marble =</th>
<th>Height of Track</th>
<th>Height of Second Rise</th>
</tr>
</thead>
<tbody>
<tr>
<td>___ g</td>
<td>100 cm 110 cm 120 cm 130 cm 140 cm 150 cm</td>
<td>110 cm 100 cm 90 cm 80 cm 70 cm 60 cm</td>
</tr>
<tr>
<td>Slope of “roller coaster”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Does marble complete loop?</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Once students have completed their investigation, have them compare their data tables and discuss the general patterns. Ask students to look at the effects of height and mass on the potential energy of the marble and on its ability to complete the loop or reach the height of the second rise. Finally, have students write a concluding paragraph describing the effects of mass and height on energy transfer. They should use the data that they gathered and the observations that they made to support their conclusion.
Analysis and Conclusions

1. What is the marble’s potential energy at the top of the track? What is its potential energy at the bottom of the track?
   Sample response: The marble’s potential energy at the top of the track is equal to the marble’s mass times the height of the track times the acceleration due to gravity. The marble’s mass is 5 grams, or 0.005 kg. The height of the track was 110 cm, or 1.1 m. The acceleration due to gravity is 9.8 m/s². Multiplying these together gives a potential energy of 0.05 Joules. At the bottom of the track, the marble’s potential energy is 0 Joules, because its height is 0 m.

2. What is the marble’s kinetic energy at the top of the track? Using the conservation of energy, what is the marble’s kinetic energy at the bottom of the track?
   Sample response: At the top of the track, the marble is not moving, so its kinetic energy (given by \(\frac{1}{2}mv^2\)) is 0 Joules. Because of the conservation of energy, the potential energy at the top of the hill becomes kinetic energy as the marble rolls down the hill, so at the bottom of the track, the marble’s kinetic energy is 0.05 Joules.

3. Consider a roller coaster being pulled on a track to the top of the hill.
   a. How does the angle of the ramp affect the work done on the car to lift it to the top of the hill?
      Sample response: When total work done on an object, the path the object takes does not matter, just its starting and ending points. So, the angle of the ramp will not affect the work done on a car being lifted to the top of the hill.

   b. How does it affect the total potential energy at the top of the hill?
      Sample response: It also will not affect the potential energy at the top of the hill, because potential energy is equal to mgh, and the height will be the same regardless of the angle of the ramp.

   c. How do work and energy compare at the top of the hill?
      Sample response: Because of the work-energy theorem, the total work done and the energy gained will be the same regardless of the car’s path to the top; therefore, these quantities will be equal.
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable — the one variable the investigator chooses to change
    - Dependent variables — what changes as a result of, or in response to, the change in the independent variable
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
  - Choose appropriate tools to conduct an investigation:
    - Ruler/Tape measure
    - Meter stick
    - Balance
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Writing (journal, worksheet, electronic text)
    - Sketch

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Scientific explanations/arguments
    - Table/graph showing data

- **Scientific Endeavor**
  - Characteristics of Science:
    - One way to make sense of something is to think of how it relates to something more familiar.
    - Scientific claims can be substantiated using data and observation.
Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Determining the Specific Heat of a Metal

Timing:
Directed Inquiry – 70–90 minutes
Guided Inquiry – 90 minutes

Objective(s):
Students will determine the identities of various unknown solids by conducting a calorimetry experiment on them to find their specific heat capacity and then comparing the experimental heat capacities to known values for each substance.

Safety Precautions:
Students should wear closed-toe shoes for all labs. Students should not touch the water bath or the brass mass, since both will be very hot. The thermometer should not be used to stir. If the thermometers break, students should not try to clean it up but should report it to the instructor. Thermometers must be disposed of properly.

Materials:
Per group:
- 1 calorimeter (a polystyrene foam cup with an insulated lid can be used)
- 1 thermometer
- 1–4 blocks of different metals (Note: 3 cm × 3 cm × 3 cm cubes work for this purpose; suggested metals: copper, brass, steel, aluminum, iron)
- 1 graduated cylinder or beaker
- 1 pair of tongs
- 1 triple-beam balance or electronic scale

Teacher Preparation:
Teachers should prepare a hot water bath for the metal blocks to raise the temperature of the metals to a certain level. Different metals can be used for this experiment such as brass, steel, aluminum, and copper. Electronic thermometers are preferable, if available. Teachers should prepare copies of the Student Investigation Sheet.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Introduce the lab with the following sequence:
1. Demonstrate the lab setup and pose the following question: *If a metal block that is at high temperature is placed into colder water, what will happen to the system?*
2. Students may write their answers down.
3. Ask for responses. Students should identify the concept that the water’s temperature will increase, the metal block’s temperatures should decrease, and eventually the system will reach thermal equilibrium.
4. Explain that students will have the opportunity in this lab to determine the temperature change for a variety of different types of metals. Ask that students complete the hypothesis question.
5. Students should make a prediction as to what the final equilibrium temperature will be.

Hypothesis:
Answer the following questions in the hypothesis section of the lab handout.
1. Will different metals produce the same or different temperature changes when immersed in water? Make a prediction and explain your thinking.

Procedure:
1. Measure the masses of each of the metal blocks.
2. Measure 150 mL of water and place it into the calorimeter.
3. Record the initial temperature of the water in the calorimeter.
4. Using the density of water (1000 kg/m³), determine the mass of the water and record it in your data table.
5. Using a Bunsen burner or hot plate, heat the beaker with the water.
6. Place a block of metal into the hot water bath and leave it for 5 minutes.
7. Measure and record the water’s temperature at the end of the heating period. You can assume that the blocks have been in the water long enough to be at the same temperature as the water.
8. Using tongs, remove the hot metal block from the beaker and place it into the calorimeter and close the clover. Be sure not to bring hot water with the metal. Unwanted hot water on the metal will impact the results of the lab.
9. Wait for the system to reach thermal equilibrium and record the final temperature. The system has reached thermal equilibrium when the thermometer’s reading evens out and remains constant for a longer period of time.
10. Repeat multiple trials for the same and different blocks.
11. Use the equation \( Q = mcT \) to determine the specific heats of each metal.
12. Compare calculated specific heats with known values to identify the metals.

Notes: It is assumed that the heat lost by the block will equal the heat gained by the water in the cold water bath, so the temperature changes of the metal and water should be identical. If the density of liquid water is assumed to be 1.0 g/mL, 100 mL of water will have a mass of 100 g. Assume the specific heat capacity of the liquid water is about 4.18 J/(g\(\cdot^\circ\)C). The specific heat capacity of aluminum is about 900 J/(g\(\cdot^\circ\)C), copper about 390 J/(g\(\cdot^\circ\)C), iron or steel about 450 J/(g\(\cdot^\circ\)C), and a glass marble about 840 J/(g\(\cdot^\circ\)C).

Student Data Table:

<table>
<thead>
<tr>
<th>Metal Block #:</th>
<th>Initial Temperature of Metal Block (K)</th>
<th>Initial Temperature of Water (K)</th>
<th>Mass of Water (kg)</th>
<th>Mass of the Metal Block (kg)</th>
<th>Final Equilibrium Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>383</td>
<td>293</td>
<td>0.15</td>
<td>0.044</td>
<td>297</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Sample data assumes an aluminum block.
Guided Inquiry
Students can develop their own data table and their own procedure with limited instructions for this lab. For instance, the following general instructions can be given to students:

- **Using the calorimeter, determine the effects of adding different metals from the hot-water bath to 150 mL of room temperature water. In the process, you will need to measure the initial and final temperatures and the mass of both the water and the metal blocks. Create your own data table with this information.**

Ask the students some guiding questions to help them focus their inquiry. For instance:
- Why is the mass of both objects important to know?
- What is the appropriate time to measure the final temperature? Why?

The following suggestions may also be useful to provide to students:
- Use the density of water to calculate the mass given the volume. (Density and conversion factors may be provided if students do not have a readily available resource.)
- The mass of the metal block can be measured after it has cooled to the temperature of the water.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. **What is the specific heat of each metal?** Show all calculations. The sample calculation below is for aluminum. Since, the thermal energy transferred to the water is equal to the thermal energy lost by the aluminum block:

   \[ Q_{\text{water}} = Q_{\text{aluminum}} \]
   \[ m_w c_w \Delta T_w = m_{\text{Al}} c_{\text{Al}} \Delta T_{\text{Al}} \]

   \[ c = \frac{m_w c_w \Delta T_w}{m_{\text{Al}} \Delta T_{\text{Al}}} = \frac{(0.15 \text{ kg})(4.1 \text{ kJ/(kg} \cdot \text{K}) \times 4.2 \text{ K}}{(0.044 \text{ kg})(66 \text{ K})} = 0.91 \text{ kJ/(kg} \cdot \text{K}) \]

2. **What is the change in internal energy (\(\Delta U\)) for the water in each of the test cases?** Apply the first law of thermodynamics:

   \[ \Delta U = Q - W \]

   Note that no work is performed by the system, so \(W = 0\).

   \[ \Delta U = Q_{\text{aluminum}} \]
   \[ \Delta U = m_{\text{Al}} c_{\text{Al}} \Delta T_{\text{Al}} \]

   \[ \Delta U = (0.044 \text{ kg})(0.91 \text{ kJ/(kg} \cdot \text{K}) \times 66 \text{ K}) \]

   \[ \Delta U = 2.6 \text{ KJ} \]
3. Was the calorimeter an open, closed, or isolated system? How do you know? The calorimeter is technically a closed system since matter cannot enter or leave the system but energy can (although very gradually). In practice, however, the calorimeter is meant to approximate an isolated system since it severely limits the amount of heat that can enter or leave the system.

4. What are some sources of experimental error in your procedure? The calorimeter loses a small amount of heat to the external environment. The thermometer does not record temperature perfectly. It may be hard to determine exactly when the system reaches thermal equilibrium which may introduce error into the final temperature reading. Hot water may have been transferred into the calorimeter when the metal cube was placed inside it.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Temperature
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Thermometer
    - Scale
    - Glassware
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns:
    - Trends in data
    - Graphed data points
    - Based on an analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause–effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
• Peer presentation
• Written report
• Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    ▪ Scientific investigation leads to more questions.
    ▪ What people expect to observe can affect how they perceive what they observe.
  o Scientific Data and Outcomes:
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ It is important in science to keep honest, clear, and accurate records.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
    ▪ A law is a description of a specific relationship under given conditions in the natural world.
Overview

Processes in nature always tend to drift toward a disordered state. If one has to restore order in a system, work has to be performed on the system. In this Exploration, students will observe change in entropy for a reversible and an irreversible process.

Student Learning Objectives

- Observe the change in volume with change in pressure.
- Examine the change in the entropy of a system for both reversible and irreversible system.
- Analyze the graph of pressure versus volume for different values of temperature.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, a piston and cylinder arrangement is displayed. This arrangement is placed on a thermal reservoir. Students select the pressure applied on the gas inside the cylinder using the options in the Select Pressure dropdown list. Using the options in the Select Volume dropdown list, students select the initial volume of the gas inside the cylinder. Students select the temperature of the gas using option in the Select Temperature dropdown list. Two radio buttons, Reversible and Irreversible, are provided in the Nature of Process section. Students can choose if they want to investigate a reversible or an irreversible process using these radio buttons.

Once the students click on the Expand button, the number of lead shots decreases. This indicates a decrease in the pressure and an increase in the volume. The final values of pressure and volume are displayed after expansion. The Expand button toggles to a Contract button. Using the Contract button, students observe the contraction process. Lead shots are added. This indicates an increase in pressure and a decrease in volume. The values of pressure and volume after contraction are displayed. The value of entropy change is also displayed.

Using the Reset button, students can reset the Exploration and observe the values for a different selection.

The Graph tab displays the graph of pressure versus volume. Students can use this graph to examine the change in volume as the pressure changes. Analyze the change in entropy using the expansion and contraction graphs.
The Tracker tab displays a summary of the values for all the runs. Students can observe the value change in entropy for the selected pressure, volume, temperature, and nature of process.

**Answers to Questions in the Student Worksheet**

1. In this Exploration, investigate the change in the number of lead shots and determine its role in the Exploration. State how the entropy changes for the two processes, reversible and irreversible, with the change in the number of lead shots.

   **Answer:** The number of lead shots on the piston determine the pressure applied on the gas and hence, the volume of the gas. For a reversible process, as the lead shots are removed, the gas expands and attains definite final values of pressure and volume. During contraction, lead shots are added and the gas contracts till the pressure and volume reach the same initial values (i.e. values before expansion). For an irreversible process, the expansion and contraction occurs in a manner similar to reversible process. However, for irreversible processes the same initial values of volume is not reached for the same value of pressure because of friction between the piston and the cylinder.

2. In this Exploration, the piston is assumed to be frictionless (for reversible process). Explain the significance of this assumption.

   **Answer:** It is necessary to assume the piston to be frictionless. A system with friction will not be able to perform the same amount of work as a frictionless system. This is because a part of energy supplied to the system will be used by friction and the process will not be reversible.

3. State the unit of entropy.

   **Answer:** The unit of entropy is Joules per Kelvin (JK⁻¹).

4. State whether the entropy of the universe is increasing or decreasing.

   **Answer:** The entropy of the universe can never decrease. The entropy of a system can decrease, if there is a corresponding increase in entropy of one or more other systems resulting in a total increase in the entropy of the universe.

5. Arrange the following in ascending order of entropy values.
   a. Diamond crystal.
   b. Water vapor.
   c. Liquid nitrogen.

   **Answer:** Diamond crystal has the least entropy, followed by liquid nitrogen, and water vapor.
6. In this Exploration, observe the initial and final values of the volume for reversible and irreversible processes. Comment on the ratio of the final and initial volume and also on the change in entropy.

**Answer:** For reversible process the ratio of final volume to initial volume is unity i.e. the change in entropy is zero. For irreversible process the ratio of final volume to initial volume is greater than unity i.e. the entropy is positive which implies the system becomes more disordered.

7. Determine in which of the following processes the entropy will remain constant:
   a. Reversible
   b. Irreversible
   c. Both
   d. None

**Answer:** Reversible. The entropy of an irreversible process always increases.

8. Naturally occurring processes tend toward a disordered state. Determine if these processes can be brought back to an ordered state.

**Answer:** Yes, naturally occurring processes can be transformed from a disordered state to an ordered state. For bringing order back to the system, work has to be done on the system. For example, arranging your desk.

9. The entropy of water molecules decreases when they freeze. State whether this implies that the entropy of the universe decreases too. Justify.

**Answer:** The entropy decreases when water is frozen. However, this decrease in entropy is only for a part of the system. This decrease is offset by a greater increase in entropy elsewhere in the universe. In this case, the entropy of the air in the room increases.

10. Determine whether entropy increase or decreases in the following cases.
   a. An explosion.
   b. Air conditioner installed in a room.
   c. Water freezing in a refrigerator.
   d. Shuffling a fresh deck of cards.

**Answer:**
   a. Increases the entropy in its surrounding.
   b. Decreases the entropy in the room but increases the entropy of the outside atmosphere.
   c. Decreases the entropy of the water molecules but increases the entropy of the freezer.
   d. The cards become disordered and so the entropy increases.
Hands-On Lab

Entropy

Timing: one 90-minute class session

Objective(s):
In this activity, students will devise a statistical model of entropy. This model will show that entropy increases from a minimum in its ordered microstate to a maximum stable value that represents various disordered microstates.

Safety Precautions:
Minimal precautions are required. Advise students not to eat or drink in the lab.

Materials:
Per pair:
- 37 counters, two-sided with "heads" and "tails," such as pennies
- number cubes (six-sided, if at all possible two different colors)
- tracking sheet
- graph paper

Teacher Preparation:
Have students work in pairs. Gather the needed materials a few days before the activity. Also, prepare a copy of the Student Investigation Sheet for each of your students ahead of time.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
Directed Inquiry

Explain to students that their activity is a simulation of a system’s change from an ordered state into a disordered state while arbitrary changes make varying microstates.

Demonstrate to the class how to go over the investigation.

1. First, set up a 6 × 6 grid of counters, all heads if you are using pennies. Inform the class that this represents the initial ordered microstate and that the full information of every particle consists of its color and position.
2. Then have one volunteer toss the two (2) dice and the 37th coin or counter. The results from the dice will correspond to the \((x, y)\) coordinate of a board counter (first die is \(x\), second die is \(y\)) while the 37th counter will indicate its color or whether it is a head or a tail. If the dice are indistinguishable, have them throw the dice one at the time. If they are different colors, agree before tossing which color represents the \(x\)-coordinate. If the colors/faces of the 37th counter and the board are the same, leave the board counter; otherwise, flip it.
3. Have another volunteer execute the move generated by the other student. Inform the class that they will generate moves and execute them this way.
4. For each 10 moves, the number of “tails” counters should be counted. Each pair should be able to make a minimum of 100 moves. They could also make more moves if time allows them to.

Inform the class that they will draw a graph of the number of “tails” counters versus the move number. The number of “tails” should approach and fluctuate around 18, where half of the counters are “tails” and half are “heads,” which corresponds to maximum disorder in equilibrium. This also corresponds to a macrostate that can be made by many variations of microstates, which is more likely to happen.

As an alternative, you can also have capable students design a computer program to simulate the moves and results. If possible, have them show that the higher the number of moves and counters, the more the system moves toward maximum entropy, and then varies around it slightly but never really decreases significantly.

Encourage students to compare their results with other pairs of students, and have them discuss the differences among their results.

Guided Inquiry

Explain to students that their activity is a simulation of a system’s change from an ordered state into a disordered state while arbitrary changes make varying microstates. Inform the class that the counters will represent particles of a system. The full information of each particle consists of its color and position. The system will be represented by a 6 × 6 grid of counters.

Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask students some guiding questions to help them focus their inquiry:

- How will you represent an initial ordered microstate? (*They will use the 6 × 6 grid of counters with all “heads” or all “tails.”*)
- How will you then alter these microstates? (*They will use the dice and the last counter to generate moves and then execute it.*)
• How many moves will you make? *(The more, the better.)*
• How will you determine the frequency of the appearance of “tails”? *(For a certain number of moves, say 10, we will count the number of “tails” counters.)*
• How will you determine the state of maximum disorder for your system? *(Graph the number of “tails” counters versus the move number. It should be around half the number of the counters.)*

As an alternative, you can also have capable students design a computer program to simulate the moves and results. If possible, have them show that the higher the number of the moves and counters, the more the system moves toward maximum entropy, and then varies around it slightly but never really decreases significantly.

Encourage students to compare their results with other pairs of students, and have them discuss the differences among their results.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How can you explain the differences between your results to other pairs of students? *(The differences among our results can be attributed to the fact that we do not always get similar results each time we roll the dice and toss the counter.)*
2. Describe a physical situation that can be represented by your system of grid of counters. *(An ice cube tray filled with ice cubes left on a table can be represented by our model. Initially, the ice cubes are “in order,” but as time goes by, the ice melts and they become less orderly.)*
3. If you had the time and resources, how would you be able to improve your experimental design? *(We could extend our activity by using more counters and more moves.)*
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Recognize and develop testable questions that:
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use the appropriate format to record data:
    - Table
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
  - Assess the conclusion by:
    - Comparing results to hypothesis
    - Extrapolating results beyond the investigation

- **Communication in Science**
  - Report results using:
    - Peer presentation
    - Written report
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
Overview

The laws of Thermodynamics are fundamental rules governing the behavior of matter. In this Exploration, students observe the behavior of ideal gases as they try to achieve thermodynamic equilibrium.

Student Learning Objectives

- Investigate the relationship between temperature, pressure, and volume of a gas.
- Observe how the gas achieves equilibrium by returning to standard conditions.
- Calculate the values of thermal energy of the gas and work done by the piston.
- Deduce the implications of the laws of thermodynamics on the selected gas.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

Students can use the Apparatus tab to get familiar with the equipment used in the Exploration. The Experimental Setup and Temperature Sensor radio buttons can be used to gather information about the apparatus.

Using the Explore tab, students can observe the behavior of gases. They can click on the valve between the two cylinders to open or close it. The Select Gas dropdown can be used to choose the gas students wish to study. They can use options in the Select Pressure Applied on Piston dropdown list to vary the pressure. The Select Number of Moles dropdown can be used to vary the number of moles of the gas in the cylinder. Students can use the Start button to view the values of temperature of the gas, its thermal energy and work done by the piston. The Reset button can be used to restart the Exploration with different values of the physical quantities.

Students can use the Data tab to observe the values of volume, temperature, thermal energy, and work done by piston with respect to time for the last run of the Exploration.

The Tracker tab can be used to track the number of moles, pressure, final volume, and final temperature of the gas for each run of the Exploration.
Answers to Questions in the Student Worksheet

1. Describe how temperature, pressure, and volume of an ideal gas are related.

   **Answer:** Temperature, pressure, and volume are related using the equation \( PV = nRT \), where \( P \) is the pressure of the gas, \( V \) is its volume, \( n \) is the number of moles of the gas, \( R \) is the ideal gas constant, and \( T \) is the temperature of the gas. This is known as the ideal gas equation.

2. Explain the difference between isothermal and adiabatic processes.

   **Answer:** Isothermal processes are the ones that are carried out at a constant temperature. On the other hand, an adiabatic process is one in which heat is neither supplied, nor released.

3. List the factors affecting work done during expansion of a gas.

   **Answer:** The pressure and volume of a gas directly affect the work done by it during expansion. Work done by a gas during expansion is given by \( W = P \Delta V \), where \( P \) is the pressure of the gas and \( \Delta V \) is the change in its volume.

4. State the equation for calculating the thermal energy of diatomic gases.

   **Answer:** Thermal energy of a diatomic gas is calculated using the formula \( 2.5 \times n \times R \times T \), where \( n \) is the number of moles of the gas, \( R = 8.314 \text{ J/mol·K} \), and \( T \) is the temperature of the gas in Kelvin.

5. Describe how the motion of molecules of a gas is a function of temperature.

   **Answer:** The molecules of a gas are always in random motion. However, as the temperature of the gas decreases, the RMS velocity of the molecules decreases due to a fall in their thermal energy. Hence, RMS velocity of gas molecules is a directly proportional to the square root of temperature.

6. If the pressure of a gas is kept constant at \( 3.50 \times 10^5 \text{ Pa} \) and its volume reduces from 10.0 liters to 5.00 liters, calculate the work done by the gas.

   **Answer:**
   \[
   W = P \Delta V \\
   W = 350 \times (10.0 - 5.00) \\
   W = 1.8 \text{ kJ.}
   
   Hence, work done by the gas is 1.8 kJ.
7. Using the Exploration, comment on the probe used and state if it can be replaced with any other simpler instrument.

**Answer:** In the Exploration, a temperature sensor is used as a probe. The interface connected between the probe and the computer computes the values of thermal energy and work done by the piston by measuring the temperature of the gas. A thermometer could also be used instead of the temperature sensor. However, this would add the element of human error and the calculations for thermal energy and work done would have to be done manually.

8. State the zeroth law of thermodynamics.

**Answer:** The zeroth law of thermodynamics states that, ‘If two systems are each in thermal equilibrium with a third, they are also in thermal equilibrium with each other.’

9. Calculate the thermal energy of a diatomic gas at 25.5°C and standard pressure, having a volume of 5.00 liters. Number of moles of the gas = 2.00. R = 8.314 J/mol·K.

**Answer:**

\[
\text{Thermal Energy} = 2.50 \times n \times R \times T \\
= 2.50 \times 2 \times 8.314 \times (25.5 + 273.16) \\
= 12415.3 \text{ J} \\
= 12.4 \text{ kJ}
\]

Hence, thermal energy of the gas is 12.4 kJ.

10. State one example of a machine whose efficiency can be increased by applying the laws of thermodynamics and analyzing the work done.

**Answer:** Heat engines incorporate all the laws of thermodynamics. Efficiency of engines can be increased by optimizing the heat energy supplied and varying pressure and volume of the cylinders.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

**Creating a Data Table**

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work

b) load data from another user by typing in the ‘Save Code’

c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handsan and height, they could easily turn off all the columns except height and handsan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Bending Light

Timing: one 90-minute class session

Objective(s):
In this investigation students will investigate refraction of light in water.

Safety Precautions:
Do not put hands in aquarium, to avoid spillage. Do not use optical laser to do this lab, as reflection from aquarium may cause injury.

Materials:
- power supply
- slide projector
- books to boost slide projector
- flat-sided aquarium or goldfish bowl, filled with water to a depth of five inches, about the diameter of a compact disc.
- two compact discs
- two meter sticks
- masking tape
- dark colored paper
- sticky notes
- pen

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- This lab is a demonstration lab, as the material setup is extensive, and things like an aquarium, slide projector and power supply are unique in a classroom. If you, as the teacher, demonstrate the procedure, students can still collect and analyze data on their own.
- This lab repeatedly refers to an aquarium. Since this is only a large flat-sided translucent container of water, this can alternately be a flat-sided goldfish bowl, a vase shaped like a rectangular prism, or any other similarly-shaped transparent container.

Directed Instruction
An aquarium, placed in the center of a single lab bench, is the target for a light beam from a slide projector. As that projector is moved along a meter stick taped to the near side of this lab bench, students find and mark locations of the output beam near a second meter stick on the far side of the bench.

Students should be familiar with Snell’s Law. Students should also have graph paper in their notebooks, to allow them to sketch the lab setup very accurately. This will allow them to carefully calculate how light bends as it moves through the aquarium or goldfish bowl.
Procedure

1. Plug slide projector into power supply.
2. Tape one compact disc over the front of the slide projector’s front lens, aligning the hole in the center of the compact disc with the center of the lens. Use books to boost slide projector if required for the central hole to align.
3. Tape second compact disc on front of aquarium, and place this container in the center of the lab bench. Make sure second compact disc is positioned to allow light beam from the projector to go through central hole in compact disc.
4. Tape one meter stick on the side of the lab bench in front of students and behind the slide projector. Use tape to mark positions every five centimeters along length of meter stick.
5. Use second meter stick to measure lab bench and placement and dimensions of aquarium. Sketch and record these measurements in a lab notebook.
6. Use masking tape to tape second meter stick to back of lab bench, behind aquarium. Align end of second meter stick to be directly across lab bench from meter stick from Step 4.
7. Use pen to draw vertical arrows on several sticky notes.
8. On these notes, note projector positions, in terms of distance along the meter stick along the front of the lab bench.
9. Place slide projector at one marked position, and activate it.
10. Pivot slide projector in place to aim beam of light into hole in compact disc on front of aquarium.
11. While the teacher aims light beam from slide projector, a student should use the dark paper to find the bright center of the beam that emerges from the back of the aquarium.
12. When the position of this beam is found along the meter stick on the back of the bench, a sticky note should be placed on the lab bench at this position. Care should be taken to match position notations on each sticky note with the actual projector position that created the output beam position.
13. Turn off slide projector.
14. Move slide projector to next marked position along the front of the lab bench, and repeat Steps 9 through 13.
15. Repeat Step 14 until every marked position on the front of the lab bench has a corresponding sticky note along the back of the bench.
16. Students should use the second meter stick to note the output beam positions in terms of their corresponding slide projector positions. A chart might look like:

<table>
<thead>
<tr>
<th>Projector Position</th>
<th>Output Beam Position</th>
<th>Projector Position</th>
<th>Output Beam Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 cm</td>
<td>85 cm</td>
<td>10 cm</td>
<td>72 cm</td>
</tr>
<tr>
<td>5 cm</td>
<td>78 cm</td>
<td>15 cm</td>
<td>65 cm</td>
</tr>
</tbody>
</table>

17. Students should use their accurate drawing of the setup to analyze how light was bent in the water. The drawing should be to scale, and a line (the “normal”) should be drawn perpendicular to the front and back of the aquarium, through the taped compact disc position.
a. Starting from one projector position, the student then draws a line to the center of the taped compact disc on the front of the aquarium in the drawing.
b. The student then constructs a line, parallel to the first, which extends from the beam endpoint to the back of the aquarium.
c. A line connecting these points on the front and the back of the aquarium will make a smaller angle with the normal than the exterior beamlines do.
d. Students then use geometry to accurately estimate each angle made by interior and exterior beamlines with the normal.
e. Plotting the sine of one angle against the other for several points will show a linear relationship between these data.
f. The slope of a line through the data will allow estimation of the index of refraction of water.
Analysis and Conclusions

1. What did you find about the path of the light beam from the projector?
   Sample Response: *We found that if the light beam entered the aquarium at an angle, the beam would be bent toward an imaginary line running straight through the aquarium. Upon emerging from the aquarium, the light would be bent back to its original angle.*

2. Why do you think compact discs were used on the slide projector and the aquarium, and why did you have to use dark paper to find the bright center of the beam?  
   Sample Response: *Light diffuses in water, and the compact discs were used to produce a tight beam of light from the projector. Even this diffused, and so we had to find the output beam’s bright center. We used the dark paper to provide contrast to surroundings.*

3. Was there any position of the slide projector for which an output beam did not emerge from the aquarium? If there was, what was this position, and why did an output beam not emerge?  
   Sample Response: *Any light beam that is incident on water or other translucent substance is both reflected and refracted by the material. If an incident beam is at too high an angle to a normal through the material, the beam is only internally reflected in it, and not refracted.*

4. Why was it important for you to draw an accurate layout of the lab setup?  
   Sample Response: *The beam was bent in the water, and unbent when it emerged from the water. We used our accurate drawing to estimate the bent light path in the water. A ratio of the sines of the angles involved gave us an estimate of the index of refraction of water, about four-thirds, or 1.3.*
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design or conduct field studies using:
    - Survey – collects multiple data points at one point in time.
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable – the one the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable.
  - Practice lab safety by:
    - Following lab safety procedures.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Length
  - Uses Senses to Observe:
    - Seeing (color, shape, size, texture, motion)
  - Chooses appropriate tools to conduct an investigation
    - Ruler/tape measure
  - Uses the appropriate format to record data:
    - Table
    - Graph or chart

- **Patterns and Systems**
  - Patterns and change:
    - Some small changes can be recorded by making measurements
    - Many patterns in nature contain symmetry
Hands-On Activity
Electromagnets

Objective:
In this activity, students will see how an electric current can be used to create an electromagnet.

Estimated time to complete: 20 minutes

Materials:
For each pair or small group:
- 2 long pieces of insulated wire
- 2 nails or thin iron rods at least 8 cm long
- 2 batteries in holders
- 10 paper clips
- 10 thumb tacks (or push pins)
- 1 small pencil eraser
- 1 small piece of chalk

Procedure:
1. Make sure at least 1 cm of the wire is exposed on each end.
2. Wrap the wire around the nail, leaving at least 3 cm on each end. Attach the exposed part of one end of the wire to the positive terminal of the battery and the exposed part of the other end of the wire to the negative terminal. The nail is safe to touch, since there is no current flowing through the nail itself.
3. Try to pick up paper clips by touching one end of the nail to the paper clip. Explain what is going on.
4. Try to pick up the eraser and the chalk. Explain the results.
5. Try to pick up some other small, light, metallic objects such as thumb tacks (or push pins.) Explain why there may be limits to what can be picked up and how the magnetic effect might be stronger.
6. Prepare a second nail like the first and attempt to touch the like ends together. Try to touch opposite ends together. Make observations and offer explanations.
Inquiry and Nature of Science Skills in this Activity:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Analyzing scientific explanations
    - Analyzing scientific arguments
Hands-On Lab
Investigating Coulomb’s Law

Timing: one 90-minute class session

Objective(s):
Students will test Coulomb’s Law to find out if electric force varies with the square of the inverse of charge separation.

Safety Precautions:
Remind students to follow all general lab safety rules, wear closed-toe shoes and safety goggles, and not to eat or drink anything in the lab.

Materials:
Per group:
- 2 pith balls, graphite-coated
- thread, 20 cm in length
- stand, insulated, with a hook for suspending pith balls (a ring stand with boss head clamp and a 20-cm wooden rod or dowel may be substituted for the stand)
- 1 ring stand with boss head clamp
- 2 wooden dowels, 20 cm in length
- paper strip, 30 cm in length
- metric ruler or meter stick
- protractor, large

Per class:
- rod, ebonite or hard rubber
- rod, glass or lucite
- wool, or animal fur, piece, 10 cm x 10 cm
- silk, piece, 10 cm x 10 cm
- thumbtack
- putty, adhesive
- tape, masking

Teacher Preparation:
None required except to gather supplies.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry

Begin by demonstrating the basic Coulomb’s Law procedure that students will follow:

1. Measure the masses of the pith balls using the analytical balance. Record the values in the data table.
2. Attach one end of a length of thread to one pith ball, using a very small amount of adhesive putty. Tie the other end of the thread to the hook of the insulated stand so that the ball is about 10 centimeters above the lab table surface. (Alternatively, set up the ring stand and clamp and place the 20-cm wooden rod in the clamp. Tie the thread to the end of the rod so that any electrical effects from the stand are minimized.)
3. Attach the second pith ball to a 20-cm dowel, using a small amount of adhesive putty. Set the other end of the dowel in a boss clamp and attach to the ring stand so that the ball is “fixed” in a chosen position.
4. Align the paper strip with the centers of the two balls. Leave enough paper on either sides of the stands for measurements and secure the strip to the lab table using tape.
5. Place the two balls so that they are in contact with each other.
6. Rub the ebonite or hard rubber rod with the piece of fur and touch the rod to the fixed ball.
7. Carefully adjust the horizontal and vertical position of the fixed ball until its center is horizontally level with the center of the suspended ball, and the separation between the two balls is between 5 and 10 centimeters. (Note: the fixed ball will be higher above the table for this measurement than for subsequent measurements.)
8. Exercising great care not to touch either of the balls, locate the positions on the paper that are directly beneath the centers of each ball. Mark these positions with a pencil.
9. Without disturbing the pith balls, carefully measure the separation between the two marks with a meter stick or metric ruler. Record the distance in the column headed $d$ of the data table.
10. Using the protractor, carefully measure the angle that the thread of the suspended pith ball makes with respect to the vertical. Record the angle in the data table.
11. Move the fixed pith ball away from the suspended ball until the separation between their centers is between 10 cm and 15 cm.
12. Repeat steps 7 through 10 for the new separation.
13. Repeat steps 11 and 12 for a separation of the centers of the balls that lies between 15 cm and 20 cm and again for a separation between 20 cm and 25 cm.
14. Construct a grounding tool by attaching the thumbtack to the end of the 20-cm dowel with adhesive putty. Use the grounding tool to discharge both spheres.
15. Repeat steps 5 through 14 now using the glass or lucite rod and silk to provide the charge.
Before demonstrating the apparatus, ask students to predict what they expect to happen. After the demonstration, ask the students about what they saw.

Ask students the following questions:

- How does the field force between the two charges relate to the angle that the suspended pith ball makes with the vertical? [The angle of the suspended ball increases with greater electric force.]
- What is the expression, in terms of distance, for the electric force between two charges? [Answer: For identical charges \( q \) that are separated by a distance, \( d \), \( F_{\text{electric}} = \frac{kq^2}{d^2} \).]
- What forces act on the suspended ball when there is a charge on both pith balls? Which forces balance which? [Gravity, the electric repulsion between the balls, and the tension in the thread act on the suspended ball. The upward component of the tension balances the force of gravity, and the horizontal component of the tension balances the electric force.]
- How does the electric force on the fixed ball relate to the electric force on the suspended ball? [The force on each of the charged pith balls is equal in magnitude and opposite in direction.]
- Why should the balls be horizontal before making measurements? [By making the separation horizontal, the electric force can be treated as a purely horizontal force and is, therefore, easier to analyze with respect to the other forces acting on the suspended pith ball.]
- Why is it important for the balls to be in contact when first charged and to not touch the balls once they are charged? [When the charge is transferred from the rods to the balls, both balls will have equal amounts of charge. If the balls are touched, some of the charge will be removed, which will reduce the electric force between them at a given separation.]
- How might the results of the investigation differ when repeated? [The amount of charge created by rubbing the rods with the fur and silk will most likely be different with each repetition and, therefore, the electric force will be different. This will result in different angle measurements for the same charge separations.]
- Based on the previous questions, what are the independent, dependent, and controlled variables in this investigation? [Charge separation is the independent variable, the angle at which the forces on the suspended pith ball balance is the dependent variable, the charge on both balls and the masses of both balls are controlled variables.]

Have students separate into groups of 2 or 3 to repeat the procedure demonstrated. Before they begin, have them write a summary of the procedure in their lab notebooks, including a labeled sketch of the setup. Ask students to predict what they expect to observe. How does the field force between the charged balls vary with the distance between them? How does changing the polarity of charge on both pith balls from positive to negative affect the results? Can they anticipate any sources of error?

When setting up their apparatus, each group should notice whether there are strong air currents or high humidity present. Moving air can prevent the suspended pith ball from remaining still during distance and angle measurements, while humidity can make it difficult to charge the pith balls or to keep them charged during the investigation. Both conditions will affect measurement accuracy, especially if smaller pith balls are used.

To make the investigation proceed more efficiently, have the other member(s) of the group start setting up the apparatus while one student obtains the mass values for the pith balls.
Students should place the adhesive putty on the pith balls before obtaining their masses as the putty can significantly affect the masses of the balls. Advise students to exercise extreme care when using the balance, to first place a tare sheet on the balance to protect it from the weighed objects, and to take the mass of the tare sheet into account when determining the mass of the pith balls and putty.

Have students attempt a few trial runs to become familiar with the process of adjusting the “fixed” pith ball position so that it is horizontal to the suspended pith ball, carefully measuring the horizontal separation of the balls and carefully measuring the angle that the suspended pith ball makes with the vertical.

Students should take turns measuring pith ball separation and angle. For one set of variables, one student measures the separation while the other measures the angle between the thread and vertical.

Students must be very careful not to accidentally alter the charge on the spheres during each trial of the investigation. Similarly, the charged pith balls must be kept isolated from conducting substances (such as the metal of the ring stand) and any charged objects. To accurately determine how the electric force varies with charge separation, the charge must be kept constant so that there are only the two variables. If the balls lose charge during the investigation, it will have to be started again with a new net charge.

A sample data table will look like the following (Note: These values are for larger pith balls (33 mm diameter)):

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass pith ball 1 (fixed) (g)</td>
<td>2.5</td>
</tr>
<tr>
<td>Mass pith ball 2 (suspended) (g)</td>
<td>2.3</td>
</tr>
<tr>
<td>Horizontal separation of balls (cm)</td>
<td>Angle of suspended ball (degrees)</td>
</tr>
<tr>
<td>5.5</td>
<td>15.0</td>
</tr>
<tr>
<td>11.0</td>
<td>3.8</td>
</tr>
<tr>
<td>15.0</td>
<td>2.1</td>
</tr>
<tr>
<td>20.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Point out to students that a repetition of the experiment will produce somewhat different results, even if identical separations are used, because of the different amounts of charge that may be produced and transferred to the pith balls.

You may choose to give students time to review this procedure on their own or talk through it with them. If time permits and equipment is available, encourage the students to try variations on this procedure. These could include measuring the charge with an electrometer or using different sized pith balls that have distinctly different masses. Have students choose an independent variable to adjust. In their notebooks, have students identify constants, independent variables, and dependent variables, and write down their hypothesis for what will happen.
You may need to review with students the vector analysis of the forces acting on the suspended pith ball so that they will be able to understand clearly the mathematical relationship between the horizontal separation of the two pith balls ($d$) and the angle at which the suspended pith ball is in equilibrium ($\theta$). Remind them that the force of gravity ($mg$) on the pith ball is offset by the upward component of tension in the thread ($T \cos \theta$), while the electric force ($\frac{kq^2}{d^2}$) is balanced by the horizontal component of tension in the thread ($T \sin \theta$). By taking the ratios of the equations, an expression for the tangent of $\theta$ is found that is in terms of constants $g$ and $k$ and quantities $m$, $q$, and $d$.

Have students plot the inverse square of the horizontal separations on the $x$-axis of a graph and the values of the tangent of the angle on the $y$-axis. They should note a linear trend, although it is unlikely that their data will lie exactly on a straight line. Have students consider whether or not these deviations are the results of experimental technique and if so, what might be done to reduce their effect. For example, placing the apparatus in a large shielded volume would reduce errors caused by air disturbance.

Encourage groups to share their results with each other. Have the class discuss their investigations as a group and try and explain any similar patterns or differences in results.

Guided Inquiry
Students can develop their own procedure and plans for collecting data on the basis of their knowledge of Coulomb’s Law demonstrations and the materials available. Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- What will be your independent and dependent variables?
- How will you vary the independent variables?
- How will you keep the constants constant?
- What method will you use to determine the separation of the charged pith balls?
- What method will you use to determine how great is the electric force between the pith balls?
- Why will it be necessary to be able to adjust the separation between the charged pith balls?
- Why will it be desirable to make the separation between the charged pith balls perpendicular to the force of gravity?
- Why will it be desirable to make the charge on the pith balls the same?
- What sources of error do you expect to encounter in the investigation?

Have students separate into groups of 2 or 3. Before they begin, have them write a summary of the procedure in their lab notebooks, including a labeled sketch of their equipment setup. Ask students to predict what they expect to observe. How does the field force between the charged balls vary with the distance between them? How does changing the polarity of charge on both pith balls from positive to negative affect the results? Can they anticipate any sources of error?
Guide students toward using the measuring charge separation and angle without touching the charged balls. Students will also need to understand the mathematical relationship between the various forces acting on the suspended charge or charges. They may choose a variety of variables to investigate, but a simple procedure is as follows:

1. Measure the masses of the pith balls using the analytical balance. Record the values in the data table.
2. Attach one end of a length of thread to one pith ball, using a very small amount of adhesive putty. Tie the other end of the thread to the hook of the insulated stand so that the ball is about 10 centimeters above the lab table surface. (Alternatively, set up the ring stand and clamp, and place the 20-cm wooden rod in the clamp. Tie the thread to the end of the rod so that any electrical effects from the stand are minimized.)
3. Attach the second pith ball to a 20-cm dowel, using a small amount of adhesive putty. Set the other end of the dowel in a boss clamp and attach to the ring stand so that the ball is “fixed” in a chosen position.
4. Align the paper strip with the centers of the two balls. Leave enough paper on either sides of the stands for measurements and secure the strip to the lab table using tape.
5. Place the two balls so that they are in contact with each other.
6. Rub the ebonite or hard rubber rod with the piece of fur and touch the rod to the fixed ball.
7. Carefully adjust the horizontal and vertical position of the fixed ball until its center is horizontally level with the center of the suspended ball and the separation between the two balls is between 5 and 10 centimeters. (Note: the fixed ball will be higher above the table for this measurement than for subsequent measurements.)
8. Exercising great care not to touch either of the balls, locate the positions on the paper that are directly beneath the centers of each ball. Mark these positions with a pencil.
9. Without disturbing the pith balls, carefully measure the separation between the two marks with a meter stick of metric ruler. Record the distance in the column headed \( d \) of the data table.
10. Using the protractor, carefully measure the angle that the thread of the suspended pith ball makes with respect to the vertical. Record the angle in the data table.
11. Move the fixed pith ball away from the suspended ball until the separation between their centers is between 10 cm and 15 cm.
12. Repeat steps 7 through 10 for the new separation.
13. Repeat steps 11 and 12 for a separation of the centers of the balls that lies between 15 cm and 20 cm and again for a separation between 20 cm and 25 cm.
14. Construct a grounding tool by attaching the thumbtack to the end of the 20-cm dowel with adhesive putty. Use the grounding tool to discharge both spheres.
15. Repeat steps 5 through 14 now using the glass or lucite rod and silk to provide the charge.
A sample data table will look like the following (Note: These values are for larger pith balls (33 mm diameter)):

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<td>2.3</td>
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<tr>
<td>Horizontal separation of balls (cm)</td>
<td>Angle of suspended ball (degrees)</td>
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You may choose to give students time to review this procedure on their own or talk through it with them. If time permits and equipment is available, encourage students to try variations on this procedure. These could include measuring the charge with an electrometer or using different sized pith balls that have distinctly different masses. Have students choose an independent variable to adjust. In their notebooks, have students identify constants, independent variables, and dependent variables, and write down their hypothesis for what will happen.

Have students plot the inverse square of the horizontal separations on the x-axis of a graph and the values of the tangent of the angle on the y-axis. They should note a linear trend, although it is unlikely that their data will lie exactly on a straight line. Have students consider whether or not these deviations are the results of experimental technique and if so, what might be done to reduce their effect. For example, placing the apparatus in a large shielded volume would reduce errors caused by air disturbance.

Encourage groups to share their results with each other. Have the class discuss their investigations as a group and try and explain any similar patterns or differences in results.
Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Did the graph of your data confirm Coulomb’s Law? If so, why? If you had plotted the tangent of the angle versus charge separation instead of tangent of the angle versus the inverse square of the charge separation, what would the graph have looked like? [Yes, the straight line that resulted when $1/d^2$ was used as the independent variable confirmed Coulomb’s Law. This showed that electric force, as indicated by the tangent of the angle at which the suspended charged pith ball was acted on by balanced forces, is inversely proportional to the square of the distance separating the two charges. Had the graph been of tangent of the angle vs. distance, the graph would have been an exponential curve with large angle values at small distances, which would have decreased rapidly with increasing distance.]

2. Write the equations to describe the balanced forces on the suspended pith ball. What is the mathematical representation of Coulomb’s Law in terms of experimental quantities and physical constants? Rearrange this representation to give the mathematical form of the slopes of your graphed lines. $mg = T \cos \theta$; $F_{\text{electric}} = T \sin \theta$, where $T$ is the tension in the thread, and $\theta$ is the angle the thread makes with the vertical. In terms of experimental quantities, Coulomb’s Law take the form of $F_{\text{electric}} = kq_1^2/d^2 = mg \tan \theta$. The slope of the line is therefore $\tan \theta / (1/d^2) = kq^2/mg$.]

3. What patterns in your measured data and in your graphed data suggest that Coulomb’s Law is obeyed in this investigation? [The change of angle and, therefore, tangent of the angle decreased as the separation of the charges increased. The straight line that resulted from plotting the tangent of the angle versus $1/d^2$ indicated an inverse-square relationship, the same as Coulomb’s Law.]

4. Did the graphs of the different sets of data differ? If so, how, and what did these differences represent in terms of physical quantities? [Yes. The slopes were greater for some data than they were for others. This suggested that the amount of charge was different for different sets of data.]

5. Why is Coulomb’s Law considered to be a law and not a theory or hypothesis? [Coulomb’s Law describes the behavior of a physical system, in this case, the force between two charges. It does not provide an explanation as to why the force is proportional to the amounts of charge and inversely proportional to the square of their separation distance, so it does not qualify as a theory. Nor is it a hypothesis, because it has been tested and confirmed by experimental evidence.]

6. Identify some possible sources of error in your experiment. Can you think of ways to improve the experimental technique? [Some of the sources of error included 1) variations in determining the exact distance between the centers of the two balls, 2) inconsistency in making the separations truly horizontal, 3) imprecision in measuring the angles between the thread and the vertical, 4) loss of charge because of humidity in the air, and 5) movements of the suspended ball due to turbulence in the air. Improvements might include using a larger protractor for better angle measurements, using a level to check horizontal alignments, using dehumidifiers or heating lamps to dry the air, and using a large cabinet or box to shield the equipment during the investigation.]
7. List another question your experiment suggested that you would like to test. [Sample Answer: I would like to repeat the experiment with pith balls of different mass to see how this would affect the data. I would also like to measure the amounts of charge on the pith balls so that the direct proportionality of the angle measurements to the product of the charges could be tested.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Length/distance/depth
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape measure
    - Scale or balance
  - Uses the appropriate format to record data:
    - Table
    - Graph or chart

- **Interpret Data**
  - Identifies and interprets:
    - Trends in data
    - Graphed data points
    - Tables and graphs
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting out trends and patterns in the data.
  - Assessing the conclusion by:
    - Answering the testable question
• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating a conclusion

• Scientific Investigation
  o Scientific Data and Outcomes:
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
Hands-On Lab
The Many Colors in Light

Timing: one 90-minute class session

Objective(s):
Students will investigate the spectrum of wavelengths of visible light in the output from discharge tubes, which are a type of cathode-ray tube. They will also investigate how the glow from a discharge tube is affected by a horseshoe magnet. Finally, they will compare the properties of light from the discharge tube with those from other lighting sources available in the classroom.

Safety Precautions:
Use precautions appropriate to using electrical equipment, and operating in a darkened room.

Materials:
Per group:
• discharge tube (H, He, Ne, Ar) with power supply
• hand-held visible spectrometer
• horseshoe magnet

Teacher Preparation:
• Gather materials in advance of students performing the lab.
• Give different teams discharge tubes that contain different gases, and have them repeat their observations by looking at light from other teams’ discharge tubes. Ultimately, all teams should observe the light from discharge tubes containing all gases (i.e., H, He, Ne, Ar) that are available, and sketch all spectra.
• If different discharge tubes use the same gas, teams using either tube should look at the light from each tube, to satisfy themselves that properties of the emitted light arise due to the identity of the gas in the tube.
• If incandescent bulbs, fluorescent tubes, or compact fluorescent bulbs are operating in the room, have students look at these operating lights, to learn their associated visible light spectra.

Procedure
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Instruction

Students should be familiar with the concepts of the electromagnetic spectrum and the spectrum of visible light. Explain to them why certain gases, when excited, produce visible light photons. Electrons in these gases absorb energy and move between energy levels above the nucleus, releasing a photon when they fall from a high energy level to one with lower energy. These photons produce a visible spectrum that is characteristic to a given element.

1. Dim lights in room.
2. Look through hand-held visible spectrometer at area near (inactive) discharge tube, and note any visible light spectrum recorded by the spectrometer.
3. Activate discharge tubes.
4. One member of each team should look at the light from the tube, and describe the light spectrum to other team members, who will sketch the spectrum in their notebooks.
5. Rotate possession of spectrometer, and repeat Step 4 until every team member has looked at light from the discharge tube.
6. Feel the air near the discharge tube, and note if it is warm.
7. If different teams have discharge tubes that contain other gases (i.e., H, He, Ne, Ar), have members of each team observe light from each other team’s discharge tube until all have observed and sketched the visible light spectrum from discharge tubes that contain all available gases.
8. Have each team hold a horseshoe magnet close to the discharge tube and observe the effect it has on the light.
9. Once all teams have looked at light from discharge tubes containing all available gases, bring lights back up in room, and have students repeat Steps 4, 5 and 6 for any operating incandescent bulbs, fluorescent tubes, or compact fluorescent bulbs.

Guided Instruction

Students can be encouraged to use the visible light spectrometer to look at the output of various lighting systems. The slight differences in output spectra can help students identify the individual gases that are used in these systems. Technical specifications of these systems, if available, can tell students about these output spectra, and give a point of reference that they may compare against their observations.
Analysis and Conclusions

1. Why did you look through the hand-held visual spectrometer before activating the discharge tube?
   Sample Response: *We did so to find a background level of light, so that we could disregard it in our sketches of the output visible light spectrum from our team’s discharge tube.*

2. What output visible light spectrum did you observe from your discharge tube, and what do you think this means?
   Sample Response: *We saw different lines on the spectrometer’s output. This means that the light from the tube is made up of several different wavelengths of visible light, some brighter than others for a given spectrum.*

3. If you looked at the light from two discharge tubes that contained the same gas, how did the output visible light spectra of the tubes compare?
   Sample Response: *We saw the same output visible light spectra from two or more different discharge tubes which contained the same gas.*

4. What did you see when you looked at the light of various lighting systems with the spectrometer?
   Sample Response: *We saw a continuous spectrum from incandescent lighting, and a more discrete, well-divided spectrum from both fluorescent tubes and compact fluorescent bulbs.*

5. What did you notice when you felt for heat near the discharge tubes and other lighting systems?
   Sample Response: *We identified that the discharge tubes, and fluorescent lighting systems, do not emit much heat. Incandescent systems do emit a lot of heat.*

6. What did you notice when you held the horseshoe magnet near the gas discharge tube? What did it tell you about the nature of the particles causing the tube to glow?
   Sample Response: *The magnet seemed to cause the glow to move to be nearby, instead of spread throughout the tube. The particles caused by the glow must be electrically charged for them to be affected that way by a magnet.*
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design or conduct field studies using:
    - Survey – collects multiple data points at one point in time.
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable – the one the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable.
  - Practice lab safety by:
    - Following lab safety procedures.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system) to accurately measure:
    - Visible Light Spectra
  - Uses Senses to Observe:
    - Seeing (color, shape, size, texture, motion)
  - Chooses appropriate tools to conduct an investigation
    - Hand-held visual spectrometer
  - Uses the appropriate format to record data:
    - Sketch
Exploration Teacher Guide: Conductors and Insulators

Overview

Different types of materials allow varying amounts of electric current to flow through them. Based on their conductivities they are classified as conductors, semiconductors, or insulators. In this Exploration, students examine the conductive properties of various materials.

Student Learning Objectives

- Examine the conductivity of conductors, semiconductors, and insulators.
- Observe and verify Ohm’s law for various substances.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, a closed electric loop is displayed on the screen. This loop consists of a voltage source along with a current indicator. A sample material to be analyzed is also connected in this loop. Students select the sample material to be tested for its conductivity, at room temperature, using the radio button options in the Select Material section. Using the radio button options in the Select Current Indicator section, students select a current indicator. The options for current indicator are an ammeter and a bulb. If an ammeter is selected, the value of current flowing through the loop is displayed. If a bulb is selected, current value is indicated by the brightness of the bulb. Using the options in the Select Voltage dropdown list, students select a maximum voltage value to be applied to the loop. They then use the Start button to apply the selected voltage to the loop. The voltage value starts from zero and increments by 0.1 V until it reaches the selected voltage value. The flow of electrons inside the loop is shown. As the voltage increases, the speed of the electrons also increases.

Students may use the Reset button to reset the Exploration and observe the flow of electrons for a different set of selections.

The Data tab displays the values of the current run. In this tab, students analyze the voltage and current values for the selected material. This tab also displays the classification of the selected material into conductors, semiconductors, or insulators.

The Tracker tab displays a summary of all the previous runs. Students observe the value of current for the selected voltage. Classification of the selected material into conductors, semiconductors, or insulators is also displayed here.
Answers to Questions in the Student Worksheet

1. Explain the importance of insulators.

   **Answer:** Insulators are materials that do not allow electric current to flow through them. Insulators can be used in places where the flow of electric current has to be restricted. For example, wires are insulated using rubber to avoid the leakage of current. This helps in keeping electrical appliances safe for use.

2. Use the Exploration to examine the final current values of the samples of copper and germanium for a voltage of 2 V. Comment on your observation.

   **Answer:** The final value of current when copper is selected is 10 A and when germanium is selected it is 4.88 µA. Copper is a good conductor of electricity whereas germanium is a semiconductor. This means that the conductivity of copper is greater than germanium. Hence, when copper is placed in the loop the amount of current flowing through it is greater than when germanium is selected.

3. Explain the term semiconductor. Give two examples of semiconductors.

   **Answer:** Semiconductors are materials with electrical conductivities greater than insulators but smaller than conductors. Their electrical conductivities lie in the range of 10 to 10^{-6} (Ωm)^{-1}. Silicon and germanium are examples of semiconductors.

4. Observe the conductivities of the following materials and classify them into conductors, semiconductors, and insulators.

   a. Pure water \(4.00 \times 10^{-7} (Ωm)^{-1}\)

   b. Platinum \(9.43 \times 10^{6} (Ωm)^{-1}\)

   c. Iron \(10.3 \times 10^{6} (Ωm)^{-1}\)

   d. Pure Silicon \(4 \times 10^{-4} (Ωm)^{-1}\)

   e. Glass \(5 \times 10^{-11} (Ωm)^{-1}\)

   **Answer:**

   a. Pure water \(4.00 \times 10^{-7} (Ωm)^{-1}\) Insulator

   b. Platinum \(9.43 \times 10^{6} (Ωm)^{-1}\) Conductor

   c. Iron \(10.3 \times 10^{6} (Ωm)^{-1}\) Conductor
5. Classify the following into conductors, semiconductors, or insulators.

   a. Steel wire
   b. Toothpick
   c. Copper
   d. Air
   e. Salt Water
   f. Rubber

   **Answer:**
   
   a. Steel wire  Conductor
   b. Toothpick  Insulator
   c. Copper  Conductor
   d. Air   Insulator
   e. Salt Water Conductor
   f. Rubber  Insulator

6. Define conductivity and explain its relation with resistivity. Give their units.

   **Answer:** Conductivity is the capacity of a material to allow the flow of electrons or conduct electric current. Conductivity is the reciprocal of resistivity. The unit of resistivity is Ωm and that of conductivity is (Ωm)^{-1}.

7. Determine if the following statements are true of false. If a statement is false correct it so that it is true.

   a. The resistivity of a semiconductor is greater than that of an insulator.
   b. The conductivity of a conductor increases if its temperature is increased.

   **Answer:**
a. False. The resistivity of a semiconductor is smaller than that of an insulator.

b. True.

8. Explain how the conductivity of a semiconductor can be increased.

**Answer:** Semiconductors have moderate conductivity at room temperature. Pure samples of semiconductors produce a very small amount of current. Their conductivities can be increased by increasing the temperature of the sample. When the temperature of a semiconductor sample is increased, the electrons gain more energy and a greater number of free electrons are available for conduction. Another method of increasing the conductivity of a semiconductor is by adding appropriate impurity to the semiconductor sample. The added impurity provides free electrons for electric conduction. The process of adding impurity to a pure semiconductor sample is known as doping.

9. Explain the difference between conductors and semiconductors.

**Answer:** Conductors are materials with very high conductivity. They are good conductors of electricity. This means that they allow electrons to flow through them easily. Their electrical conductivities lie between $10^2$ to $10^7 \ \Omega m$. Semiconductors possess electrical conductivities lower than that of conductors. The flow of electrons is restricted to a greater extent for semiconductors and so they generate a very minute current (of the order of $\mu A$ or $nA$). Their electrical conductivities lie between $10$ to $10^{-6} \ \Omega m$.

10. Observe the value of current for the sample of aluminum for all the three values of voltage. Comment on your observation.

**Answer:** When a voltage of 1 V is applied the value of current is 2.94 A. For a voltage of 1.5 V the current value is 4.41 A, and for 2 V it is 5.88 A. It can be observed that as the voltage applied to the loop increases, the current increases in direct proportion. This linear relationship proves that aluminum as a conductive element follows Ohm’s law.
Hands-On Lab
Conductors and Insulators

Timing: one 90-minute class session

Objective(s):
Students will investigate conductivity of assorted objects and materials. They will have a chance to ask an experimental question and design a protocol to test it. Students will present their results by creating graphs or tables and sharing results with classmates.

Safety Precautions:
Remind students not to eat or drink in lab, especially if you choose to use any food samples.

Materials:
Per group:
- A multimeter with two leads
- Assortment of simple items or materials for testing, possibly including
  - aluminum foil
  - bare copper wire, 50 cm long.
  - coins
  - paper clips
  - steel nails (approximately 15 cm or longer)
  - zinc strips or rods
  - nichrome wire
  - silverware
  - other metallic objects
  - rubber pieces of various sizes
  - wood strips (or wooden rulers)
  - pencil "lead" (graphite rod)
  - plastic rulers
  - plastic strips (made from plastic bags)
  - cup of water
  - cloth pieces
  - any other interesting items
  - calculator
  - Computer access

Teacher Preparation:
Obtain the materials above. Duplicate the Student Investigation Sheet to give to each student.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
In this lab, students will determine the conductivity of various materials/objects and combinations of materials/objects. A multimeter will allow students to measure resistance and then use this to calculate a value for conductivity. Units for conductivity will not be used.

• Begin the lab-session by demonstrating to students how to use the multimeter. Explain that they will be measuring resistance and that the greater the resistance the lower the conductivity. Emphasize that they will compare the conductivity of different materials by determining the inverse of the resistance (1/r). Students will study aspects of this same relationship later, when they study Ohm’s Law. In this lesson students should not be introduced to the units used to measure conductivity, they should simply determine the relative conductivity of the materials.
• Ensure students understand which units and scale to read on the multimeter. To switch to the scale for resistance look for the symbol for ohms (Ω). If you’re your multimeters do not auto range you should explain to students that they may also need to switch the meter between different “ranges” of resistance.
• Demonstrate how to read the meter by simply touching the free wires together, so that students get a sense of how the multimeter works.
• Demonstrate how to use the multimeter to determine the conductivity of a sample. Connect one of the wire leads from the multimeter to one end of the sample and the other to the other end.
• Take the reading on the meter.
• Demonstrate how they will calculate their measure of resistance using \(1/r\)
• Have students break into groups. Have them conduct the procedure for a variety of objects.
• Students should record data in a table like the one shown below

<table>
<thead>
<tr>
<th>Material or Object</th>
<th>Resistance in ohms (r)</th>
<th>Measure of conductivity ((1/r))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

• Next, have students choose an experimental question based on their findings so far. You can let them choose freely, or provide a list of options. Instruct students that the dependent variable in their study will be the conductivity of a sample. Ask them to choose one independent variable. Sample questions might include:
  • Does the conductivity of a material, such as aluminum foil, depend on how far apart the wire probes are on the material?
  • Does the conductivity change if the wires are kept at a fixed distance, but the size of the sample is increased?
  • Does conductivity depend on how thick or massive the material is?
  • How does the conductivity of a combination of objects compare to their individual conductivities?
If time permits, students should investigate multiple questions. Make sure groups discuss their question and their protocol with you before beginning.

Have students prepare a presentation of their data using a display method that is appropriate for their question. For instance, measurements of conductivity versus separation of lead wires might use a graph while conductivity of different materials might use a bar chart. Each student should prepare a written report of their procedure and findings, including an answer to their testable question. As a class, discuss any discrepancies in measurements between groups.

**Guided Inquiry**

Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask students some guiding questions to help them focus their inquiry:

- How can you measure the conductivity of a material or object?
- What will be your independent and dependent variables?
- How will you adjust your independent variable, and how many different values will you use?

If they are unfamiliar with using multimeters you will need to begin by demonstrating to students how a multimeter works.

- Explain that they will be measuring resistance and that the greater the resistance the lower the conductivity. Emphasize that they will compare the conductivity of different materials by determining the inverse of the resistance \((1/r)\). Students will study aspects of this same relationship later, when they study Ohm’s Law. In this lesson students should not be introduced to the units used to measure conductivity, they should simply determine the relative conductivity of the materials.
- Ensure students understand which units and scale to read on the multimeter. To switch to the scale for resistance look for the symbol for ohms \((\Omega)\). If your multimeters do not auto range you should explain to students that they may also need to switch the meter between different “ranges” of resistance.
- Demonstrate how to read the meter by simply touching the free wires together, so that students get a sense of how the meter works.
- Demonstrate how to use the meter to determine the conductivity of a sample. Connect one of the wire leads from the multimeter to one end of the sample and the other to the other end.
- Take the reading on the meter.

Students should perform two investigations.

- The first should be measurements of a variety of samples and materials. This investigation will help them familiarize themselves with the multimeters.
- Students should design their own data table to record their results.
- The second study should be a focused study of a specific question (or questions) if time permits. Suitable questions include the following:
• Does the conductivity of a material, such as aluminum foil, depend on how far apart the wire probes are on the material?
• Does the conductivity change if the wires are kept at a fixed distance, but the size of the sample is increased?
• Does conductivity depend on how thick or massive the material is?
• How does the conductivity of a combination of objects compare to their individual conductivities?

Have each group decide on a question (or questions) and prepare a protocol for testing. Have them explain their procedure to you before they begin. Make sure students include a procedure for measuring the conductivity of "nothing," that is, just the measuring device with no other sample. (They should simply touch the two free wires together.) Also, ask students to consider how they will present their data (a graph of conductivity vs. separation of wire leads, for instance). Each student should prepare a written report of their procedure and findings, including an answer to their testable question. Have the class discuss all groups’ findings. Have the class discuss any discrepancies in measurements between groups that studied similar questions.
Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions or assigning them as homework:

1. How did your results compare to another group that asked a similar question? How do you account for differences? Sample answer: Our results were not exactly the same, but they were similar. The difference might be due to different sizes of the samples or to different conductivity of the bulbs.

2. How would the results of your experiment changed if you wrapped your sample in a large piece of aluminum foil? The conductivity of the samples would always be high, because the electric current could just flow along the foil.

3. How did your results compare to your hypothesis about the answer to your testable question? How would you change or defend your hypothesis based on the results you found? We predicted that conductivity would not change as we made the foil thicker, but the conductivity did decrease a little. I would change my hypothesis to say that the conductivity does go down as the sample gets thicker.

4. What can you conclude from the results you observed when you changed your independent variable? What results would you expect if you changed the variable to new values beyond what you tested? I can conclude that conductivity does depend on the amount of material that a current has to flow through. Maybe if we made a very thick piece of foil, the conductivity would be small.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape measure
    - Scale
    - Other laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
Use the appropriate format to record data:
- Table
- Graph
- Chart
- Writing (journal, worksheet, electronic text)

Interpret Data
- Sort and classify using scientific reasoning by:
  - Sorting objects, substances, and organisms by characteristic
  - Applying a classification scheme to objects, substances, or organisms
- Identify and interpret patterns using:
  - Trends in data
  - Repeating physical or data patterns
  - Graphed data points
  - Tables and graphs
  - Analysis of data collected during an investigation

Evaluate Evidence
- Draw and support a conclusion by:
  - Using data to determine the cause–effect relationship observed in the investigation
  - Reporting trends and patterns in the data
  - Comparing results to hypothesis
  - Answering the testable question
  - Extrapolating results beyond the investigation
  - Formulating scientific explanations/arguments

Communication in Science
- Report results using:
  - Peer presentation
  - Written report
  - Scientific illustration with proper labeling
  - Scientific explanations/arguments
  - Table/graph showing data

Analyze Scientific Results
- Participate in critiquing/peer review by:
  - Evaluating an investigative design
  - Evaluating data for accuracy
  - Evaluating a conclusion

Patterns and Systems
Systems:
- A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
- In some systems, it may not always be possible to predict accurately the result of changing some part or connection.

Scientific Investigation:
- Science investigation begins with a testable question.
- New observations should be made when there is disagreement among initial observations.
- When a scientific investigation is repeated, a similar result is expected.
- Science takes place in many locations including labs, offices, in the field, and under the ocean.
- Scientific investigation results in things we know and things we do not know.
- Scientific investigations generally work the same way in different places.
- Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
- Scientific investigation leads to more questions.
- Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
- What people expect to observe can affect how they perceive what they observe.
- Scientific investigations lead to the development of scientific explanations.

Scientific Data and Outcomes:
- Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
- Comparisons of data are not accurate when some of the conditions are not kept the same.
- Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
- Statements not based on hard data (e.g., “Leading doctors say . . .”) are questionable and do not meet scientific standards.
- It is important in science to keep honest, clear, and accurate records.
- When similar investigations give different results, it often takes further studies to decide what is right.

Scientific Endeavor:
- Characteristics of Science:
  - Science is based on factual knowledge.
  - Scientists are curious about wanting to know how things work.
  - Scientific claims can be substantiated using data and observation.
  - Scientific theories are based on accumulated evidence.
  - An important part of science is the critical review and analysis of any idea or conclusion.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Heat Flow in Solids and Fluids

Timing: one 90-minute class session

Objective(s):
Students will investigate heat flow

Safety Precautions:
Do not use very hot water for this lab. Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should report any water spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
Per group:

• Ring stand and two ring clamps
• Beaker to fit ring clamp
• Metal, wooden, ceramic or plastic spoons to fit beaker
• One thermometer per spoon.
  Note: Thermometers should be small, a few inches long. If desired, temperature probes can be substituted for thermometers.
• One additional thermometer
• Electrical or masking tape
• Hot plate
• Ice cube made of colored water
• Watch
Teacher Preparation:
• Gather materials in advance of students performing the lab, and freeze colored water beforehand in ice cubes of uniform size.
• If possible, collect spoons with long handles, but generally of the same length.
• Once water is heated, use thermometer to measure the original temperature of hot water, and make a note of this for use by each group.

Part 1: Heat Flow from Conduction

Procedure

1. Have students clamp ring clamp to ring stand, with ring aligned parallel to lab bench.
2. Have students tape one thermometer to the stand, a little above where the ring clamp is clamped to the stand.
3. Have students tape a thermometer to the end of each spoon. The thermometer bulb should be placed next to the material of the spoon, and the thermometer should be oriented straight up from the spoon handle.
4. Take measurements of the temperature measured by each thermometer.
5. Place beaker in ring stand.
6. Use a hot plate to gradually warm water. Be sure not to boil the water.
7. Place hot water (warm but not boiling) in beaker.
8. Place spoons in water with handles extending out of the top of the beaker. Try to align thermometers for easy reading.
9. Every thirty seconds after placing the spoons in the water, students should read temperatures measured by each thermometer.
10. Students should make a chart of spoon handle temperatures for their spoon of each material. A chart might look like this:

<table>
<thead>
<tr>
<th>Time</th>
<th>Ring Stand</th>
<th>Metal Spoon</th>
<th>Plastic Spoon</th>
<th>Ceramic Spoon</th>
<th>Wooden Spoon</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>0:30</td>
<td>21</td>
<td>22</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>1:00</td>
<td>21</td>
<td>24</td>
<td>21</td>
<td>22</td>
<td>22</td>
</tr>
</tbody>
</table>

11. Continue taking measurements of all thermometers on ring stand and spoons for several minutes.
Part 2: Heat Flow from Convection

Procedure

1. After several minutes of taking temperature measurements, remove the spoons from the beaker.
2. Refresh hot water (warm but not boiling) in beaker. Students should use the hot plate to keep the water warm from Part 1 above.
3. Distribute colored-water ice cubes. Each team should drop, without splashing, one cube into the warm water in their beaker.
4. Observe what happens to colored water from the ice cube as it melts.
5. Lightly touch the top and bottom of the side of the beaker while the ice cube is melting, and note which is warmer.

In Part I of this lab, students will watch as energy moves toward the top of each of the spoon handles. Students will graph observed temperatures over time for purposes of presenting results to the class.

In Part 2 of this lab, students will watch colored water fall straight down into the beaker from the melting ice cube. Convection cells in the warm water will make the top of the beaker’s side warmer than the bottom of the beaker’s side.
Analysis and Conclusions

1. What happened to the temperatures measured by each of the thermometers on the spoons over time? How does this temperature compare to the original temperature of the hot water?
Sample answer: They increased, as shown in a graph, over several minutes, approaching but not exceeding the original temperature of the hot water.

2. Through which spoon did heat move most quickly? How could you judge this?
The temperature measured for the metal spoon increased most quickly of any of the spoon temperatures, so we infer that heat moved most quickly through the metal spoon.

3. Why was one thermometer taped to the ring stand? What temperature did it record over time?
The thermometer taped to the ring stand was put there to measure the temperature in the room near the ring stand. This data point is known as a control, and it was taken to measure how temperature changes in the room, beyond the effect of the experiment.

4. What happened to colored fluid from the melting ice cube? Why did this happen?
It fell straight down into the surrounding water, and stayed mostly in the bottom of the beaker, because it was colder and denser than the surrounding water.

5. How warm did the bottom and top of the beaker feel while the ice cube was melting, and why?
The top of the beaker felt warmer than its bottom, because heat was flowing up in the warm water due to convection.
In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct field studies using
    - Survey: collects multiple data points at one point in time
    - Observational Survey: compares changes in data points over time.

- **Gather Data**
  - Use Tools and Use SI units to accurately measure temperature
  - Uses senses to observe: Seeing
  - Uses senses to observe: Touching
  - Uses a chart and a graph to record data.
Hands-On Lab
Making or Breaking A Circuit

Timing: one 90-minute class session

Objective(s):
Students will learn how to use knife-edge switches in simple series or parallel circuits.

Safety Precautions:
Remind students to follow all general lab safety rules, especially those governing use of electricity.

Materials:
Per group:
- 1.5-V battery
- battery holder
- three resistors, with different values of resistance
- three knife-edge switches
- light bulb
- multimeter with data probes
- several insulated wire pieces, with bare ends
Teacher Preparation:
- Gather materials in advance of students performing the lab.
- If possible, collect resistors of different values of resistance.

Procedure

Part 1: Series Circuit

1. Each team is to connect the following series circuit, including an open switch:
2. Turn multimeter to measure voltage.
3. Using probes, measure voltage across 1.5-V battery.
4. Measure voltage across the open switch in the open circuit.
5. Close switch, and see that light bulb comes on.
6. Measure voltage across each resistor in the closed circuit.
7. Turn multimeter to measure current.
8. Measure current across each resistor in the closed circuit.
9. Calculate power expended in each resistor. This is a product of current and voltage.
10. Students should make a chart of their observations. A chart might look like:

**Chart of Resistor Data**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Resistor #1</th>
<th>Resistor #2</th>
<th>Resistor #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance, ohms</td>
<td>1</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Voltage, volts</td>
<td>0.09</td>
<td>0.47</td>
<td>0.94</td>
</tr>
<tr>
<td>Current, amps</td>
<td>0.09375</td>
<td>0.09375</td>
<td>0.09375</td>
</tr>
<tr>
<td>Power, watts</td>
<td>0.0088</td>
<td>0.044</td>
<td>0.088</td>
</tr>
</tbody>
</table>

**Part 2: Parallel Circuit**

1. Each team is to connect the following parallel circuit, including three open switches:
2. Turn multimeter to measure voltage.
3. With all switches open, measure voltage across each resistor in the open circuit.
4. Close all switches, and see that light bulbs come on.
5. Measure voltage across each resistor in the closed circuit.
6. Switch multimeter to measure current.
7. Measure current across each resistor in the closed circuit.
8. Open switch in one branch, and repeat Steps 5 through 7.
9. Measure voltage across both open switch and resistor in open branch.
10. Close the switch that was opened in Step 6, open the switch in the other branch, and repeat Steps 5 through 9.
11. Students should make a chart of their observations. A chart might look like:

**Chart of Resistor Data**

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Resistor #1</th>
<th>Resistor #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance, ohms</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Voltage, volts</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Current, amps</td>
<td>0.67</td>
<td>0.3</td>
</tr>
<tr>
<td>Power, watts</td>
<td>0.45</td>
<td>0.45</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. What do knife-edge switches do in any circuit?
   *If a circuit contains a switch, that switch can be opened to break it.*

2. What voltage did you measure across resistors in the simple series circuit with the switch turned off? What voltage did you measure with the switch turned on?
   *When the switch is open, the circuit is broken, so no voltage is measured across any of the resistors. When the switch is closed, the voltage across any resistor is a portion of the battery’s voltage. That portion is equal to the ratio of the resistance of the measured resistor over total resistance in the circuit.*

3. Why was a light bulb included in either circuit?
   *A light bulb, when lit, shows that the circuit is closed, there is current in a circuit and voltages can be measured.*

4. What voltage did you measure across resistors in the simple parallel circuit with the outer switch turned off or on? What about with switches turned on or off in either of the two parallel branches of the circuit?
   *When the main switch was open, there was no current in either branch of the circuit, and no voltage was measured across resistors in that branch. When the main switch was closed, but the switch in either branch was open, there was no current in that branch, and no voltage was measured across resistors in that branch. When the main switch was closed, and the switch in either branch was closed, there was no current in the branch and voltage measured was a little less than that of the battery.*

5. When the main switch was closed in the simple parallel circuit, and one switch in either branch was closed and the other open, why did you measure voltage across even the branch with an open switch? Can you explain the value of this measured voltage?
   *Voltage gains (the battery) and voltage drops around any circuit loop total to zero. The branch with an open switch still formed a circuit loop with the battery, so voltage measured across the entire branch was a little less than that of the battery. It was less than that of the battery because there was a small voltage drop across the light bulb.*
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop
    - state the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by
    - Using data to determine the cause-effect relationship observed in the investigation.

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Nuclear Physics

Overview

Some elements have unstable isotopes that decay and emit alpha particles, beta particles, and gamma rays. These particles and radiations can be recorded using a digital radiation monitor. In this Exploration, students analyze the three types of emissions and record the radiation level at various altitudes from Earth’s surface.

Student Learning Objectives

- Analyze the particles and radiation emitted by unstable isotopes of some elements.
- Understand the principle and working of a digital radiation monitor.
- Record radiation levels at various altitudes from Earth’s surface using a digital radiation monitor.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Apparatus tab, students get familiar with the apparatuses used in the Exploration. They learn how the digital radiation monitor is used to record alpha particles, beta particles, and gamma radiation. They can use the Digital Radiation Monitor, Laboratory Setup, and Cosmic Setup radio buttons to gather details about the monitor and understand how it is used in a laboratory and within an aircraft.

In the Laboratory tab, one vertical and two horizontal metal plates are connected to radiation sensors and a digital radiation monitor. A lead box with a narrow aperture contains the radiation source. When the emitted particle strikes any of these plates, it is recorded by the sensor. Students select the type of radiation they want to analyze using the options in the Select Type of Radiation dropdown list and the field strength between the horizontal plates using the options in the Select Field Strength dropdown list. They then use the Start button to start recording the data for counts.

Students may use the Include Gas checkbox to introduce a gas between the horizontal metal plates. They may use the View Animation button to observe the emission of a single particle or radiation, of the selected radiation, at the atomic level. Students may use the Reset button to reset the Exploration and note the counts per minute for a different type of radiation.

In the Cosmic Rays tab, an aircraft carrying a digital radiation monitor is shown. Students use the options in the Select Altitude slider to select the altitude at which they want to determine the radiation level. They then use the Record button to record the radiation level, in counts per
minute (CPM), at the selected altitude. They may use the Reset button to note the counts per minute at a different altitude.

In the Tracker tab, students view a summary of all the previous runs for both the setups, Laboratory and Cosmic Rays. They select the setup using the options in the Select Setup dropdown list.

**Answers to Questions in the Student Worksheet**

1. Explain how a digital radiation monitor works.

   **Answer:** A digital radiation monitor has an inbuilt Geiger-Müeller tube and a digital rate meter. It counts the number of particles (alpha or beta) or amount of radiation (gamma rays) and gives the value in counts per minute. The operating range is between 0 to 350,000 counts per minute.

2. Using the Laboratory tab of this Exploration, observe and comment on the effect of including gas between the metal plates when alpha particles are emitted.

   **Answer:** If gas is included between the plates, the number of particles detected by the digital radiation monitor reduces. This happens because the alpha particles get deionized and lose energy.

3. Using the Laboratory tab of this Exploration, observe the distance covered by a beta particle for different values of electric field strength. Comment on your observation.

   **Answer:** For zero electric field strength, beta particles are emitted in random directions because no electric field is present to influence their motion. If an electric field is applied, the beta particles get deviated toward the positive plate. As the electric field strength is increased, the distance covered by them decreases. This is because the applied electric field restricts their motion and pulls them toward the positive plate with greater intensity.

4. Using the Cosmic Rays tab in this Exploration, note the rate of radiation (in counts per minute) for varying altitudes. Comment on the trend of these values as the altitude increases.

   **Answer:** The rate of radiation (in counts per minute) increases as the altitude increases. This increase in the rate is almost exponential. Since these values are greater at a higher altitude, it can be concluded that the origin of this radiation is the outer space.

5. Compare and contrast the properties of alpha particles and beta particles.

   **Answer:** The alpha particles are positively charged where as beta particles are negatively charged. The mass of an alpha particle is greater than that of a beta particle. Alpha particles
have greater ionizing strength as compared to beta particles but the penetration depth of beta particles is much greater than that of alpha particles.

6. Explain why gamma rays do not get deflected when they pass through an electric field. Determine whether increasing the electric field changes this behavior.

Answer: Gamma rays are neutral as they don’t carry any charge. Hence, they are unaffected by an electric field. An increase in the electric field will not change this behavior. Gamma rays will still not get deflected as they are neutral and electric fields are unable to influence neutral objects.

7. Determine if the following statements are true or false. If a statement is false, correct it so that it is true.

   a. Alpha particles have a higher penetration depth as compared to beta particles.
   b. Gamma rays are electromagnetic waves.

Answer:
   a. False. Beta particles have a higher penetration depth as compared to alpha particles.
   b. True.

8. Determine the change that a nucleus undergoes during beta decay.

Answer: A beta particle can be an electron or a positron. An electron has negligible mass and unit negative charge. A positron too has negligible mass but has a unit positive charge. If an electron is released from a nucleus, it gains a positive charge and its atomic number increases by one. If a positron is released from a nucleus its atomic number decreases by one.

9. Determine the mass and charge of an alpha particle (mass of a proton = mass of a neutron = 1 a.m.u. (atomic mass unit) and charge of a proton is 1 e (elementary charge)).

Answer: The mass of a proton is equal to the mass of a neutron, which is equal to 1 a.m.u. (atomic mass unit) An alpha particle has two protons and two neutrons. So, the mass of an alpha particle is 4 a.m.u. (atomic mass unit). The charge of a proton is 1 e (elementary charge) and a neutron is electrically neutral. An alpha particle has two protons. So, the charge on a proton is 2 e (elementary charge).

10. Consider an atom with atomic mass 238 and atomic number 92. Determine the new atomic mass and atomic number after it undergoes two successive beta decays, releases gamma rays, and then undergoes an alpha decay.
**Answer:** If a beta particle is released, the atomic number increases by one. After an alpha decay, the atomic number decreases by two and the atomic mass decreases by four. When an atom emits gamma rays, the atomic mass and the atomic number are not affected.

The atomic mass of the atom is 238 and the atomic number is 92.

If this atom undergoes two successive beta decays, the atomic number will increase by two. After the two beta decays the atomic mass of the atom is 238 and its atomic number is 94.

This atom then emits gamma rays, so the atomic mass and atomic number are not affected. After emitting an alpha particle, the atomic mass will decrease by four and the atomic number will decrease by two. So, the atomic mass of the atom is 234 and its atomic number is 92.
Hands-On Lab
Penny Half-Lives

Timing:
Directed Inquiry – 80 minutes
Guided Inquiry – 90 minutes

Objective(s):
It is difficult to observe radioactive decay directly, so this Hands-On Lab will model the phenomenon. Students will develop a half-life curve by using a modeling exercise involving pennies. Students will understand that a half-life is the amount of time for half of a sample to decay radioactively. Students will also understand why it is difficult to accurately measure the age of a sample after more than 6 or so half-lives.

Safety Precautions:
Students should ensure that the shoebox is closed and only shake with medium vigor to avoid the risk of pennies escaping the shoebox and hitting other students.

Materials:
Per group:
- 1 shoebox
- 100 pennies
- 1 paper plate
- 1 stopwatch

Teacher Preparation:
Teachers should set up each lab station with the materials listed above. Students should start with exactly 100 pennies in their shoebox. Teachers should prepare a copy of the Student Information Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Introduce the lab with the following sequence:
1. Review the idea of radioactive decay with students with the following questions:
   (a) What does it mean to decay radioactively? What happens to the original isotope?
   (b) What is a parent isotope? Daughter isotope?
2. Explain the overall procedure of the lab, pointing out that the pennies in the shoebox represent the parent isotopes and the pennies removed (placed on the paper plate) represent the daughter isotopes.
3. Ask students to complete their hypothesis question.

Hypothesis:
Answer the following questions in the hypothesis section of the lab handout:
1. Using a quick sketch, predict what the graph will look like for the number of pennies in the shoebox over the number of rounds. (Place the number of pennies on the y-axis and the number of round on the x-axis.)
2. How many rounds do you expect it to take before there are no more pennies left in the shoebox?

Procedure:
1. For round zero in the data table:
   (a) Put all 100 pennies inside the shoebox and flip all the pennies “heads” up.
   (b) Record the number of parent isotopes (pennies) that are originally in the sample (shoebox)—initially this will be 100 since none of the parent isotopes have yet been converted to daughter isotopes.
   (c) Record the number of daughter isotopes—initially this will be 0 since none of the parent isotopes have yet been converted to daughter isotopes.
   (d) Initially, all the parents are still in the sample, so record 100% as the “% of Parents Remaining” and 1 as the “Approximate Fraction of Parents Remaining.”
2. Secure the lid of the shoebox with your hands. Then shake the shoebox with medium vigor for 7 seconds. Do not shake such that the pennies can escape from the shoebox.
3. Set the shoebox down and remove the lid. Count and remove all the pennies that are “tails.” These are the atoms that have become daughter isotopes. Place the removed pennies on the paper plate.
4. Record the number of pennies remaining in the shoebox and pennies removed from the shoebox in the parents and daughters columns, respectively, of the data table.
5. Repeat steps 2–4 until there are no more pennies in the shoebox.
Guided Inquiry
To increase the level of independence in this lab, challenge students to develop their own procedure. The general purpose of the lab should still be introduced and a data table should still be provided. The following general instructions may help:

- **Develop a procedure by using the shoebox full of pennies that will model how radioactive isotopes decay. You will want to shake the box in a series of rounds and remove all the pennies that are either “heads” or “tails.” Record your data in the data table.**

Developing a procedure may be challenging for some students. Ask students some guiding questions to help them focus their inquiry. For instance:

- Which pennies represent the parent isotopes? Which pennies represent the daughter isotopes?
- What fraction of the pennies is removed after each round?

---

### Student Data Table:

<table>
<thead>
<tr>
<th>Round (# of Half-Lives)</th>
<th>Parents</th>
<th>Daughters</th>
<th>% of Parents Remaining</th>
<th>Approximate Fraction of Parents Remaining</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>100%</td>
<td>1</td>
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</table>
**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Create a graph of the number of parent isotopes versus the round. Place the round number (independent variable) on the x-axis. Place the number of parent isotopes (dependent variable) on the y-axis. The graph should show that the number of parent isotopes decreases as the round number increases and asymptotically approaches zero (although it should actually reach zero once the pennies are completely removed from the shoebox.)

2. Describe how the number of parent isotopes varies with the number of half-lives. Is it a linear relationship or some other type of relationship? Be specific in your answer. The number of parent isotopes decreases as the number of half-lives increases. It is not linear, but rather it is an exponentially decaying relationship that approaches zero.

3. By approximately what factor does the number of parent isotopes change in each half-life? In each half-life, the number of parent isotopes changes by a factor of 1/2.

4. Explain what the term half-life means. Use your graph to support your answer. It means the time after which half of the original isotopes will decay to daughter isotopes. Since the number of pennies is roughly halved in each round, this means that each round represents a half-life.

5. Using your data as evidence, explain why it is difficult for scientists to get accurate results using half-life dating after 6–7 half-lives have already occurred. After many half-lives, a very small proportion of the parent isotopes in the original sample remain. The smaller this proportion, the more difficult it is for scientists to measure it accurately. This is evident in the modeling exercise with pennies because some groups lost all their pennies after 6 or 7 rounds while others still had pennies after 9 rounds. In this case, random chance plays too large a role once the number of pennies becomes very small. In real life, the accuracy of the measurement tools becomes too large a factor once the proportion of parent isotopes becomes too small.

6. How well does the shoebox model simulate the radioactive decay? Are there any instances of radioactive decay that cannot be modeled with this shoebox model? The chance of a coin coming up heads or tails is 50–50. To model other rates of radioactive decay, something else would have to be used (e.g., six-sided dice). The shoebox method will not work to model decay chains.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause–effect relationship observed in the investigation
    - Comparing results to hypothesis
    - Answering the testable question

- **Communication in Science**
  - Report results using:
    - Peer presentation
    - Written report
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Identifying alternative explanations
    - Analyzing scientific explanations
    - Analyzing scientific arguments

- **Scientific Investigation**
  - Scientific Investigation:
    - Science investigation begins with a question.
    - Hypotheses are valuable, even when they turn out not to be true, because they lead to further investigation.
    - Scientific investigation leads to more questions.
    - What people expect to observe can affect how they perceive what they observe.
  - Scientific Data and Outcomes:
    - Scientific claims are based on data and reliable scientific sources.
Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.

Comparisons of data are not accurate when some of the conditions are not kept the same.

It is important in science to keep honest, clear, and accurate records.

- **Scientific Endeavor**
  - **Characteristics of Science:**
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
    - A law is a description of a specific relationship under given conditions in the natural world.
Exploration Teacher Guide: Absolute Dating

Overview

In this Exploration, students will measure and calculate the parent-daughter ratio of isotopes used to find the absolute age of geologic samples. They will then convert parent-daughter ratio to percentage of original parent atoms remaining, and use this to determine the absolute age of the samples.

Student Learning Objectives

- Identify the isotopes used for the absolute dating of geologic samples.
- Examine the experimental setup used for absolute dating.
- Investigate the relationship between parent-daughter ratios of isotopes, half-life of a parent, and age of a rock or mineral sample.
- Calculate the absolute age of the sample from the percentage of original parent atoms remaining in the sample.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

Students can use the Apparatus Tab to examine the apparatus used for absolute dating. The radio buttons for Experimental Setup and Mass Spectrometer can be used to toggle between the two.

The procedure for absolute dating varies from isotope to isotope and this exploration is idealized to convey the basic concepts. In the Find Age Tab, students must select one of the eight samples that they wish to place in the mass spectrometer. Samples available in the Exploration include Basalt, Granite, Gneiss, Human Skeleton, Skeleton of Animal, Living Tree, Buried Log, and Meteorite. Students must use the radio buttons for $^{14}\text{C}$, $^{238}\text{U}$, and $^{87}\text{Rb}$ to select which parent isotope they want to use for the absolute dating of the selected sample. Checkboxes for Show Information and Show Half-Life can be used for more information about each isotope. The student must then use the Measure button to measure the parent-daughter ratio of the chosen isotope in the sample. If the isotope chosen is inappropriate because of the sample’s age or composition, students will be prompted to choose a different one. Clicking on Proceed will take students to the next step, where they will use the parent-daughter ration to calculate the percentage of original parent atoms remaining in the sample. Students must then drag the yellow pointer on the graph so that it has a y-value that matches the percentage of the original parent isotope atoms that still remain in the sample. The Check button can be used to validate the answers and receive feedback about the sample. Students can use the Select Another Sample button to restart the Exploration with another sample.
Students can use the Tracker tab to track the samples that they have dated successfully. They can compare the selected elements, their half-lives, remaining element percentage in the sample, and the age of the sample for each run.

**Answers to the Questions in the Student Worksheet**

Note that some answers provide more information than would be expected from the student. These questions are better used for review and discussion than for assessment.

1. Explain what the half life of a radioactive isotope is and why it is important in absolute dating.
   
   **Answer:** The half life of an isotope is the time it takes for half of the atoms in an isotope to decay. It is a common way of expressing the rate of radioactive decay. If the half life of a radioactive isotope is known and the parent/daughter ratio can be measured or calculated, the age of the sample can be calculated.

2. Describe how a mass spectrometer is used for absolute dating.
   
   **Answer:** A mass spectrometer ionizes the atoms in a sample and then separates the ions according to their mass. It detects and counts individual ions or calculates the number of ions of a particular mass based on the electrical current carried by the beam of ions. The MS can be set to measure parent isotopes, daughter isotopes, or related isotopes. Computer software then analyzes the measurements, comparing the amounts of different isotopes in the sample and calculating isotope ratios. These ratios, along with the half-lives of the isotopes, are then used to calculate the age of the sample.

3. Why is it important to consider the half-life of an isotope, the relative age of the sample, and the composition of the sample when deciding which isotope to use to date a sample?
   
   **Answer:** The isotope to be used for dating a sample depends on the relative age and composition of the sample. This is because the carbon, uranium, and rubidium, all have different half-lives. The isotope to be used for absolute dating is selected by approximating the relative age of the sample and choosing an isotope with a corresponding half-life.

4. This exploration is about absolute dating. Yet the feedback on all of the dates says that the ages are "about" a certain number of years. Why doesn't the feedback state that the age is exactly a certain number of years?
   
   **Answer:** There is uncertainty in any measurement. With respect to absolute dating of rocks, no technique can provide a date as precise as a single year. The uncertainty in measurement can be less than 1%, but if a rock is 100 millions of years old, for example, 1% is 1 million years. The uncertainty can be caused or affected by a number of factors, including experimental error, possible loss of daughter atoms or addition of parent atoms, the half-life of the isotope being used, the amount of sample used, and the age of the sample.
5. Use this Exploration to identify the best method for dating bones of animals that are only a few thousand years old. Explain why this is the best choice.

**Answer:** The carbon dating method is the best method for dating bones because bones are very rich in carbon and are too young to be dated effectively using rubidium or uranium. Carbon-14 has a half-life of 5,730 years, which is ideal for samples that are a few thousand years old.

6. Imagine you measure the abundance of parent atoms and daughter atoms in a sample and find that there is almost the same number of parent as daughter atoms. What does this tell you about the age of the sample? Explain your answer.

**Answer:** The age of the sample must be about the same as the half-life of the isotope. After every half-life, about 50% of the parent atoms have decayed to form daughter atoms, leaving 50% as parent atoms. Assuming there are no daughter atoms to start with, the ratio will therefore be 1:1.

7. Why is it important to have some idea about the relative age of a sample before radiometric dating?

**Answer:** The isotope that you choose to use to analyze the rock should have a half-life that is appropriate for the general age of the sample. If the sample is very young and the half-life is very long, not enough atoms will have decayed to provide a statistically valid sample. If the sample is very old and the half-life of the isotope is very short, there will be too few parent atoms left to measure. In general, a half-life close to the actual age of the sample is ideal.

8. Why is it important to be careful interpreting absolute ages of clastic sedimentary rocks such as sandstones?

**Answer:** Clastic sedimentary rocks are made of pieces of other rocks and minerals. If you date a sedimentary rock, you may actually be dating a piece of an older rock.

9. Identify three assumptions that radiometric dating relies on.

**Answer:** Decay rate of an isotope is constant; there is no addition or removal of parent or daughter atoms except through radioactive decay once the rock forms; the instrument (the mass spectrometer) is measuring accurately.
10. Carbon-14 decays to form nitrogen-14. Nitrogen-14, however, is a gas and can therefore escape from the sample over time? Because of this, we cannot calculate the age of a sample by measuring the carbon-14 to nitrogen-14 ratio in it. (We use a slightly different method instead.) If we did use this ratio to calculate the age, how would this calculated age differ from the actual age? Explain your answer.

**Answer:** The calculated age would be less than the actual age. This would happen because atoms of the daughter isotope, N-14, have escaped. The ratio of parent to daughter atoms would be higher, which would make it look like the percentage of parent atoms remaining was higher than it is, and that therefore less time has passed.
Hands-On Activity
Absolute Dating

In this activity, students use beads to simulate radioactive decay. They conduct multiple “half-life” trials while recording data, then calculate the average half-life for each trial and graph their results. Students will gain a better understanding of radioactive dating, half-lives, and how scientists use half-lives to date the age of rocks.

Suggested Materials
Per Group:
- 100 beads with two distinct sides
- Graph paper
- Clean sheet of paper
- Small container with lid

Part 1: Collect radioactive half-life data

Procedure

1. Explain to students that they will be conducting multiple trials of an experiment in which beads represent a radioactive element, and each trial corresponds to one half-life of this element.
2. Each group should begin with 100 beads in a container.
3. The procedure for each trial is to gently shake the container and then pour the beads onto the table. Select one side of the beads to represent “radioactive” and another side to represent “stable.” Set aside all the beads that land “stable” side up. “Radioactive” beads should be counted and put back into the container after the quantity is recorded.
4. Repeat the trial procedure until all beads have become stable, or for 10 trials, whichever comes first.
5. After all groups have finished the experiment, record each group’s data and calculate class averages for each trial run on a class data table like the one shown below.
6. Discuss as a class how individual group trial run results compare with the class average, and whether the class average for each run is what the students expected. If it is not what students expected, have them consider what errors or factors might have influenced the outcome (e.g., small sample size, outliers).
Class Data Table:

<table>
<thead>
<tr>
<th>Trial Run</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
<th>Group 4</th>
<th>Group 5</th>
<th>Group 6</th>
<th>Class Total</th>
<th>Class Average</th>
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</table>

Part 2: Graph the half-life

1. Have students regroup.
2. Each group should design a graph on graph paper and title both axes, then use different colors to plot both their group’s results and the class average results for each trial run. If students struggle with the layout of the graph, the graph below can be used as a template.
3. After each group has completed its graph, students should answer the questions on their Student Investigation Sheet (individually or in groups).

Graph of data: **Bead “Radioactive Decay”**
Analysis and Conclusions

1. Which line, the class average or your group’s results, is closest to the probable values for actual radioactive decay? Why?

   **Sample answer:** The class average is closer because larger sample sizes tend to be closer to actual expected values.

2. Do you think the earlier or later class averages are closer to the probable values? Why?

   **Sample answer:** The earlier class averages are probably closer to the probable values because each group started with the same number of beads, but toward the end of the experiment each group had a different number of beads to start each trial run with.

3. Carbon-14, which decays into nitrogen-14, has a half-life of 5,730 years. Some species of wooly mammoths went extinct about 35,000 years ago. What is the minimum number of carbon-14 half-lives a mammoth bone has undergone? Show your work.

   **Sample answer:** $35,000/5,730 = 6.1$ half-lives

4. Calculate the percentage of carbon-14 that would be left after 10 half-lives. Then explain why scientists can’t use radiocarbon dating to date dinosaur bones.

   **Sample answer:** Approximately 5.6% of carbon-14 would be left after 10 half-lives. Because dinosaur bones have undergone at least 174.5 half-lives, the percentage of remaining carbon-14 would be very small and probably insufficient for testing.
Inquiry and Nature of Science Skills in this Lab:

- **Gather Data**
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Comparing results with hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Formulating scientific explanations/arguments

- **Communication in Science**
  - Report results using:
    - Written report
    - Scientific explanations/arguments
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participating in critiquing/peer review by:
    - Evaluating data for accuracy

- **Patterns and Systems**
  - Patterns and change
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive ways.

- **Scientific Investigation**
  - Scientific investigation:
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
    - Science takes place in many locations, including labs, offices, in the field, and under the ocean.
    - Scientific investigations lead to the development of scientific explanations.
    - Recognize that differences in the scales of time, size, and energy measurements affect the relevance of these measurements.

  - Scientific data and outcomes:
    - Scientific claims are based on data and reliable scientific sources.
    - The best way to understand a changing pattern is to collect and analyze data.
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - It is important in science to keep honest, clear, and accurate records.
- Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

- Scientific Endeavor
  - Characteristics of science:
    - Scientific claims can be substantiated using data and observation.
    - An important part of science is the critical review and analysis of any idea or conclusion.
    - Science involves creativity, both in designing experiments and in creating explanations that fit evidence.
Data/Graph Tool
Teacher's Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.
- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Determining the Absolute Age of Minerals

Timing: one 90-minute class session

Objective(s)
Students will create models of mineral samples that contain parent isotopes and daughter isotopes. They will collect and record data on the ratio of parent to daughter isotopes in the model sample. Students will then apply concepts of radioactive decay, half-life, and radiometric dating to determine the absolute age of their model samples.

Safety Precautions:
This lab uses “tiny, beadlike objects” to represent isotopes. In the Materials list, these objects include various unpalatable items such as dry, uncooked popcorn, beans, and rice. You may also use tiny candies or food items such as jelly beans or chocolates. Whatever items you use, however, students should never eat or drink anything in the lab. Be aware that some students might have unique allergies (e.g., peanut allergies), and do not expose such students to potentially hazardous items. Always follow your school policies and use your discretion when selecting these items. Also, be aware that some students are tempted to throw tiny objects at fellow classmates. Warn students about potential eye injuries and provide goggles or other eye protection. Properly dispose of any food items when lab activities are finished.

Materials:
Per small group:
- Set of several large, plastic jars with lids. Each jar contains a large number (at least hundreds) of a single color/type of “tiny beadlike objects.” Each student group should have the same representative set of jars. Examples of “tiny beadlike objects” could be:
  - colored beads, buttons, etc.
  - dry rice grains, popcorn grains, barley, etc.
  - dried beans, peas, lentils, etc.
  - small or tiny dry seeds (e.g., bulk bird seed, etc.)
  - colored paper clips, BBs, plastic foam packing beans, etc.
- Small/medium plastic bottle with lid (or plastic pill case, small box with lid, etc.)
- Funnel or paper for making a funnel
- Tray (e.g., cafeteria tray, aluminum pie pan, etc.)
- Masking tape
- Colored markers (various colors)
- Calculator
- Graphs created during the Hands-On Activity
- Ruler
- Pennies
**Teacher Preparation:**
Gather a set of materials for each student group. You will also need a set of your own materials to use for the demonstration in Directed Inquiry. If funnels are not available, students may make temporary funnels by wrapping a piece of paper and taping it with masking tape. Preview the second example in Guided Inquiry to determine whether you want students to get a specific test result from a model. If so, you will need to prepare this model before class or assign someone to develop such a model.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
All students will work in small groups (approximately 3 students per group) to complete both the Directed and Guided Inquiry parts of this lab. To complete the Guided Inquiry part, however, each student group will first need to create a model representing a mineral that contains both parent isotopes and daughter isotopes. So, all students should complete Directed Inquiry before they proceed to Guided Inquiry.

Here is one possible procedure for Directed Inquiry:

1) Briefly explain to students that they will create models of mineral samples that contain parent isotopes and daughter isotopes. Also, they will examine models of mineral samples created by other students (counting “parent” and “daughter” atoms), record data in a data table, and calculate the absolute ages of those samples based on those data. A sample data table is shown immediately following this set of procedures.

2) Each mineral sample should consist of two sets of “tiny objects” (e.g., colored beads, dried beans or seeds, BBs, etc.). Advise that each group’s sample should contain at least 100 (but not more than 500) items, representing the combined total of parent isotopes and daughter isotopes.
daughter isotopes. Groups should first choose the objects they want to use to represent the parent isotope.

3) Each group should pour several handfuls of its selected “parent isotopes” from the large jar into the tray. Group members should count the number of objects in the tray and record that number in a data table (for example, the “Sample 1” column of the sample data table below). This number represents the number of atoms of parent isotope in the group’s mineral sample.

4) Each group should then use a funnel to pour its selected parent isotopes from the tray into a smaller, empty plastic bottle. Explain that the smaller bottle will represent the sample mineral.

5) Each group should repeat steps 3 and 4 for the tiny objects that represent the daughter isotopes in its mineral. They should pour their selected daughter isotopes into the same small bottle that contains their parent isotopes.

6) Next, groups should secure the lids on their small bottles and label them with pieces of masking tape. Each group should write the following information on its masking tape label:
   a. Group = (e.g., Electrics, Radiators, Mighty Nukes, etc.)
   b. Mineral = (e.g., Electric Diamond, Rad Ruby, Nuclear Zircon, etc.)
   c. Parent Isotope = (e.g., yellow popcorn, etc.)
   d. Daughter Isotope = (e.g., white beans, etc.)
   e. Half-Life = (e.g., 7 days, 10 years, 5 billion years, etc.)

Encourage each group to invent its own Group Name and Mineral Name and to decide upon a chosen length of time for the Half-Life of its parent isotopes. Be sure that some groups choose relatively short half-life times—e.g., hours, days, centuries, or millennia. Encourage other groups to choose relatively long half-life times—e.g., hundreds of millions of years or billions of years. (To ensure variety, you may wish to determine the half-life of each parent-daughter pair prior to the lab and assign different pairs to different groups.)

7) Once each group has properly labeled its mineral sample, the group members should determine the proportion of parent isotopes remaining in their sample. To use the example from the sample data table below, if a sample of “Nuclear Zircon” contains 60 atoms of parent isotope and 130 atoms of daughter isotope, then of 190 total atoms, 60/190 or approximately 32% are parent isotopes. Make sure students understand that in this model, the original number of parent atoms is equal to the current number of parent + daughter atoms—i.e., all atoms were originally parent atoms. (Emphasize that actual mineral samples contain many more atoms; this lab is a simplification.)

8) Group members should then use this percentage and the half-life of their sample to determine the sample’s age.
   a. First, students should make a rough “back-of-the-envelope” estimate of the age:
   Using the example from the sample data table, yellow popcorn has a half-life of 100
years. This means that every 100 years, half of the remaining parent isotopes in the sample will have decayed into daughter isotopes. Therefore, after 100 years, 50% of the original sample’s atoms will be parent isotopes, and after 200 years, half this number—or 25% of the original sample’s atoms—will be parent isotopes. If our sample of Nuclear Zircon contains approximately 32% of the original parent atoms, it must be between 100 and 200 years old.

b. Next, have students use the graphs that they created in the Hands-On Activity: Making a Half-Life Graph to estimate the number of half-lives that have passed through interpolation. (A sample graph from that activity is shown below.) Students can then multiply this number by the actual half-life (i.e., the number of years per half-life) to get a better estimate of the age of our sample of Nuclear Zircon. The example below shows that the y-coordinate 0.32 intersects with the curve at about the same point where the x-coordinate 1.6 intersects with the curve. So, 32% remaining parent isotope corresponds to a passage of time of just over 1.6 half-lives.
c. Finally, students with adequate mathematics background and skill should calculate the exact half-life and use that number to determine the absolute age. The equation and steps in solving the equation are shown below:

\[ P = 0.5^n , \]

where \( P \) equals the proportion of the parent remaining, and \( n \) is the number of half-lives.

We have already calculated \( P \), so we solve for \( n \):

\[
P = 0.5^n \\
\log(P) = \log(0.5^n) \\
\log(P) = n \log(0.5) \\
\frac{\log(P)}{\log(0.5)} = n
\]

So for the example given, \( P = 0.32 \).

\[
\frac{\log(0.32)}{\log(0.5)} = \frac{-0.4949}{-0.3010} = 1.644 \text{ half - lives}
\]

\[(1.644 \text{ half - lives}) \times (100 \text{ years per half - life}) = 164.4 \text{ years old}.
\]

9) When students have completed their calculations, they should proceed to the Guided Inquiry part of this lab.
<table>
<thead>
<tr>
<th>Sample</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group Name</td>
<td>Mighty Nukes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral</td>
<td>Nuclear Zircon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description of Parent Isotope</td>
<td>yellow popcorn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Half-Life of Parent Isotope</td>
<td>100 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Atoms of Parent Isotope</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Description of Daughter Isotope</td>
<td>white beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Atoms of Daughter Isotope</td>
<td>130</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Parent+Daughter Isotopes (original number of parent atoms)</td>
<td>190</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculated Proportion of Parent Isotope Remaining</td>
<td>60/190 or 0.32 or 32%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough estimate of Number of Half-Lives</td>
<td>1–2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rough Estimate Absolute Age</td>
<td>100–200 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimate of number of half-lives based on graph</td>
<td>About 1.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimate of age based on graph</td>
<td>160 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of half-lives based on calculation</td>
<td>1.644</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of half-lives based on calculation</td>
<td>164 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Guided Inquiry

Students can develop their own plans for collecting and analyzing data, based on their knowledge of the procedure and materials used. Begin by instructing groups to place their labeled samples around the classroom. Groups should move from sample to sample, completing the additional columns in their data tables. To facilitate discussion, you may wish to divide the class so that half the groups remain with their samples as the other half moves; the moving group can then compare its calculations for a sample with those of the group that created the sample.

Once students have grown proficient at calculating a sample’s age based on its half-life and rate of radioactive decay, encourage them to design their own investigations using their sample minerals or to pursue one of the following possibilities:

- Before a student group passes a mineral sample to another group, it could modify the sample by replacing some of the original parent isotopes with daughter isotopes, record the changes, and calculate the new absolute age. Then, the group could exchange its modified sample, but not its calculations, with the second group. The second group could count the isotopes, calculate the new absolute age, and check back with the first group to confirm the age and discuss any discrepancies.

- Explain that some rocks (e.g., sandstone and many other sedimentary rocks) contain minerals that have different origins and different absolute ages. Explain that, when possible, scientists often corroborate their absolute dating results by testing for several types of isotopes in a rock or substance. The scientists are limited to using only the isotopes within a given sample. Students could model a rock or substance that contains several pairs of parent/daughter isotopes with different half-lives and thus different proportions of parent remaining. They could do this by filling a medium-size plastic bottle with multiple sets of tiny objects to represent different parent/daughter isotope pairs. Students will need to calculate the proper ratio of each parent/daughter pair to include such that the ages calculated from each pair agree with each other. (If they do not agree, students need to be challenged to explain why they might not.) Groups can then exchange their samples and compare their calculations. Students could also model the composition of a real-world rock formation that they learn about through research. Note: If you want students to get a specific result (e.g., a corroborated test result), you will need to prepare this model before class or assign someone to develop such a model.

- Groups could develop half-life graphs from a scatter plot of data. For example, they could model a first half-life by dumping a chosen number of pennies into a counting tray. Pennies that land heads up could be counted as unstable (radioactive) parent isotopes. Those pennies would be recorded on a data table and returned to the dumping jar. Pennies that land tails up could be counted as stable daughter isotopes, recorded, and removed from the process. Students would continue dumping their pennies, with each dumping episode representing a half-life, until all pennies have landed tails up and been removed from the process. Students should repeat the
entire procedure to get several sets of data and combine data if possible. Afterward, groups can plot the combined data and use their graphing skills to produce a half-life graph.

Students should then compare this graph to the graph they created in the Hands-On-Activity. It is likely that the graph will not be very smooth. Students should be challenged to analyze dumping pennies as a model for radioactive decay. How is it similar? How is it different? Students will probably notice that although the theoretical probability of a penny landing tails up is 50%, the actual frequency of tails up is rarely exactly 50%. Some trials will result in many more than 50% tails, some in many fewer. According to the law of large numbers, the more pennies that are used and the more trials, the closer the results should be to 50%. How then can we be sure that 50% of parent atoms in a sample decay over one half-life? The answer is in the numbers. There are billions of atoms decaying over millions to billions of years.

Ask the students some guiding questions to help them focus their inquiry:

- What will be your objective?
- What will be the general plan or design of your lab?
- What will be your step-by-step procedure?
- Do you foresee any problems or limitations that might interfere with your investigation?

Instruct students to write down their objectives and general procedures and submit them to you for approval. Explain that even the best developed procedures can encounter unanticipated problems. Instruct them to confer with you to reevaluate and adjust the procedure if problems become evident. After you have approved a group’s activity, instruct the group to proceed with its plan.

Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Assume your model mineral contained all parent isotopes and no daughter isotopes. What absolute age and stage of development would that represent in a real mineral? The absolute age would be zero. This would represent the time when the radioactive parent isotope became trapped within the sample mineral—e.g., the time when the mineral formed. Alternatively, it could indicate that the daughter isotope was escaping from the mineral.

2. In what ways does your model accurately reflect real-world processes? During radioactive decay, the number of parent isotopes decreases as the number of daughter isotopes increases. Parent isotopes and daughter isotopes are distinct substances that can be counted within a sample. These counts can be used to calculate the sample’s absolute age.

3. In what ways does your model differ from real-world processes? Our models are oversimplifications of real-world decay. Actual rock samples contain many more atoms of each isotope, and they typically contain...
contain additional isotopes (both radioactive and stable) other than the parent/daughter isotopes used to establish the sample’s age. Also, special equipment is necessary to count parent and daughter isotopes in actual rocks.

4. One of the options for Guided Inquiry was to model radioactive decay by replacing one type of item (e.g., a popcorn kernel) with another type of item (e.g., a rice grain). In real-world processes, does this mean that radioactive parent isotopes leave a substance as stable daughter isotopes enter the substance? Explain your answer. No. A parent isotope changes into a daughter isotope through radioactive decay. When this happens, the parent isotope no longer exists.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- Design Investigations
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant- identify variables that must remain unchanged in
    - Sample (if needed) - a portion of the affected elements in an investigation used to extrapolate what would have happened to a larger set of elements
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have been revised as new knowledge and information has been obtained
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Choose appropriate tools to conduct an investigation:
    - Funnel
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)

- Interpret Data
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
    - Applying a classification scheme to objects, substances or organisms
  - Identify and interpret patterns using:
- Trends in data
- Tables and graphs
- Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Extrapolating results beyond the investigation
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Scientific explanations/arguments
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Analyzing scientific explanations

- Patterns and Systems
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.
    - Many patterns in nature occur in cycles.
    - Cycles may be short, such as the second hand of a clock, or long such as the cycle of a year.
    - Mathematical patterns help to predict future events and describe change in systems.

- Scientific Investigation
  - New observations should be made when there is disagreement among initial observations.
- When a scientific investigation is repeated, a similar result is expected.
- Science takes place in many locations including labs, offices, fields, and under the ocean.
- Scientific investigation results in things we know and things we don’t know.
- Scientific investigations generally work the same way in different places.
- Scientific investigation leads to more questions.
- Scientific investigations lead to the development of scientific explanations.

  **Scientific Data and Outcomes:**
  - Scientific claims are based on data and reliable scientific sources.
  - Collecting and analyzing data is the best way to understand a changing pattern.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - Some data can be collected in a short period of time (e.g. motion of a rolling ball) and some data takes much longer (e.g. the growth of a tree).
  - Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
  - It is important in science to keep honest, clear, and accurate records.
Hands-On Activity
Modeling Geologic Time

In this activity, students will analyze a geologic rock sequence by applying relative and absolute dating techniques. They will develop an understanding of the geologic history represented by the rock sequence, and use this understanding to create a model.

Suggested Materials
Per Pair:
- 1 copy of the Geologic Rock Sequence handout
- 1 copy of the Age Ranges of Index Fossils handout
- 1 copy of the Sm-147 Graph handout
- 1 copy of the K-40 Graph handout
- 1 copy of the U-235 Graph handout
- 1 Geologic Time Scale diagram
- Science Notebook or loose leaf paper
- pencils
- access to Board Builder

To introduce the activity, provide time for students to review the principles of relative and absolute dating. Students may wish to review the reading passages Radiometric Dating, Biostratigraphy, and Mass Extinctions.

Part 1: Analyzing a Rock Sequence

Procedure

1. Have students examine the Geologic Rock Sequence handout.
   a. Explain that this handout represents a rock sequence of 10 layers, along with two unconformities, a fold, and a fault.
   b. Instruct students to begin by using relative dating techniques—including the principles of superposition, cross-cutting relationships, original horizonality, etc.—to determine the order in which the layers, unconformities, fold, and fault formed. Students should ignore the index fossils and isotopes for the moment, focusing solely on the relative ages of the rock layers/features.
   c. Students should record the order of the layers/features in their notes, or in an observation table (see sample observation table below).
2. Next, students should focus on the index fossils they see in the rock layers.
   a. First, instruct students to record the index fossils found in the layers in their notes, or in an observation table (see sample observation table below).
   b. Then, students should record the age range of the layers based on the index fossils.
   c. Students can then use the principle of superposition to further constrain the age range of the layers containing the index fossils. Students should record the adjusted age ranges in their notes, or in an observation table (see sample observation table below).
3. Next, students should focus on the geologic features containing radioactive isotopes.
   a. Instruct students to record the geologic features found in the rock layers in their notes, or in an observation table (see sample observation table below).
   b. Then, have students record the percentage of the parent isotope remaining in each geologic feature in their notes, or in an observation table (see sample observation table below).
   c. Students should then use the graphs below (i.e., for Sm-147, K-40, and U-235) to determine the absolute age of each geologic feature based on the percentage of each parent isotope remaining. Instruct students to record this in their notes, or in an observation table (see sample observation table below).
   d. Students can then use the principle of superposition to further constrain the age range of the layers containing these geologic features. Students should record the adjusted age ranges in their notes, or in an observation table (see sample observation table below).
4. When students have completed the relative and absolute dating of the rock sequence, they should focus on other conclusions that can be drawn from the rock sequence. Instruct students to record their conclusions in their notes, or in an observation table (see sample observation table below).
   a. Students may infer whether each rock layer formed in a marine or terrestrial environment, based on the types of fossil organisms found in the layers (e.g. trilobites and brachiopods = marine; land plants = terrestrial).
   b. Students may use stratigraphic principles to infer the types of tectonic forces that were applied to the area in which the rock sequence formed.
   c. Students may infer other events that occurred during the formation of the rock sequence (e.g. iridium is rare on Earth, but common in meteorites; K-40 is used to date glass from meteorite impacts; Sm-147 is used to date meteorites).

Students may wish to use DE resources to support and/or expand their conclusions. Helpful resources may include the Decay Rates diagram and the videos Zircons: Time Capsules From Early Earth (8:51) and Iridium and Asteroids (5:54).

Part 2: Making a Timeline

Divide students into small groups so that they may design a timeline using Board Builder. Students should use the information they have gathered and the conclusions they have drawn, as well as further research through DE and other resources, to create a timeline of events that happened in the area in which the rock sequence formed. Events can include extinction events, meteorite impacts, tectonic activity, deposition of sediment, changes in environment, biological activity, etc. Students should answer the Analysis and Conclusions questions at the end of the student sheet to help guide them in drawing conclusions that could help with their timelines.

Potentially helpful DE resources include these video segments:
- Iridium: Meteoritic Mass Extinction (5:38)
- Iridium’s Link to the Dinosaurs (3:02)
- Cretaceous-Tertiary Extinction (0:49)
- The First Extinctions on Earth (3:38)
- Paleoenvironments (4:45)
- Science in Progress: The Fossil Record (3:18)
- Seedless Plants: Review (2:24)
Sample observations chart: **Ages of Rock Layers** (student version):

<table>
<thead>
<tr>
<th>Layer/Feature</th>
<th>Environment</th>
<th>Adjusted Age Based on Superposition</th>
<th>Absolute Age Based on Isotopes</th>
<th>%Parent Isotopes</th>
<th>Age Range Based on Index Fossils</th>
<th>Index Fossils</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Youngest</td>
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<tr>
<td>Oldest</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Sample observations chart: Ages of Rock Layers (answer key):

<table>
<thead>
<tr>
<th>Environment</th>
<th>Paleogene (65 Ma) - Present</th>
<th>Mesozoic-Cenozoic Boundary</th>
<th>Terrestrial</th>
<th>Terrestrial</th>
<th>Terrestrial</th>
<th>Terrestrial</th>
<th>Marine</th>
<th>Marine</th>
<th>Marine</th>
<th>Marine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Layer/Feature</strong></td>
<td><strong>Age Range Based on Index Fossils</strong></td>
<td><strong>%Parent Isotopes</strong></td>
<td><strong>Adjusted Age Based on Superposition</strong></td>
<td><strong>Layer C</strong></td>
<td><strong>Layer B</strong></td>
<td><strong>Layer M</strong></td>
<td><strong>Layer H</strong></td>
<td><strong>Layer G</strong></td>
<td><strong>Layer E</strong></td>
<td><strong>Layer D</strong></td>
</tr>
<tr>
<td>Youngest</td>
<td>Jurassic - Present</td>
<td>96.45% K-40</td>
<td>Jurassic - Present</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
<td>Lycococarpus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>99.575% Sm-147</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>66% U-235</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>425 Ma</td>
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<td>425 Ma</td>
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</tr>
</tbody>
</table>
Geologic Rock Sequence handout:

Index Fossil Symbols

- **Ammonite**
- **Spiniferid Brachiopod**
- **Orthid Brachiopod**
- **Pentamerid Brachiopod**
- **Strophomenid Brachiopod**
- **Phacopida Triobite**
- **Proetida Triobite**
- **Angiosperm**
- **Calamites**
- **Lycopod**
- **Gymnosperm**
- **Fern**

Iridium-rich Zone

Geologic Feature Symbols

- **%U-235** Zircon Crystal with Decaying Uranium-235
- **%Sm-147** Natural Glass with Decaying Samarium-147
- **%K-40** Meteorite Fragment with Decaying Potassium-40

Unconformity
Fault
Age Ranges of Index Fossils handout:

- **Ammonites**
  - Neogene (50 Ma)
  - Paleogene (100 Ma)
  - Cretaceous (150 Ma)
  - Jurassic (200 Ma)
  - Triassic (250 Ma)
  - Permian (300 Ma)
  - Carboniferous (350 Ma)
  - Devonian (400 Ma)
  - Silurian (450 Ma)
  - Ordovician (500 Ma)

- **Trilobites**
- **Brachiopods**
- **PLANTS**
  - Gymnosperms (pine trees)
  - Angiosperms (broad leaf and flowering trees)
  - Lycophytes (ferns)
  - Mosses
Analysis and Conclusions

1. What can you infer about the environment in which the rock layers formed, based on the types of fossil organisms found in each layer?

   Sample answer: The layers below unconformity “I” contain marine organisms, while the layers above this unconformity contain terrestrial organisms. This indicates that a marine regression occurred.

2. What can you infer, based on the shape of the features of the layers, about the tectonic forces applied to the area in which the rock sequence formed? In what type of geologic setting would these forces be applied?

   Sample answer: Pressure was applied inward from either side of the rock layers, causing both the fold and the fault (although at different times). This type of pressure indicates a location near a convergent boundary. This also indicates that the entire sequence is in a continental setting, suggesting that the marine organisms lived in a shallow sea on a continent, rather than in an ocean or over oceanic crust.

3. What can you infer about other events that may have occurred during the formation of this rock sequence, based on the geologic features (such as the iridium-rich zone, natural glass, and meteorite fragments) found in the layers?

   Sample answer: Iridium is rare on Earth, but common in meteorites. K-40 is used to date glass from meteorite impacts. Sm-147 is used to date meteorites. This all implies that a meteorite impact occurred while layer C was forming. Since this layer is about 65 million years old, this was most likely the major meteorite impact that caused the mass extinction that marks the Cretaceous-Tertiary (Cretaceous-Paleogene, Mesozoic-Cenozoic) boundary.

4. Based on all the available information, what can you infer about the geological and biological history of the area in which this sequence formed?

   Students’ answers will vary.
Calculating the Energy of Electromagnetic Waves

Use the wavelength-frequency equation or Planck’s Wave Equations to solve the following problems.

For your reference:

\[ h = \text{Planck’s constant} = 6.626 \times 10^{-34} \text{ J} \cdot \text{s} \]
\[ c = \text{speed of light} = 3 \times 10^8 \text{ m/sec} \]

1. A ray of light has a frequency of \(7.9 \times 10^{14}\) cycles per second (Hz). What is its energy? 
   \[5.2 \times 10^{-19} \text{ joules}\]

2. The light from a laser has a wavelength of 500 nm. What is the energy of one photon? 
   \[4.0 \times 10^{-19} \text{ joules}\]

3. What happens to a wave’s energy if its frequency is doubled? 
   \[ \text{It doubles.} \]

4. What is the energy of light with a wavelength of 662 nm? 
   \[3.00 \times 10^{-19} \text{ Joules}\]
5. A photon’s energy is $8.0 \times 10^{-19}$ J. What is its frequency?

$[1.2 \times 10^{15}$ Hz$]$
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:

- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term 'toggle.'

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Activity
Designing Solutions: Analog and Digital Information

Timing: one 90-minute class session

Objective(s):
Students will gather and assess data about analog and digital communications and storage systems. They will use this data to create a model (either a diagram, a physical model, a computer animation, or some other type of model) of at least one analog and one digital communication or information system. They will evaluate and analyze the models in a cost-benefit analysis, including considerations such as stability, efficiency, suitability for different conditions, risk of use, and expense.

Suggested Materials
Note that the materials necessary will depend upon whether you place constraints on the types of models students can build.

Materials for diagrams
- poster boards
- markers
- pencils
- erasers
- rulers

Materials for physical models
- cardboard
- cups, plastic foam
- paper, construction
- tape

Materials for computer models
- glue
- scissors
- string
- wire
- chenille sticks (pipe cleaners)
- beads
- other craft supplies and tools

Part 1 Brainstorming Analog and Digital Information Systems

Procedure
1. Lead the class in a discussion about what analog and digital mean.
2. Organize students into groups.
3. Explain that they are going to do two rounds of brainstorming, have a discussion, and then create a presentation for the rest of the class.
4. In the first round of brainstorming, which should last no more than 10 minutes, ask students to look at their possessions, look around the room, and create a list of all the communication and storage systems they see, identifying whether each one is analog or digital. Keep a class list visible, either projected or on a board at the front of the room. (This could include phones, books, computers, filing cabinets, calendars/diaries, brains, photographs, paintings, etc.)
5. In the next round of brainstorming, which should also require no more than 10 minutes, ask students to include items, systems, objects, and ideas that aren’t in the room. For each one, students should identify whether it is analog or digital. These responses get added to the class lists.

Part 2 Building Models
Procedure
6. Either assign devices to groups of students, or have them pick from the class list. Each group should have one digital device and one analog device.
7. Each group should plan to create a model and a cost-benefit analysis for their assigned systems. The model can be a diagram, a physical model, a computer animation or simulation, or another type of model. Even a skit with students acting as parts of a system could be used as a model. Have students submit their plans to you for approval so you can ensure they are appropriate, achievable, and involve materials or equipment that is readily available.
8. Remind students as they work on their model to be sure that the similarities, differences, advantages, and disadvantages of each system should be apparent in their models so they can be taken into account in their cost-benefit analysis. The cost-benefit analysis should also include discussion of which conditions or situations are best suited and least suited for a given technology.

Analysis and Conclusions

1. How did you categorize the types of communication and storage solutions on your list? [Student answers will vary. Sample answer: teacher’s handwritten calendar notes: analog; teacher’s computer: digital; intercom system: analog; cell phones: digital.]

2. Based on your cost-benefit analysis, describe the advantages and disadvantages of the analog and digital systems. [Student answers will vary. Sample answer: One advantage of handwritten calendar notes is that it is easy to see all entries at a glance. One disadvantage is that it involves limited space. One advantage of the teacher’s computer is that it can hold a lot of information and access even more over the Internet. One disadvantage of the teacher’s computer is that it can take longer to find what you need.]
3. Based on your cost-benefit analysis, describe ways that the analog and digital systems you modeled are stable and ways they are unstable. [Student answers will vary. Sample answer: Papers in files can last for many decades, but they are subject to damage by fire, water, or insects. Computer storage is usually less fragile than papers but may be subject to corruption by viruses or power surges. In addition, changes in technology may make old computer systems obsolete.]

4. Evaluate the systems you modeled. Which situations or locations are best suited for them? Which are worst suited for them? [Student answers will vary. Sample answer: An analog intercom system may be effective for communicating rapidly with all rooms within a given building when you have a wide variety of people in the rooms, but it is not as effective in communicating to many different places that are widely separated. A cell phone can digitally communicate to many different people all at once, but it may not be as efficient in communicating to everyone in a series of rooms within a given building unless the phone has been programmed with every person’s contact information.]

5. Describe one way each of the systems you modeled impacted either society or the environment. [Student answers will vary. Sample answer: With an intercom, the whole school can hear an announcement together. With a cell phone, people may spend more time texting and speaking with friends who are far away and not spend as much time in conversation with people nearby.]

6. Based on your models, identify an improvement that could be made to one of the systems to make it more effective, stable, or otherwise suitable. [Student answers will vary. Sample answer: Cell phones could be improved to function more like intercoms if they included conference-calling capabilities so you could contact many people all at once with the same spoken message.]
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing.

- **Interpret Data**
  - Sorts and classifies using
    - Apply a classification scheme to objects, substances, or organisms

- **Engineering and Technology**
  - **Uses of Technology**:
    - An invention can be used in different ways, such as a radio being used to get information and for entertainment.
    - Technologies, such as pesticides, often have drawbacks as well as benefits.
    - Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.
  - **Engineering Design**
    - An invention may lead to other inventions.
    - Human beings have made tools and machines, such as x-rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
Hands-On Activity
Designing Solutions: Photovoltaic Cells

Timing: one 90-minute class session

Objective(s):
Students will explore how the characteristics of light and area exposed can affect how much energy a photovoltaic system generates. Using their observations, they will develop a model that can help predict how a photovoltaic cell reacts to real-world conditions.

Safety Precautions:
Remind students:
Be careful when working with or near electrical systems.
Lamps can get hot.
Concentrating a light source with a magnifier or other means could be dangerous if viewed directly.

Suggested Materials
Per group:
- photovoltaic cell
- leads, with alligator clips
- ammeter
- transparency films, various colors (at least 3)
- lamps or flashlights
- magnifiers
- cardboard
- mirror
- goggles

Procedure
1. Attach the photovoltaic cell to the ammeter.
2. Shine a light source on the photovoltaic cell and observe the reading on the ammeter. Increase the intensity of light and see what happens. Make notes about your observations in a lab notebook.
3. Carefully place one of the colored transparencies on the photovoltaic cell so the transparency is positioned between the cell and the light source and only filtered light reaches the cell.
4. For each colored transparency, record the results and create a chart. (Be careful not to move or adjust the light source while collecting data about the transparencies.)
5. After completing the investigation of the transparencies, try concentrating the light on the photovoltaic cell with the magnifiers or mirrors. Record the changes observed in the ammeter.
6. Experiment with covering part of the photovoltaic cell. Create a chart and record the findings.
7. Finally, adjust the angle of light falling onto the cell. (Hint: it may be easier to move the photovoltaic cell so that light reaches it at a different angle rather than moving the light source.) Create a chart and record the findings for light striking the cell perpendicularly at a 30° angle and at 60° angle with the surface of the cell.

8. Based on the observations, develop a model describing how a photovoltaic cell is affected by changing conditions. The model could be an explanation, a flowchart, a diagram, or some other model.

Analysis and Conclusions

1. How did changing the color of the light affect the current readings on the ammeter? How did you account for this in your model? Why was it important not to move or adjust the light while comparing the effects of the transparencies? [Colors such as blue and those near it in the spectrum, as well as white, which contains all colors, resulted in a current. But other colors, such as red light, resulted in no current. There were no readings "in between," so a gradual change in color (the frequency of light) did not result in a gradual change in the amount of current. The model we used took into account that blue light is higher-energy per photon than other light, such as red light. Only light with a sufficient amount of energy per photon (near blue) would have enough energy to cause the photovoltaic cell to output current. If you moved or adjusted the light while comparing the transparencies, you would not be able to tell if the change was due to the color change or the movement of the light.]

2. Electric power is current times voltage. Once the photovoltaic cell is activated by photons of sufficient energy, it has a constant voltage. So an increase in current will lead to an increase in power. What did you notice about how much power was generated as you changed how much of the surface was covered? How does your model account for this? [The more area left uncovered, the more power was generated. In the model, only areas that are exposed to light will provide electricity.]

3. What happened when you concentrated the light? Did that match what you thought would happen? [Concentrating the light resulted in increased current and, thus, electric power up to a point. But once the light was focused only on the photovoltaic cell, focusing it further to a smaller area of the photovoltaic cell did not increase the current or power.]

4. Describe and explain the results for varying the angle of the light. [When the light striking the cell was perpendicular to the cell surface, the reading on the ammeter was the highest. The more the angle varied from the perpendicular, the lower the ammeter's reading fell. This is because having light strike the cell from an angle instead of perpendicular has the effect of diffusing the light instead of concentrating it.]
5. What other kinds of experimental questions could you explore through this activity given the same materials? [Student answers will vary. Sample answers: a new experiment combining some of the variables; checking different combinations of lights or taking the experiment outside; also using combinations of the color transparencies and determining the effects of having solar cells in series or parallel.]

6. Can you think of any issues that might have made your results less reliable? If so, how would you address those issues in a future iteration of this activity? [Student answers will vary. Sample answer: I would check the reliability of the ammeter by measuring some circuits of known current to be sure it was accurate. I would also use a light meter or other device to be sure the transparencies were consistent with each other.]

7. Imagine you are proposing installation of large array of these photovoltaic cells as part of a plan to provide energy for a building located in a remote area. Using your observations and information from your model, propose a specific configuration for the array. Create a cost-benefit analysis for your approach, taking into account efficiency, stability, suitability, cost, benefits, and risk. [Student answers will vary. Sample answer: I propose that the array has the cells spread out so they don’t shade each other. While having the cells change their orientation to “track” the sun across the sky like sunflowers would result in more energy being gathered, it would make the system more costly and much more likely to break down. So I propose the cells be positioned to gather light during the mid-day hours. At sunset or sunrise, the light from the sun is more yellow and red, and as a result, it may not be of high enough energy to trigger the photovoltaic cells to convert the light into electrical energy. A risk of the plan is that if there are many cloudy days, the array may not gather enough light to convert it into electrical energy.]
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Control (control group)—used for comparison in which the independent variable is not changed
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
  - Assessing the conclusion by:
    - Extrapolating the results beyond the investigation

- **Engineering and Technology**
  - Uses of technology:
    - An invention can be used in different ways, such as a radio being used to get information and for entertainment.
    - Technologies, such as pesticides, often have drawbacks as well as benefits.
  - Engineering design:
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
Student Investigation Sheet
Illustrating Wave Behaviors

Springs are popular toys. They can also be used to show wave behaviors, such as the oscillation of transverse and longitudinal waves, or constructive or destructive interference.

Safety Precautions:
Wear closed-toe shoes for all labs. Do not deform a toy spring by stretching it too much.

Objective(s):
With a partner, demonstrate oscillation of different kinds of waves. Demonstrate wave energy in both, and show constructive and destructive interference.

Materials:
Per group:
  • one toy spring
### Key Question

**What is the question you want to answer?**

**Directions:** Write the question for the investigation. The question should be specific and investigable.

**Key Components**
- Is specific (one general thought, does not combine two or more questions)
- Is able to be investigated

### Hypothesis

**What do you predict will be the result of the investigation?**

**Directions:** Develop a claim about what you think is going to happen.

**Key Components**
- Expresses a cause-and-effect relationship
- Is testable
- Incorporates prior knowledge
**Plan**

<table>
<thead>
<tr>
<th>How will you investigate the question?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Directions:</strong> Describe the plan that you will use to study your question and analyze your hypothesis.</td>
</tr>
</tbody>
</table>

**Key Components**

- Plan is easily repeatable by others
- Plan describes the use of materials
- Plan is in a logical order
### Data

<table>
<thead>
<tr>
<th>What evidence was gathered during the investigation?</th>
</tr>
</thead>
</table>

**Directions:** Record all of the evidence that has been collected. Use graphic organizers, tables, and graphs when appropriate.

**Key Components**

- Data (from an investigation and/or other sources, such as observations, reading material, archived data, etc.)
- Appropriate (data apply directly to the question)
- Sufficient (uses enough data to completely answer the question and determine a finding on the hypothesis)
## Conclusion

**What did you learn from this investigation?**

<table>
<thead>
<tr>
<th><strong>Directions:</strong> Develop a conclusion for your investigation. The conclusion should contain clear thoughts and proper vocabulary. This section focuses on the answer to your question. It should support or refute the hypothesis by using logical reasoning to link the hypothesis to the data.</th>
</tr>
</thead>
</table>

**Key Components**

- Use precise and accurate language
- Use scientific vocabulary
- Provide clear logical thoughts
- Use evidence and reasoning to support or refute the hypothesis
Analysis and Conclusions

1. What does the spring toy represent, with regard to waves in general?

2. How were you able to demonstrate wave energy in simulating either transverse or longitudinal waves? As you increased your input energy, what happened to the characteristics of the wave?

3. How were you able to simulate constructive or destructive interference for either transverse or longitudinal waves?

4. If one of you did not move their end of the spring toy, what happened to the wave? If one of you applied energy to a free-hanging spring toy, what happened? In both cases, why did this happen, and what does this model about waves in general?
Hands-On Lab
Investigating Light Reflection and Refraction

Timing: one 90-minute class session

Objectives:
Students will plan and carry out investigations to analyze mathematical relationships involved in light reflection and refraction.

Safety Precautions:
Remind students to follow all general lab safety rules, especially those associated with using glass objects and operating in a darkened lab. Have students report any broken mirrors or lenses for immediate cleanup. Warn students that the ray box may get very hot if the light is on for a long period of time. Have students turn off the light when not actively making measurements. Caution students to avoid looking directly at the light source.

Materials:
Per pair:
- ray box and light source
- glass block
- clay or tape
- plane mirror
- protractor
- holder for mirror and protractor
- white paper
- straight-edge
- marker

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- For each setup, the mirror should be held upright and perpendicular to a lab bench; the protractor should lie flat on the bench at a right angle to the plane of the mirror. Align the center of the protractor with the center of the mirror. You may use a variety of common materials, such as modeling clay or tape, to hold the mirror and protractor in place. The figure at right models the correct setup.
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Procedure**

**Directed Inquiry**

To begin this lab, set up the apparatuses as shown on the previous page. Then direct students as they following the procedure below.

1. Have students place a large sheet of white paper on a flat surface. Using a straight-edge, they should draw a line down the middle of the paper and position the mirror/protractor unit at one end of the line, so that the line corresponding to the 90-degree mark on the protractor aligns with the line drawn on the paper. Have students set up the ray box and light source so that a narrow beam of light can be projected at various angles onto the mirror. The incoming and outgoing light beams should both be clearly visible on the white paper in a darkened room.

2. Instruct students to identify the path of the incoming light beam. Using the protractor, they should find the angle of this beam relative to the drawn line. Then they should identify the path of the reflected beam and find the angle of this beam relative to the drawn line. Students should note both angles in a data table.

3. Now have students repeat Step 2 with several different orientations of the ray box and mirror. Each time, they should record their observations in a chart, such as the one below:

<table>
<thead>
<tr>
<th>Incoming Angle, degrees</th>
<th>Outgoing Angle, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>15</td>
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<tr>
<td>30</td>
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<tr>
<td>45</td>
<td>45</td>
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<tr>
<td>60</td>
<td>60</td>
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<tr>
<td>75</td>
<td>75</td>
</tr>
</tbody>
</table>
4. Next, have students remove the mirror from the setup. They should use the protractor to draw on the sheet of paper a new line perpendicular to the original line drawn. They should position this new line to bisect the drawn line.

5. Tell students to place a glass block on the paper surface so that one edge of the block lines up with the newly drawn line.

6. Now have them set up the ray box and light source so that a narrow beam of light can be projected at various angles onto the glass block (similar to the procedure used earlier for the mirror). Both an incoming light beam and an outgoing light beam should be observed, with both light beams clearly visible on the white paper in a darkened room.

7. Tell students to carefully move the ray box so that the incoming light beam intersects both the edge of the glass block and the perpendicular line on the sheet of paper. They should not move the ray box once this position has been established.

8. Have them use the protractor to find the angle of the incoming light beam relative to the perpendicular line. They should note this angle in a data table.

9. Now asking students to find the outgoing light beam and mark two dots on the paper anywhere along this light beam. They should remove the glass block from the setup and use a straight-edge to draw a line from both dots back to the perpendicular line. This line represents the outgoing light beam. Instruct students to use the protractor to find the angle of this line relative to the perpendicular line. They should note this angle in the data table.

10. Have students repeat Steps 7 through 10 with several different orientations of the ray box and glass block. Some example data are shown below. Note that actual results will depend on the index of refraction of the glass block used.

<table>
<thead>
<tr>
<th>Incoming Angle, degrees</th>
<th>Outgoing Angle, degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td>30</td>
<td>22</td>
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<tr>
<td>45</td>
<td>32</td>
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<tr>
<td>60</td>
<td>41</td>
</tr>
<tr>
<td>75</td>
<td>47</td>
</tr>
</tbody>
</table>

11. Ask students to calculate sine values for all angles measured. Then, make a graph of the sine of the incoming angle on the y-axis versus the sine of the outgoing angle on the x-axis.

When students have completed their graphs, introduce Snell’s law to the class:

Snell’s law: $n_i \sin(\theta_i) = n_o \sin(\theta_o)$

In this equation, $n_i$ is the index of refraction of air (equal to 1.00); $\theta_i$ is the incoming angle; $n_o$ is the index of refraction of the glass block; $\theta_o$ is the outgoing angle.

Instruct students to use Snell’s law to determine the index of refraction for the glass block that they used. (Students should observe that they obtain a straight line on their plot with a slope equal to the ratio of $n_o / n_i$.) As an extension activity, provide students with lenses of varying shapes. Have them conduct investigations of light refraction through the lenses to explore how lens shape affects the direction of refracted light.
Guided Inquiry

You can encourage students to design their own investigations of reflection and refraction by providing the apparatus and allowing them to decide on a procedure to follow and to make measurements of incoming and outgoing light beams. Once students have found the relationships, have them predict where a particular beam of light will emerge from a given setup.

Analysis and Conclusions

1. In what direction did the light beam reflect after it hit the mirror? What does this mean in general for wave reflection from a plane mirror?
   Sample response: The incident beam came in at a certain angle to the surface of the mirror. The reflected beam was also at this angle from the mirror surface, but on the other side of the normal. This means that the reflected angle equals the incident angle for reflections from plane mirrors in general.

2. What mathematical relationship can be used to describe the direction of light before and after reflection from a plane mirror? Write an equation to show this relationship.
   Sample response: The angle of incidence equals the angle of reflection for light striking a plane mirror: incoming angle = outgoing angle.

3. How did light behave when the beam was directed at the glass block? How did this behavior compare to the behavior when the light beam was directed at the mirror?
   Sample response: The light passed through the glass block instead of bouncing off as it did when striking the mirror. However, the light did not pass straight through the glass; rather, it emerged at an angle different from the one of entry.

4. Based on your graph, what mathematical relationship can be used to describe the direction of light before and after refraction through a glass block? Write an equation to show this relationship.
   Sample response: The sine of the angle of entry is proportional to the sine of the angle of exit of the light beam passing from air through a glass block: sin(angle of entry) = constant × sin(angle of exit).

5. Explain how the relationships that you found during this lab could be used in the following situation: An engineer has to project a beam of light in a particular direction. However, the light source to be used is fixed and cannot be moved, and it does not shine light in the direction desired.
   Sample response: The engineer could either use a mirror to reflect the light in the desired direction or he/she could use a refracting substance to change the direction of light to cause it to shine in the desired direction. In either case, the mathematical relationships for reflection or refraction could be used to predict the angle of the mirror or the index of refraction of a substance that could do the job.
Hands-On Lab
Investigating the Dual Nature of Light

Timing: one 90-minute class session

Objective(s):
Students will work with a model to explore how the wave theory of light does not adequately account for the photoelectric effect.

Safety Precautions:
Remind students to follow all precautions in a lab setting, even if the items they are working with aren't dangerous in and of themselves.

Suggested Materials
Per group:
- basin, wash tub, or sink that can be filled with water
- cork stopper, large, as for a flask
- board, small (or other planar object that will fit into the basin, wash tub, or sink)
- toy squirt gun

Teacher's Note
This lab can be performed as a teacher demonstration followed by student analysis.

Procedure
1. Begin with a discussion of the photoelectric effect, describing how only light with a threshold frequency above a certain amount is able to dislodge an electron from metal. While very bright light of frequencies below the threshold will not dislodge electrons, even dim light above the threshold will create a small current. Be sure students understand why this result is counterintuitive, if light is only considered as a wave phenomenon.
2. Introduce the model. The cork floating in the basin is like an electron, and its movement across the basin is analogous to electrical current in a metal, exhibiting the photoelectric effect.
3. Place the cork in the basin so it is stationary and about 1/3 of the way across the basin.
4. Gently dip the board a centimeter or so into the water and gradually pull it out. Repeat the process about once every two seconds. This should set up a pattern of waves in the basin analogous to light waves. The cork "electron" may move a little but will probably not go directly to the other side of the basin.
5. Let the water come to rest, and reset the cork so it is stationary and about 1/3 of the way across the basin. Now dip the board and pull it out, repeating the process about once every second. There will be more waves in the basin, but the cork "electron" still does not move directly to the other side of the basin.
6. Let the water come to rest. Reset the cork so that it is stationary about 1/3 of the way across the basin. Then, aim the squirt gun at the cork's side and pull the trigger to shoot a single strong squirt of water at the cork. The squirt of water is analogous to a photon. The cork "electron" will move more rapidly in the direction of the squirted water, toward the opposite end of the basin.

7. Let the water come to rest. Reset the cork so that it is stationary and about 1/3 of the way across the basin. Now, aim the squirt gun at the cork's side, but squeeze the trigger very gently so that the stream of water just barely reaches the side of the cork. The cork "electron" will move much less rapidly.

Analysis and Conclusions

1. This model used water to model light in the form of lower-energy waves and higher-energy waves and squirts of water to model low and high energy particles of light. Explain how your model's results were similar to those of the actual photoelectric effect when compared to classical models of waves and particles. [The wave's energy did not necessarily predict whether the cork "electron" would move. But being struck with a particle-like stream of water of sufficient energy was enough to make it move. If the stream was too weak, it would have little effect.]

2. In what ways was this model not like a real example of the photoelectric effect? [The water in the basis was analogous both to the medium for the waves and the substance within which the cork "electron" was moving or not moving. In the real photoelectric effect, the waves do not need a medium, but the electrons are loosely bound to metal atoms.]

3. In this model, the intensity of the "light" was not varied. Describe how you might change this model to include intensity as a factor. [For intensity of light waves, one could use a bigger basin with a bigger board so that the wave pattern extended over a greater area. For intensity of light particles, one could use multiple squirts instead of just one.]

4. Suppose you read an advertisement for a new invention: sunglasses that block UV radiation and include tiny solar cells behind the glasses that use the photoelectric effect to power little fans to cool you on a hot day. Explain how to improve the design of the invention based on what you've learned about the photoelectric effect. [If the solar cells are behind the glasses, much of the light energy will be blocked. This reduction in intensity will result in a smaller current. As such, the power output of the cells may not be enough to power the little fans. An improvement would be to place the solar cells in front of the glasses so they can absorb more light energy and provide more power for the fans.]
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Control (control group)—used for comparison in which the independent variable is not changed
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
  - Assessing the conclusion by:
    - Extrapolating the results beyond the investigation
Hands-On Lab
Light Intensity and Distance

Timing: one 90-minute class session

Objective:
Students will investigate the change in intensity of light striking an object as a function of the distance between the object and the light source. From their data, they will derive the inverse square law.

Safety Precautions:
Remind students to follow all general lab safety rules, especially those associated with working in a darkened room. Students should avoid looking directly into lit lightbulbs and should be instructed to turn off bulbs when not conducting experiments.

Materials:
Per group:
- lamp with lightbulb
- index card
- 2 ring stands with clamps
- meter stick
- photodiode
- ammeter

- 2 alligator clips
- black cloth or paper
- string
- scissors
- graph paper (one sheet per student)

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Arrange desks so that each group has 1) a flat surface with a length of one meter or more to work on, and 2) access to an electrical outlet.
- Prepare one index card per group by cutting a small slit in the center of each card.
- At each lab station plug in a lamp, checking that it lights properly. Also set up two ring stands, each with one clamp. Assemble other materials needed at each station.
Procedure

Have a demonstration setup prepared in advance for students to study before setting up their own. The setup should have the materials positioned according to the diagram below. One ring stand can be used to hold the index card, while the other can hold the diode. The lamp, slit, and diode should all be lined up along the same horizontal line.

1. Turn off the lights in the room. Have students verify that their photodiode registers a current reading on the ammeter when illuminated with light from the lamp. Explain that the current reading is proportional to the intensity of light detected by the diode.
2. Ask students to discuss predictions about how the current reading will be affected as they move the photodiode different distances from the lamp. Ask each group to develop a plan for testing their prediction and write an outline of the procedure they will follow. Suggest that groups may want to use the string to help measure distance of the photodiode from the light source.
3. Before each group gets started, show the group how to measure background current readings by turning on the light source and covering the slit with a piece of black cloth or paper. Explain that the photodiode is sensitive to light and that background illumination may cause a small current reading to be registered on the ammeter. Students should understand that this background current can be subtracted from current readings taken during their investigation.
4. Have students follow their proposed procedure once you have given your approval.
5. Circulate among groups to observe their lab technique and to offer guidance as needed.
6. When each group finishes, ask them to graph their data.
Analysis and Conclusions

1. Based on your results, describe how light intensity varies with distance from a light source.
   Sample Answer: Light intensity decreases rapidly as the distance from the light source increases.

2. Can you develop a mathematical equation to describe your results? Try using the general equation: Intensity = slope × (1/distance)^a. Is there a value of a that fits your data? Explain.
   Sample Answer: Yes, the value of a equals 2. We found this by plugging in one set of x, y coordinates and a value for a to find slope and then testing other x, y coordinates to see if they fit the equation. Only when a was set to a value of 2 did the equation fit our data.

3. How might astronomers use the relationship that you found to determine the distance from Earth to a star?
   Sample Answer: If astronomers can measure the star’s light intensity and if they know the slope for the equation, then they can use the equation to calculate the distance between Earth and the star.

4. How does the relationship you found apply to a person using a tanning booth?
   Sample Answer: People should limit their exposure to the ultraviolet light in the booth based on the distance between the light source and their bodies. The closer the distance, the shorter the time people should spend in a tanning booth.

5. Does the outcome of this experiment provide any insight into why you feel a high intensity of heat from a campfire when you are close to the fire, but then quickly lose that feeling as you move away? Explain.
   Sample Answer: Yes, the outcome shows that radiation intensity rapidly decreases as the inverse square of the distance. We feel this every time we move even a short distance away from a campfire because the radiating heat from the fire falls away with this same relationship.
Hands-On Lab
Malus’ Law

Timing: one 90-minute class session

Objective(s):
Students will investigate refraction and polarization of light by using prisms and polarized film.

Safety Precautions:
Remind students to follow all general lab safety rules, especially those associated with working in a darkened room. Students should not stare into flashlight beams. Students should be careful not to tear film.

Materials:
Per group:
• flashlight
• two prisms
• white paper
• two ringed pieces of polarized film
• two film holders
• light meter
• holders for flashlight and light meter probe
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- Build holders for flashlight and light probe where either can rest without moving. This may involve pipe cleaners, toothpicks, or tongue depressors. Students may help designing and building these.
- Holders for ringed film pieces could involve four tongue depressors, glued or taped to the ends of a tongue depressor, two on each end. Film holders should be able to hold the ringed film pieces standing up and so that the flashlight beam passes through the center of each piece.
- Polarized film pieces should be ringed with pipe cleaners that are taped to each piece and run along the outside circumference of each (round) piece. One half of the circumference of each pipe cleaner should be marked with thirteen different marks, to produce twelve fifteen-degree increments around this part of the circumference of each film piece. It will be helpful to make every other mark or every third mark longer, or with a different color of marker.
- Before pipe cleaner is taped to the outer circumference of any piece, rotate film piece to maximize intensity of a flashlight beam projected through it. Maximum intensity should correspond to centermost mark on pipe cleaner.
- Prospective setup should look like this diagram, with the flashlight beam perpendicular to the polarizing films.

Procedure

Set flashlight holder on lab bench. Activate flashlight, and place it in the flashlight holder. Stage film pieces in film holders and light meter probe in light meter holder. Set film holders and light meter holder aside, out of flashlight beam path. Darken lab.

1. Have students hold one prism in the beam of the flashlight, and project the output of the prism onto the white paper. Have students rotate the prisms until a colored spectrum can be seen.
2. Have a second student in each team hold the team’s second prism in the beam from the first. Rotate this prism until only white light comes out of this prism onto the white paper.
4. Move light meter and its holder into the path of the flashlight beam. Leave room for film holders, as the light meter and flashlight holder should not move after this step.
5. Record light intensity measurement from the meter.
6. Move one ringed film piece in its film holder into path of the beam, with flashlight beam shining perpendicular to surface of film. Repeat Step 5.
7. Move the second ringed film piece, in its film holder, into the path of the beam behind the first piece. Align marks on top of pipe cleaners around each ringed piece. Rotate second ringed film piece to maximize beam intensity behind film pieces. The intensity should be comparable to that obtained in Step 6. Repeat Step 5.
8. Rotate second ringed film piece relative to the first one. Repeat Step 5.
9. Your students may want to enter this data in a chart in their lab notebooks. A sample chart might be:
<table>
<thead>
<tr>
<th>Film Pieces and Alignment</th>
<th>Intensity</th>
<th>Film Pieces and Alignment</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Pieces</td>
<td>100</td>
<td>Two Pieces – Two Marks Δ</td>
<td>28.5</td>
</tr>
<tr>
<td>One Piece</td>
<td>38</td>
<td>Two Pieces – Three Marks Δ</td>
<td>19</td>
</tr>
<tr>
<td>Two Pieces – Start</td>
<td>38</td>
<td>Two Pieces – Four Marks Δ</td>
<td>9.5</td>
</tr>
<tr>
<td>Two Pieces – One Mark Δ</td>
<td>35.5</td>
<td>Two Pieces – Five Marks Δ</td>
<td>2.5</td>
</tr>
</tbody>
</table>

10. Repeat Step 8 and Step 5 for all thirteen marks around half the circumference of the second film piece.

Explain to your students that polarized film is an absorptive polarizer. It is made of a plastic with polymer chains that align a certain direction during manufacture. Valence electrons of this plastic's iodine dopant can move along these chains, but not transverse to them. This means that any incident light polarized parallel to the chains is absorbed, and only light that is polarized perpendicularly to these chains can be transmitted. This plastic is durable, practical and cheaper than other polarizers. It is used in sunglasses, photographic filters, and liquid crystal displays.

Malus' Law was named after Etienne-Louis Malus, a researcher in light. It states that when a polarizer, such as either of these pieces of film, is placed in the path of another polarized beam, the output intensity is:

\[
I = I_0 \cos^2 \theta_i
\]

where \( I_0 \) is the intensity of the (input) polarized beam, \( I \) is the resulting intensity, and \( \theta_i \) is the angle between the polarization angles \( \theta_1 \) and \( \theta_0 \) of the two polarizers, as shown at right.

If your students graph their output, you should see this dependence. At the endpoints, where \( \theta_i \) is about ninety degrees, the output intensity should be nearly zero.
Analysis and Conclusions

1. What did you do to the light beam by turning the prisms in its path? Why is it possible to do this?
   **Sample response:** Light from a flashlight is made up of many wavelengths of light. These wavelengths are refracted by different amounts in each prism. Running a flashlight beam through one prism separates the beam into the colored spectrum. Running it through a second prism can, if the second prism is rotated correctly, put the beam back together.

2. What light intensity did you measure behind only one piece of film in its path? What was the maximum one you saw with two pieces?
   **Sample response:** One polarizer can generally cut the intensity of a beam by about half. A second polarizer, if aligned with the first, can let almost all of the polarized beam through.

3. How does polarized film polarize an incident wave of light?
   **Sample response:** Polarized film is an absorptive polarizer. Polymer chains in polarized film are aligned in one direction. Iodine is added to this plastic, and its valence electrons can only move along these chains, but not across them. Thus, only light that is polarized perpendicular to these chains can be transmitted, and all the rest is absorbed. The electric field of light oscillates in every direction that is perpendicular to the wave motion, and almost all these oscillations are absorbed. Only oscillation in a single plane, normal to these chains, is transmitted.

4. What is Malus’ Law? Why did the intensity of the beam transmitted through two pieces of film vary as it did?
   **Sample response:** Malus’ Law states that if a polarized beam is input to a second polarizer, the output intensity from the second polarizer will be related to the cosine squared of the difference between the polarization angles of each polarizer. Our two pieces of polarized film had one polarization plane each, and when we rotated one with respect to the other, the intensity of the beam out of the second one followed Malus’ Law.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials - repeated tests with the same variables to check for variability of results.
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system) to accurately measure:
    - Length/distance/depth
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Table
    - Graph or chart

**Nature of Science Skills:**

- **Patterns and Systems**
  - Patterns and change:
    - Some small changes can be detected by taking measurements.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - It is important in science to keep honest, clear, and accurate records.

- **Engineering and Technology**
  - Uses of Technology
    - An invention can be used in different ways, such as a radio being used to get information and for entertainment.
Hands-On Lab
Modeling Light

Timing: one 90-minute class session

Objective:
Students will use observations of wave motion in a ripple tank to model the reflection, refraction, and intensity of light.

Safety Precautions:
Remind students to follow all general lab safety rules. Use appropriate caution when operating electrical equipment around water. Caution students about moving in a darkened room, especially since there may be patches of spilled water on the floor that make it slippery.

Materials:
Per group:
- ripple tank with transparent bottom
- water
- light source with stand
- white paper
- protractor
- triangular glass shelf (2)
- sheet of acrylic glass (length should be slightly shorter than the width of the ripple tank)
- digital camera
- computer with digital image analysis software such as Adobe Photoshop
- metric ruler

Teacher Preparation:
- In advance of students performing the lab, set up the ripple tank and accompanying equipment, as shown below.
- Fill the tank with enough water to produce waves. Be sure that when waves are initiated in the water at one end of the tank, shadows of the waves can be observed on the white paper below the tank.

![Diagram of experimental setup]
Part 1: Reflection and Refraction

Procedure

1. With the room darkened and light sources turned on, have students experiment with generating waves and observing them on the sheet of paper under the table. Students should observe the shadows of the waves projected onto the white paper underneath the tank.

2. Explain that waves are moving from one end of the tank to the other end. Light passing through the water tends to form shadows in areas where the waves crest because those areas contain the greatest volume of water. Lighter areas form on the paper where troughs in the waves occur because those areas contain the smallest volumes of water. Explain that electromagnetic radiation, which includes light, can be described as a wave with many of the same properties as the waves produced by the ripple tank. Direct students to use this setup as a model for studying light waves.

3. Have students practice generating waves until they can generate a reproducible shadow image on the paper. Then, have them experiment with placing the acrylic glass as a barrier at the end of the tank opposite to the end where waves are initiated. Have students rotate the barrier at different angles with respect to the direction of wave motion. Ask students to identify the phenomenon they observe (reflection).

4. To do a quantitative analysis of reflection, students can use a pencil to draw lines on the paper where a shadow forms from the acrylic glass barrier positioned in the tank. These marks establish the angle at which the barrier is positioned relative to the direction of wave propagation. Then students can generate a wave in the tank and draw marks on the paper to show wave shadows both before and after they hit the barrier. The paper can then be removed and analyzed using a protractor to determine the angles of incidence and reflection. Students should repeat this procedure multiple times using different angles of incidence.
5. Next, direct students to place one triangular glass shelf flat on the bottom of the tank at the end farthest from the end where waves are initiated. The glass shelf should be positioned so that the edge of the glass is not perpendicular to the direction of wave propagation, but is set off by an angle closer to 45°. The placement of the glass shelf will create a shallow end of the tank because the glass will raise the level of the bottom of the tank at this end. When they initiate wave motion, students should observe a change in the pattern of waves when they reach this shallow end. This occurs because the water waves move at different speeds depending on water depth. The diagram below provides an example of the pattern change expected. Explain to students that the medium changes as the waves pass from deeper water into shallower water. Because of this change, the waves slow down as they pass from deep to shallow water. Ask students to identify this phenomenon (refraction).

![Diagram of ripple tank with glass shelf](image)

6. To do a quantitative analysis of refraction, students can begin by drawing a line to mark the boundary of the glass shelf on the paper below the tank. They can initiate wave propagation at the deep end of the tank and draw the wave shadows that appear on the paper. Students should draw shadows representing waves before and after hitting the boundary. Students can then remove the paper and draw a line perpendicular to the glass shelf boundary. Then students can use a protractor to determine the angles of incidence and refraction with respect to the perpendicular line. They can use the relationship below to determine the following ratio:

\[
\frac{\sin \theta_i}{\sin \theta_r} = \frac{\text{index of refraction of refracting medium}}{\text{index of refraction of incident medium}}
\]

7. Next, have students predict how the ratio would change if they reduced the depth of the water in the shallow end by adding another glass shelf. (The index of refraction of the refracting medium will increase while that of the incident medium will not change, resulting in a larger ratio.) Have them perform an investigation to test their prediction.
Part 2: Wave Intensity

Procedure

1. Next, have students use the ripple tank to investigate wave intensity as a function of distance from the wave source. In this investigation, students should remove everything from the ripple tank except water. Have one student give a gentle touch of his or her finger to the water’s surface at one end of the tank to generate a wave. Ask students to make observations of the intensity of the shadows formed along the direction of wave propagation. The image below shows an example of the type of results that students should observe:

2. Have students repeat the wave propagation from Step 1, but this time take a digital photo of the entire set of wave shadows. The photo should be taken just as the wave hits the far end of the ripple tank.
3. The digital image can then be uploaded into a computer, and the intensity of the bands corresponding to the wave shadows can be analyzed using digital imaging software such as Adobe Photoshop.
4. The image can then be printed onto a sheet of paper and a metric ruler used to measure the distance of each shadow band from the wave source. Students should construct a data table to record these distances as well as the relative intensity of each shadow band as determined using the imaging software.
5. Have students plot band intensity versus distance from wave source. Then, have them calculate the inverse of the distance for each band, and then plot band intensity versus inverse of distance. The second graph should approximate a straight line.
Analysis and Conclusions

1. How well did the ripple tank model reflection? Would this model serve as a good model for light reflection? Why or why not?
   Sample response: The ripple tank modeled reflection very effectively. We were able to show that the angle of incidence of the wave was always equal to the angle of reflection, which is a pattern we saw when we analyzed light waves. Because of this, the ripple tank provides a good way to model light reflection.

2. How well did the ripple tank model refraction? Would this model serve as a good model for light refraction? Why or why not?
   Sample response: The ripple tank modeled the phenomenon of refraction very effectively. We were able to show that as the water became shallower at the far end of the tank, the speed of the wave decreased, causing a larger “bend” in the light, which resulted in an increase in the index of refraction. This models the same thing that happens when light changes its speed as it passes from one material into another, making the ripple tank a good model of light refraction.

3. What relationship did you observe between wave intensity and distance from wave source? Compare this to the inverse square relationship that has been shown to describe how light intensity changes as you move away from the light source. Are they comparable? How does this result affect your evaluation of the ripple tank as a model for light waves?
   Sample response: We found that the wave intensity was inversely proportional to the distance from the wave source. This does not agree with the inverse square law of light intensity, which holds that light intensity decreases as the inverse square of the distance.

4. In what ways are water waves created in a ripple tank not a good model system for describing the wave behavior of electromagnetic radiation?
   Sample response: Water waves require a medium for propagation, whereas electromagnetic waves do not. Water waves have only one component, whereas electromagnetic waves have two components—a magnetic and an electric component. Water waves cannot be related to photons, whereas electromagnetic radiation can be described as a stream of photons.
Hands-On Lab
Ripple Tanks

Timing: one 90-minute class session

Objective(s):
Students will observe use of a wide variety of equipment, including ripple tanks

Safety Precautions:
Use appropriate precautions, including those associated with use of electrical equipment or water. Ripple tank equipment should be deactivated while placing barriers or glass plate. Absorbent material should be staged in waterproof containers for storage of barriers and glass plate after removal from the tank.

Materials:
Per class:
• Ripple tank, including associated equipment
Teacher Preparation:

- A ripple tank is a shallow tank of water, as shown at right. The paddle is a wooden board that is suspended in the water, with an unbalanced electric motor on top to make the paddle wiggle when the motor is operated.
- Progress of ripples from either the paddle or two dippers can be observed from above, and is intended to show the behavior of waves.
- A glass plate may be available to demonstrate refraction, or slight redirection of a wave. The plate is typically put at the bottom of the tank to demonstrate this.
- Barriers are used to demonstrate reflection of waves from a plane or from an ellipse.
- Barriers can also be used to demonstrate diffraction of waves through slits of various widths.
- Students will likely sketch observed wave patterns in lab notebooks, so operate the table long enough for them to do this.

Procedure

1. Operate the table to show students how ripples are made, and to familiarize them with observing ripples.
2. Place a plane barrier in the water, facing the paddle. Operate the paddle and have students observe the ripples from the barrier.
3. Rotate this barrier to demonstrate how a wave will reflect from a plane that is at an angle to the incoming wave. Repeat this step for different angles of the barrier to the paddle.
4. Remove the plane barrier, and put in an elliptical or circular one. Operate the table to show how reflected waves will reflect toward a focus, as shown at right.
5. Remove the elliptic or circular barrier, and put in a glass plate, to show how a wave front changes direction, due to refraction. The glass plate needs to be thick, with the water above it shallow, in order to show refraction well. The glass plate should have smooth edges, to minimize reflections.
6. Remove the glass plate, and put in plane barriers, to show diffraction through a wide slit or through a narrow one, as shown below. Repeat this step as necessary to demonstrate each wave geometry.
7. Remove barriers and paddle. Place two dippers, small plungers that are operated by the paddle, to make ripples on the surface of the water. Operate the dippers to form interference patterns as shown below. Grey areas are areas of destructive interference, while waves will constructively interfere elsewhere.
Analysis and Conclusions

1. How does a ripple tank demonstrate characteristics and behaviors of waves?
   **Sample Response:** Ripples in the water form waves that we can observe. Barriers and a glass plate can be placed in the tank to show us wave behaviors.

2. How were you able to watch the progress of waves and/or ripples in the tank?
   **Sample Response:** The tank is illuminated from above. Once we got used to watching ripples, we could see where they were generated, and how they interacted with barriers.

3. What does this teach you about reflection from a plane mirror or from an elliptical one?
   **Sample Response:** Reflections from a plane mirror are at an angle that is equal to the incident angle of the incoming waves. Reflections from an elliptical or circular mirror tend to move through a single focus.

4. What does this teach you about refraction?
   **Sample Response:** Ripples above the glass plate moved at a different speed than ripples elsewhere in the tank. This change in wave speed caused the wave front to change direction above the plate.

5. What does this show about diffraction and interference?
   **Sample Response:** Diffraction through a wide slit (or through a narrow one) changes the path of the waves. In both cases, the path bends around the edges of the slit, giving a trapezoidal look to the path or waves emerging from a narrow slit, or a more circular look to the path of waves emerging from a narrow slit. Interference between two sets of circular ripples causes constructive and destructive interference in different areas of the tank.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials - repeated tests with the same variables to check for variability of results.
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system) to accurately measure:
    - Length/distance/depth
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Sketch

Nature of Science Skills:

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns
    - Many patterns in nature contain symmetry.
    - Symmetry in patterns is a result of natural balance and counteraction.
    - Many patterns in nature occur in cycles.
    - Cycles may be short, such as the second hand of a clock, or long such as the cycle of a year.
  - Systems
    - A system, such as the human body, is composed of subsystems.
    - In some systems, it may not always be possible to predict accurately the result of changing some part or connection.

- **Scientific Investigation**
  - Science investigation begins with a testable question.
  - When a scientific investigation is repeated, a similar result is expected.
  - What people expect to observe can affect how they perceive what they observe.

- **Scientific Data and Outcomes**
  - Collecting and analyzing data is the best way to understand a changing pattern.
  - It is important in science to keep honest, clear, and accurate records.

- **Scientific Endeavor**
  - Characteristics of Science
    - One way to make sense of something is to think of how it relates to something more familiar.
• Engineering and Technology
  ○ Uses of Technology
    ▪ Each part of a mechanical device contributes to the purpose of that device.
Hands-On Lab
Single Slit and Double Slit Diffraction

Timing: one 90-minute class session

Objective(s):
Students will investigate diffraction and interference of colored light through single and double slits.

Safety Precautions:
Remind students to follow all general lab safety rules, especially those pertaining to operating in a darkened lab, and using a laser pointer. These include neither staring into the pointer nor pointing the pointer directly at another student.

Materials:
Per pair:
- laser pointer (may be restricted to teacher use)
- single slit or double slit slides, made of cardstock
- unslitted cardstock slide
- slide holders
- micrometer

Material Notes and Teacher Preparation:
- Single or double slits must be made in cardstock. These slits must be the thinnest slits that can be made in your school’s art studio or using a surgical steel scalpel from a hospital or doctor’s office. A slit thickness of less than one millimeter is preferred. Double slits should be a maximum of half a millimeter apart.
- Card holders for both slitted and unslitted cardstock slides should hold these slides up perpendicular to a lab bench. Holders may be made out of tongue depressors or toothpicks.
- Gather materials in advance of students performing the lab.
- You may consider keeping the laser pointer, and aiming the laser only after students have set up the slitted and unslitted slides in their respective holders.
Directed Inquiry

Procedure

1. Have students use micrometer to measure both the width of slits and width of cardstock between the double slits in the slitted cardstock slides. Have them record this data.
2. Have students set up single slit and unslitted cardstock slides in two different holders a meter apart on the lab bench. For safety, point laser beam path through slit to unslitted slide toward a wall.
3. Darken room.
4. Position laser pointer to point through slit, and activate laser pointer. One student should sketch observed diffraction pattern (light and dark stripes) that is observed on unslitted slide.
5. Student that is not sketching should use the micrometer to measure the width of the central peak. A central slit of half a millimeter thickness will produce a central peak of about two and a half millimeters on the unslitted card, if illuminated with a laser of 600 nm wavelength.
6. Deactivate laser pointer once sketching and measurement are done.
7. Have students set up double slit cardstock slide in the holder that held the single slit slide.
8. Recheck distance between double slit and unslitted cards as one meter.
9. Repeat Step 3.
10. Repeat Step 4, but this time, student with micrometer should measure distance between dark stripes in the observed pattern. Two slits that are half a millimeter apart will produce diffraction minima that are 1.2 mm apart, if illuminated with a laser of 600 nm wavelength.
11. Repeat Step 5.

Guided Inquiry

Explain to your students that they have observed planar diffraction of light through either the single or double slit slides. Although they have not measured the intensity of the output light, the illustration that follows shows the output intensity, and a pattern that looks like the one they may have observed.
Diffraction patterns occur because the light diffracts around the edges of the slit. Light paths in the diagram show how light waves can come from different sides of the slit, such as point A or point C. These waves constructively and destructively interfere, making the diffraction pattern. The bright central width is created by constructive interference of light waves from the center of the slit and the edges. The dark spaces in the pattern are created by destructive interference.

In the case of the double slit, wave diffraction and interference go on as suggested by physicist Thomas Young. The pattern is one of circles, centered on the slits and creating circular patterns of light and dark, that, when projected on a screen, produce maxima and minima. The intensities stay within the envelope of that given by single slit diffraction.

Students may be interested in calculating the intensity of the single slit diffraction pattern, or in figuring the slit width, given their measurement of the central width and the wavelength of the laser pointer. That width can be found with the following equation:

\[ d_r = \frac{2\lambda z}{a} \]

where \( d_r \) is the central field width, \( \lambda \) is the light wavelength, \( z \) is the distance from slit to unslitted card, and \( a \) is the slit width.

The angular spacing of minima in the double slit diffraction pattern is described by this equation:

\[ w_r = \frac{z\lambda}{d} \]

where \( w_r \) is the spacing between minima, \( z \) and \( \lambda \) are as in the previous equation, and \( d \) is the distance between slits.

**Analysis and Conclusions**
1. Why does light create the diffraction patterns that it does when it is projected through a single slit or through a double slit?
   Sample Response: Light diffracts as it moves through a narrow slit. Interference between waves from different areas of the slit cause the light and dark areas of the diffraction patterns that form.

2. Given what you know about the scalings of the central width in the single slit interference pattern, could the central width of the single slit pattern be discerned if the slit were ten times wider? Could spacings between the double slit pattern minima (dark stripes) be seen if the slits were ten times further apart?
   Sample Response: Neither could be discerned, for the differences in the pattern would be much less than a millimeter.

3. What would happen to the central width and the spacings if you used a blue laser, with a shorter wavelength than a sodium one (yellow) or a red one? What’s the physical explanation for this?
   Sample Response: A shorter wavelength means more waves and more chances to interfere. Central width (single slit) and spacings (double slit) would be narrower for a blue laser than for either a yellow or a red one.

4. Would you be able to see the diffraction patterns if you cut your slits in clear plastic? Why or why not?
   Sample Response: Light would still diffract and interfere, but other light would also shine through the body of the plastic. All other light from outside the slit must be blocked if diffraction patterns are to be observed.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials - repeated tests with the same variables to check for variability of results.
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Length/distance/depth
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Sketch

**Nature of Science Skills:**

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns
    - Many patterns in nature contain symmetry.
    - Symmetry in patterns is a result of natural balance and counteraction.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - It is important in science to keep honest, clear, and accurate records.

- **Engineering and Technology**
  - Uses of Technology
    - An invention can be used in different ways, such as a radio being used to get information and for entertainment.
Hands-On Lab
Sound Resonance

Timing: one 90-minute class session

Objective:
Students will use tuning forks and resonance tubes to investigate the behaviors of waves, including resonance.

Safety Precautions:
Remind students to follow all lab safety rules, especially those dealing with the use of fluids. Make sure they understand to use the rubber mallet only to strike forks. Take great care not to let a vibrating tuning fork touch the plastic resonance tube. The vibrating fork can damage the plastic.

Materials:
Per group:
- resonance tube, with water reservoir
- tuning fork
- water as needed
- ring stands and clamps as needed to hold resonance tube, water reservoir, and tuning fork
- rubber mallet to strike fork.

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- You may find it convenient to have only one mallet per class and to keep it with you to strike each group’s tuning fork.
- Resonance tubes may be too long to have space above the tube to mount the tuning fork. Students may need to place the ring stand at edge of laboratory bench, and to extend the bottom of the resonance tube below the edge of the bench.
- You may find it helpful to fill water reservoirs from a central pitcher, once resonance tubes and tuning forks have been clamped to the ring stands.
- An example of a setup is shown below.


Procedure

Directed Inquiry

On two ring stands, set up the resonance tube, with water reservoir attached to tube, and tuning fork, as shown above. One member of the team will be in charge of moving the water reservoir up or down while the fork is vibrating. Once setup is complete, position the bottom of reservoir level with top of resonance tube, and fill resonance tube to nearly full.

1. One member of each team should be designated to be in charge of moving water reservoir; another should note water column height.
2. Have students strike the fork so that it vibrates.
3. Students should then move water reservoir to drop water level in resonance tube. They should note the water level at which sound level from fork increases. Slowly, vary water reservoir vertical position above and below this position, to note it carefully.
4. Once one position has been found, students should move the water reservoir to find another position where sound level increases. Repeat Step 3.
5. Once the second position has been found, students should repeat Steps 3 and 4 to find a third position. There may not be a third, so tell students to stop looking for it if the water level in the tube reaches the tube bottom.
6. Tell students to note the frequency of the fork. They should also calculate the speed of sound as four times the product of frequency and height of air column in resonance tube at the first observed resonance from Step 3.

Sound levels should have increased at water levels that had the air column being three, or possibly five times as tall as it was for the first observed resonance in Step 3. Note this to students, and draw waveforms, like below, to help them understand why this happens.

Guided Inquiry

Students may wish to experiment with different frequencies of tuning forks. Encourage this; you may even use forks of different frequencies in different teams’ setups. Students will find that the air column heights will vary inversely with tuning fork frequency. The sound speed (found using the equation $v = f\lambda$) doesn’t change, even though sound frequency $f$ and wavelength $\lambda$ do.

Students will note that sound level from the tuning fork will greatly increase at certain air column heights. These are odd integer multiples of one-fourth of $\lambda$.

The water acts as a node of a standing wave in the tube, for air cannot move further down the tube. The open end of the tube can be taken as an antinode. The actual antinode occurs about 0.6 $r$ above the end of the tube, with $r$ being the tube radius. You may add this end effect to the estimate of $\lambda/4$ if only one resonance can be measured, but it is generally more convenient to find more than one resonance at $3\lambda/4$, $5\lambda/4$, etc.
Analysis and Conclusions

1. Why does the air in the tube resonate with the fork at only a few water levels and not at others?
   Sample response: An air column resonates only if it is an integral (and odd) number of quarter-wavelengths of the sound wave. That way, the bottom of the air column can act as a node of the wave, where vibration is least, and the top of the air column can act as an antinode, where vibration is greatest.

2. Why does a struck fork vibrate at one frequency? What in the design of the fork would change this frequency?
   Sample response: A tuning fork is designed to resonate at a particular frequency; all others die out. The resonant frequency comes from the shape of the fork, the length of its tines, and its material. Changing any of these three items will change the output frequency of the fork.

3. How does the resonance in the tube relate to wave superposition?
   Sample response: The standing wave is produced when incident and reflected waves superimpose in the tube.

4. What would happen if the tuning fork were placed further away from the top of the tube?
   Sample response: Resonance with the sound wave would still occur, but sound intensity would be less.

5. Would your results be different if the air temperature in your lab (room) was colder?
   Sample response: The speed of sound in air is a function of its temperature. If the room were colder, the resonant levels would be shorter because the speed of sound and the sound wavelength are both a little lower in colder air than in warmer.

6. Given your findings in this lab, what do you now understand about why musical instruments make the sounds they do?
   Sample response: Reeds, strings, and pipes in various instruments vibrate at resonant frequencies that are a function of those pieces’ material and dimensions. When people play these instruments, the vibrations are turned into sound waves that move through the air.

7. Explain how to apply the concept of resonance to a tuned exhaust system. Conduct additional research on exhaust systems as needed.
   Sample response: A tuned exhaust system uses precise measurements to reflect waves back to the valve at a certain time in the engine cycle. Using this concept of resonance in an exhaust system makes an engine run more efficiently.
Hands-On Lab
The Speed of Sound

Timing: one 90-minute class session

Objective(s):
Students will use tuning forks and resonance tubes to measure the speed of sound in air.

Safety Precautions:
Remind students to follow all lab safety rules, especially those dealing with use of fluids. Use rubber mallet only to strike tuning forks. Take great care not to let a vibrating tuning fork touch the plastic resonance tube. The vibrating fork can damage the plastic.

Materials:
Per group:
• Resonance tube, with water reservoir
• Tuning fork
• Water as needed
• Ring stands and 90° rod clamps (or other equipment as needed to hold resonance tube, water reservoir, and tuning fork)
• Rubber mallet to strike fork.
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- You may find it convenient to have only one mallet per class, and keep it with you to strike each group’s tuning fork.
- Resonance tubes may be too long to have space above tube to mount tuning fork. Students may find it convenient to place ring stand at edge of laboratory bench, and extend bottom of resonance tube below the edge of the bench.
- You may find it convenient to fill water reservoirs from a central pitcher, once resonance tubes and tuning forks have been clamped to the ring stands.
- An example of a setup is shown below.
Directed Inquiry

Procedure

Set up resonance tube, water reservoir attached to tube, and tuning fork as shown on two ring stands. One member of team will be in charge of moving water reservoir up or down while fork is vibrating. Once setup is complete, position bottom of reservoir level with top of resonance tube, and fill resonance tube to nearly full.

1. One member of each team will be in charge of moving water reservoir. The other will note water column height.
2. Strike fork, so that it vibrates.
3. Move water reservoir to drop water level in resonance tube. Note water level at which sound level from fork increases. Slowly vary water reservoir vertical position above and below this position, to note it carefully.
4. Once one position has been found, move water reservoir to find another position whereat sound level increases. Repeat Step 3.
5. Once second position has been found, repeat Steps 3 and 4 to find a third. There may not be a third, so stop looking for it if the water level in the tube reaches the tube bottom.
6. Note frequency of fork. Calculate speed of sound as four times product of frequency and height of air column in resonance tube at the first observed resonance from Step 3.

Sound levels should have increased at water levels that had the air column being three, or possibly five times as tall as it was for the first observed resonance in Step 3. Note this to students, and draw waveforms, like below, to help them understand why this happens.
Guided Inquiry

Students may wish to experiment with different frequencies of tuning fork. Encourage this; you may even use forks of different frequencies in different teams’ setups. Students will find that the air column heights will vary inversely with tuning fork frequency. Sound speed \( v = \frac{f}{\lambda} \) doesn’t change, even though sound frequency \( f \) and wavelength \( \lambda \) do.

Students will note that sound level from the tuning fork will greatly increase at certain air column heights. These are odd integer multiples of one-fourth of \( \lambda \).

The water acts as a node of a standing wave in the tube, for air cannot move further down the tube. The open end of the tube can be taken as an antinode. The actual antinode occurs about 0.6 \( r \) above the end of the tube, with \( r \) being the tube radius. You may add this end effect to the estimate of \( \lambda/4 \) if only one resonance can be measured, but it is generally more convenient to find more than one resonance at \( 3\lambda/4 \), \( 5\lambda/4 \), etc.

Analysis and Conclusions

1. Why does the water level in the resonance tube follow the vertical position of the reservoir?
   Both the top of the reservoir and the top of the tube are open to the atmosphere, and liquids flow to equalize pressure on any part of the liquid. Because any liquid cannot “stack up” to have one part of the liquid surface higher than another, liquids always seek the same level as any other part of the same body of liquid.

2. Why does a struck fork vibrate at one frequency? What in the design of the fork would change this frequency?
   A tuning fork is designed to vibrate at a particular frequency. This frequency comes from the shape of the fork, the length of its tines, and its material. Changing any of these three items will change the output frequency of the fork.

3. What is happening in the tube when the fork is vibrating?
   The surface of the water acts as a node of a standing wave in the tube. We can take the open end of the tube to be an antinode (or “wide spot”) in the waveform. Resonances occur with air column heights that are odd multiples of one quarter of the wavelength.

4. Why does the sound increase when the water level in the tube is at one or two certain levels?
   The vibrations of the fork set up a standing wave inside the tube. If the air height is such that the waveform can be at a minimum at the surface of the water, and at a maximum at the open end of the tube, the standing wave is resonating and the sound increases.
5. Draw a diagram to represent the interference of the waves that resulted in points of resonance.

![Diagram of interference patterns](image)

6. Would your results be different with a different tuning fork? Why or why not?

*If we used another tuning fork of a different frequency, our intermediate results of resonant air column heights would certainly change. Our final result, an estimate of the speed of sound, would not change, because this speed is constant for any sound frequency.*
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Multiple trials - repeated tests with the same variables to check for variability of results.
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system to accurately measure:
    - Length/distance/depth
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
    - Hearing (pitch, volume, reflection, direction)
  - Uses the appropriate format to record data:
    - Table

**Nature of Science Skills:**

- **Patterns and Systems**
  - Patterns and change:
    - Some small changes can be detected by taking measurements.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - It is important in science to keep honest, clear, and accurate records.

- **Engineering and Technology**
  - Uses of Technology
    - Each part of a mechanical device contributes to the purpose of that device.
Hands-On Lab
Wave Characteristics

Timing: one 90-minute class session

Objective(s):
Students will explore the similarities and differences between a mass on a spring, oscillating with simple harmonic motion, and wave motion. They will observe and record the properties of an oscillating mass–spring system and then plot the displacement as a function of time. From this, they will analyze the data to determine various properties of the motion, such as wave period, amplitude, and frequency. Finally, they will compare and contrast the oscillating spring system with actual wave motion.

Safety Precautions:
Students should wear closed-toed shoes to protect against masses that might accidentally fall. Students should treat the mass–spring system gently so that the mass remains attached to the spring. Also, they should not overstretch the spring, as this may cause damage to the spring and pose a potentially hazardous situation when released.

Materials:
Per group:
- Mass–spring system
- Stopwatch
- Ruler or meter stick
- Hook (or ring stand, to hang the mass–spring system)
- Chart paper
- Tape

Teacher Preparation:
You will want to use a mass–spring system that has a fairly low oscillation rate (long period) so that the students can make accurate measurements. If the mass is too small or if the spring constant is too high, the oscillations will be too fast for the students to measure accurately. Be sure that masses are securely attached to springs, and check that springs do not contain any sharp edges. Prepare a copy of the Student Investigation Sheet for all students.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

1. Separate students into groups and distribute materials. Review with students the definitions of the following terms: amplitude, wavelength, wave period, frequency, and wave speed. Tell students that they are going to observe the motion of an oscillating mass–spring system over time and compare this motion with wave motion.

2. Ask students to develop a hypothesis for the investigation. For example, do students believe that the motion of a spring can be analyzed in terms of wave motion? How will the motion of a spring be similar to or different from a wave?

3. Once groups have formulated a hypothesis, have them set up the experiment. Have students suspend the mass–spring system from a wall hook or ring stand (or any other object that will suspend the system above the ground). If the system is suspended from an object that is not already touching the wall, have students move the system in front of a wall. Have them tape the chart paper behind the mass–spring system on the wall.

4. Students should observe the “equilibrium position” of the mass when it hangs at rest on the spring. They should mark this position with a dash on the chart paper and label it “0.”

5. Tell students that they will raise the mass on the spring to a particular point above the rest position and, making sure they are not moving the mass, release it. They will need to observe and measure the following properties: the maximum displacement of the mass from equilibrium both above and below the rest position, and the time it takes the mass to oscillate back and forth one time. In order to measure these quantities, students may mark dashes on the chart paper indicating where the spring reaches its maximum and minimum positions. They can then use a ruler or meter stick to measure the distance from equilibrium (the rest position) to the extremes. They can use the stopwatch to measure the time it takes for the mass to oscillate back and forth 10 times and then divide by 10. This will reduce error in measurement.

6. Have students repeat Step 5 for 4 or 5 trials and then calculate the average value for each quantity in a data chart. A sample data chart is shown below:
7. Using the information they have gathered, students may now determine the position of the mass at various time intervals. Students can multiply the average time for one full oscillation (the wave period) by $\frac{1}{4}$, $\frac{1}{2}$, and so on, to determine the time at which the mass arrives at various points in its oscillation. Students should assume the following:
- At $\frac{1}{4}$ of the way through the oscillation, the mass is at 0 (equilibrium position).
- At $\frac{1}{2}$ of the way through the oscillation, the mass is at the opposite extreme value.
- At $\frac{3}{4}$ of the way through the oscillation, the mass is at 0.
- At 1 full oscillation, the mass is back where it began.
- Assume this cycle repeats.

<table>
<thead>
<tr>
<th>Trial</th>
<th>Minimum Location (cm)</th>
<th>Maximum Location (cm)</th>
<th>Time to complete 10 oscillations</th>
<th>Mean time to complete 1 oscillation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-10.3</td>
<td>11.1</td>
<td>17</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>-10.5</td>
<td>10.7</td>
<td>16</td>
<td>1.6</td>
</tr>
<tr>
<td>3</td>
<td>-10.6</td>
<td>11.3</td>
<td>18</td>
<td>1.8</td>
</tr>
<tr>
<td>4</td>
<td>-10.4</td>
<td>11.2</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td>Average</td>
<td>-10.5</td>
<td>11.1</td>
<td>16</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Note that these values are a bit large, and would be indicative of a large mass or a spring with a very low spring constant.
A sample chart is shown below:

<table>
<thead>
<tr>
<th>Fraction of oscillation</th>
<th>Time</th>
<th>Mass position (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>-10.5</td>
</tr>
<tr>
<td>¼</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>½</td>
<td>0.8</td>
<td>11.1</td>
</tr>
<tr>
<td>¾</td>
<td>1.2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>-10.5</td>
</tr>
<tr>
<td>1 ¼</td>
<td>2.0</td>
<td>0</td>
</tr>
<tr>
<td>1 ½</td>
<td>2.4</td>
<td>11.1</td>
</tr>
<tr>
<td>1 ¾</td>
<td>2.8</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>3.2</td>
<td>-10.5</td>
</tr>
</tbody>
</table>

**Guided Inquiry**

Students will develop their own experiment to model a wave propagating through space with a mass–spring system. Ask students some guiding questions to help them focus their inquiry:

- How could a mass on a spring move like an electromagnetic wave propagating through space, or a transverse wave propagating through matter? What features do they have in common?
- What materials might you need to record the position of the mass as it oscillates through space and time?
- How would you arrange these materials to perform the investigation?
- What data would you need, so as to plot the vertical position of the mass as a function of time? How would you obtain these data?
- How would you make your measurements so as to reduce experimental error and imprecision?
- How would you use your data to obtain information about the wave characteristics (for instance, wavelength and frequency) of the oscillating mass–spring system?
- What data would you need to plot the vertical position of the mass versus the horizontal position of the mass through space? How could you obtain these data?
- How would you make your measurements so as to reduce experimental error and imprecision?
- How would you use your data to obtain information about the wave characteristics (for instance,
Separate students into groups and either distribute materials to each group or make them available at a central location. Review with students the definitions of amplitude, wave period, frequency, wavelength, and wave speed.

2. Draw a sinusoidal curve on the chalkboard. Hold a mass and spring system up to the curve and move the mass up and down while walking from left to right. Show students that the oscillating mass can be graphed as a sinusoidal curve, or wave form. Explain, however, that the graph can plot the vertical position of the mass either as a function of time (which corresponds to a mass oscillating up and down from a stationary hook) or as a function of the horizontal position of the mass. The latter corresponds to a situation where the mass on the spring still oscillates vertically, but it also moves in some horizontal direction through space.

3. Have students think about how they could devise an experiment that would model the situation where the oscillating mass moves horizontally, or propagates, through space, without actually requiring their mass to move in two (or three) dimensions. Students should design an experiment that can be done using only vertical motion. Explain to students that they will need to determine the wavelength, wave period, amplitude, frequency, and wave speed of the mass. Allow students to experiment briefly with the materials and to brainstorm an experimental setup.

4. Once students have experimented briefly with the materials, have them develop the steps of a procedure that they will follow. Students should also construct a data table (or data tables) that will be used to record measured and computed values. It is a good idea to approve these procedures for each group before allowing them to proceed.

5. Allow students to carry out their investigations. Be sure to offer assistance to any groups that are struggling. A sample procedure is given below:

a. Attach chart paper behind a mass–spring system. Record the equilibrium position of the mass at the left end of the paper. Vertically displace the mass to a particular distance and mark this location on the chart paper.

b. Release the mass from rest and then walk it to the right with a steady, slow pace. (Alternatively, students may devise a method of moving the paper and keeping the mass–spring system stationary) Have a group member record the time it takes the mass to complete one full oscillation. This may be done by taking the time for several full oscillations and obtaining an average value.) Have another group member trace the path of the mass on the chart paper as the mass is walked to the right. (Alternatively, a group member could mark off the maximum and minimum locations on the paper as the mass moves to the right.)

c. Use a ruler or meter stick to measure the distance between consecutive peaks on the chart paper. Measure the distance between the equilibrium position to the maximum and minimum positions of the mass. Repeat this process for four to five trials. Record
this information in a data table, such as the one below:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Minimum Location (cm)</th>
<th>Maximum Location (cm)</th>
<th>Time to complete 1 oscillation (s)</th>
<th>Distance from crest to crest (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-10.3</td>
<td>11.1</td>
<td>0.40</td>
<td>32.5</td>
</tr>
<tr>
<td>2</td>
<td>-10.5</td>
<td>10.7</td>
<td>0.50</td>
<td>37.4</td>
</tr>
<tr>
<td>3</td>
<td>-10.6</td>
<td>11.3</td>
<td>0.30</td>
<td>29.2</td>
</tr>
<tr>
<td>4</td>
<td>-10.4</td>
<td>11.2</td>
<td>0.40</td>
<td>40.2</td>
</tr>
<tr>
<td>Average</td>
<td>-10.5</td>
<td>11.1</td>
<td>0.40</td>
<td>34.8</td>
</tr>
</tbody>
</table>

d. Calculate the average value for each quantity measured. Determine the average amplitude, wave period, frequency, wavelength, and wave speed of the wave. (Note that frequency is given by the inverse of the wave period, and wave speed is determined by multiplying the frequency by the wavelength.)

e. Analyze how the model is similar to and different from an actual wave propagating through space.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Graph a sinusoidal plot of the vertical displacement of the mass as a function of time. Plot the vertical displacement of the mass on the y-axis and time on the x-axis.

   *Sample graph follows:*
2. How could you use the chart you have drawn to calculate the average amplitude, wave period and frequency of the wave?

Sample Response: I would first match each maximum to a minimum, to have a total number of waves. I would then add up the absolute values of all these positions, and divide by two. This will give the average amplitude. I’d then note the time between the start of the first and the end of the last of these waves. Dividing this time by the number of waves gives the average period. Dividing the number of waves by this time gives the average frequency.

3. What is the average amplitude of this wave? What is the average wave period? What is the average frequency?

Sample Response: The average amplitude can be determined by averaging the absolute value of the minimum and maximum positions of the spring: \((10.3 \text{ cm} + 11.1 \text{ cm})/2 = 10.7 \text{ cm}\). The period is the time to complete one oscillation, which is 1.7 s. The frequency is the inverse of the period, which is: \(1/(1.7 \text{ s}) = 0.59 \text{ Hz}\).

4. Can you determine the wavelength and wave speed of this wave? Why or why not?

Sample Response: The wavelength and wave speed are meaningless in this plot because the mass does not propagate through space. That is, the mass oscillates only in one spatial direction.
4. How is the motion of the mass–spring system similar to and different from an electromagnetic wave propagating through space?

   Sample Response: The mass–spring system is similar to an electromagnetic wave propagating through space because it has an amplitude, frequency, and wave period. It can be plotted as a sinusoidal wave on a graph. It is different, however, because it does not propagate through space. This means that it does not transmit energy from one location to another, and it does not have a wavelength or wave speed. Note, however, that in moving the oscillating mass–spring system parallel to the paper, that the sinusoidal path of the system is analogous to the propagation of an actual wave. The horizontal distance between maximum displacements above or below the equilibrium position equals the wavelength of the “wave” that would be moving horizontally, were there an actual disturbance in the medium. Similarly, the speed at which the mass–spring system was being moved would be the counterpart to wave speed.

5. Compare and contrast the mass-spring system’s motion to the rhythmic motion of a transverse mechanical wave, such as a tension wave in a waving flag or clouds oscillating in altitude due to changing buoyancy. What do these waves have in common? How are they different?

   Sample Response: All these waves have amplitude, frequency, and wave period. Those of the mass-spring system do not have a wavelength or a wave speed, however, because waves in this system only move in one dimension. The transverse wave types move in two or even three dimensions, and so have both these quantities.
Inquiry and Nature of Science Skills in this lab:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause–effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct field studies using:
    - Survey—collects multiple data points at one point in time
    - Observational study—compares changes in data points over time
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged in
    - Control (control group)—used for comparison in which the independent variable is not changed
  - Sample (if needed)—a portion of the affected elements in an investigation used to extrapolate what would have happened to a larger set of elements
    - Make or use models that:
      - Simulate a real thing that cannot easily be studied or manipulated
      - Have as many details as possible replicated from the real thing
      - Function exactly like or similarly to the real thing
      - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
      - Apply mathematical operations and principles to replicate the real thing
      - Have been revised as new knowledge and information has been obtained
      - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
Describing it so that it can be easily repeated by a fellow scientist

- Practice lab safety by:
  - Following lab safety procedures
  - Recognizing safety equipment and materials and knowing their proper use
  - Incorporating laboratory safety practices into the investigation design

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
    - Volume
    - Temperature
    - Time
    - Speed
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape measure
    - Meter stick
    - Glassware (beakers, flasks, watch glass, etc.)
    - Clock/stopwatch
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Hearing (pitch, volume, reflection, direction)
    - Touching (temperature, texture, shape, size, vibration, motion)
    - Smelling (flavor, odor)
    - Kinesthetic (balance, position)
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)
    - Sketch
    - Diagram
    - Photograph/image
    - Audio recording
    - Video recording

- Interpret Data
  - Identify and interpret patterns using:
    - Trends in data
    - Repeating physical or data patterns
    - Graphed data points

- Evaluate Evidence
  - Draw and support a conclusion by:
- Reporting trends and patterns in the data
- Comparing results to hypothesis
- Answering the testable question
- Extrapolating results beyond the investigation
- Identifying alternative explanations
- Examining how investigations can be improved
- Formulating scientific explanations/arguments
- Explaining how technology can be used to enhance the investigation
- Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Peer presentation
    - Written report
    - Scientific illustration with proper labeling
    - Images or video segments
    - Audio recording
    - Scientific explanations/arguments
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Identifying alternative explanations
    - Analyzing scientific explanations
    - Analyzing scientific arguments

Nature of Science Standards

- Patterns and Systems
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Many patterns in nature occur in cycles.
    - Cycles may be short, such as the second hand of a clock, or long such as the cycle of a year.
    - Mathematical patterns help to predict future events and describe change in systems.

- Scientific Investigation
Scientific Investigation:
- Science investigation begins with a testable question.
- New observations should be made when there is disagreement among initial observations.
- When a scientific investigation is repeated, a similar result is expected.
- Science takes place in many locations including labs, offices, fields, and under the ocean.
- Scientific investigation results in things we know and things we do not know.
- Scientific investigations generally work the same way in different places.
- Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
- Scientific investigation leads to more questions.
- Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
- What people expect to observe can affect how they perceive what they observe.
- Scientific investigations lead to the development of scientific explanations.

Scientific Data and Outcomes:
- People are more likely to believe ideas if good reasons are given for them.
- Scientific claims are based on data and reliable scientific sources.
- Collecting and analyzing data is the best way to understand a changing pattern.
- Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
- Comparisons of data are not accurate when some of the conditions are not kept the same.
- Some data can be collected in a short period of time (e.g., motion of a rolling ball) and some data takes much longer (e.g., the growth of a tree).
- Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
- It is important in science to keep honest, clear, and accurate records.
- When similar investigations give different results, it often takes further studies to decide what is right.
- Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

Scientific Endeavor
- Characteristics of Science:
  - Science is based on factual knowledge.
  - Scientists are curious about wanting to know how things work.
One way to make sense of something is to think of how it relates to something more familiar.
Scientific claims can be substantiated using data and observation.
Scientific theories are based on accumulated evidence.
Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
An important part of science is the critical review and analysis of any idea or conclusion.
A law is a description of a specific relationship under given conditions in the natural world.
A theory is a well-supported and widely accepted explanation for what is observed in the natural world.
Hands-On Lab
Wave Characteristics

Timing: One 90-minute class session

Objective(s):
Students will use a spectroscope to investigate the different parts of the electromagnetic spectrum that create the colors we see in the world around us.

Safety Precautions:
Do not allow students to get too close to any light sources. Students should never point the spectroscope at or look directly at the Sun. Remind students to use a piece of white paper for bright light sources, letting the light bounce off the paper and looking at the paper through the spectroscope. Remind students to follow all general lab safety rules and not to eat or drink anything in the lab.

Materials:
Per pair:
- spectroscope
- white paper
- colored pencils

Per class:
- computer monitor or television
- incandescent light sources (bulb and candle)
- fluorescent light source
- LED light source
- halogen light source

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Prepare a copy of the Student Investigation Sheet for each student.
- If possible, have a variety of light sources available in the lab for students to study.
- On the computer monitor or television, have color blocks for students to look at, such as a white block (which will show up as red, blue, and green in the spectroscope) and a yellow block (which will be predominantly red and green).
- Obtain enough spectroscopes so that you have at least one spectroscope for every two students.
Procedure
Set out materials at each student station. Before students begin the investigation, explain and demonstrate how to use the spectroscope to view a light source and then how to color in the data sheet to record what students see. Using colored pencils is typically the easiest way to do this. Students should consider what the information they have collected tells them about the light source. Ask: *Does the color of the light tell us anything about the temperature of the bulb? Can you tell which bulbs are more energy efficient? How? Are the spectra of sources continuous?*

1. Have students create data sheets on which they can record what they see through the spectroscope. These should be rectangles with a range from 350 nm to 750 nm. Students should create as many of these as necessary for the light sources they will be observing.
2. Have students use the spectroscope to take turns looking at the various light sources, including a computer monitor or television, and recording what bands of color they see. Each student should have the opportunity to observe and record each of the light sources.
3. When students have made all their observations, have them compare their observations with their partner or with other groups.
Analysis and Conclusions

1. Did any of the spectra you observed have black lines in them? If so, why do you think these black lines were present?

Sample answer: Yes, the fluorescent light spectrum had black lines in it. I think these black lines are the result of the fluorescent light only emitting certain wavelengths of light.

2. What did you learn about the colors we see on a computer monitor or television versus the colors that are actually emitted by these devices?

Sample answer: Using the spectroscope, I discovered that the colors emitted by devices like a computer or television are different than the colors we actually see. For example, when I looked at the yellow block on the computer, I saw that the computer screen was actually emitting red and green light.

3. What did you notice about the electromagnetic spectrum wavelengths produced by different kinds of light (incandescent, fluorescent, and LED)?

Sample answer: The spectrum of light that I saw with the spectroscope differed depending on the source of light. For example, the incandescent light bulb produced a continuous spectrum, with all of the colors of visible light emitted at equal brightness. However the light from the fluorescent light bulb was not continuous. Instead, I saw individual bands of different colors. Also, different colors appeared with varying brightness.

4. Based on the different wavelengths you see through the spectroscope, can you explain why one type of light source would be more energy efficient than another?

Sample answer: Based on the different wavelengths I saw through the spectroscope, I think fluorescent light bulbs are more efficient than incandescent light bulbs. Because the incandescent light bulb emitted a full, continuous spectrum. It uses more energy to emit all of that light, compared to the fluorescent bulb, which only emits light of a few wavelengths.

5. What type of light sources are used to light expressways or major roadways? Why do you think these light sources are used?

Sample answer: I think that lights used to light expressways and major roadways are fluorescent lights. This is because fluorescent lights are very bright, so drivers can see the road, and they are more efficient, which is important for lights that are turned on all the time.

Extension Activities

- The spectrograph is a simple instrument that allows us to explore the visible light segment of the electromagnetic spectrum. Have students investigate the instruments that are used to study or utilize the other segments of the spectrum (gamma rays, microwaves, radio waves, infrared).
- Have students share what they have learned about other segments of the electromagnetic spectrum. Using a white board or long segment of butcher paper create a wavelength timeline and have students indicate where the portion of the spectrum they investigated falls on the line.
In this lab, students will demonstrate the following Inquiry Skills:

- **Planning and Carrying Out Investigations**
  - Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence. In the design, decide on types of data, how much data, and the accuracy of data needed to produce reliable measurements. Consider limitations on the precision of the data and refine the design accordingly.
  - Select appropriate tools to collect, record, analyze, and evaluate data

- **Analyzing and Interpreting Data**
  - Consider limitations of data analysis (measurement error, sample selection) when analyzing and interpreting data.
  - Compare and contrast various types of data sets to examine consistency of measurements and observations.
  - Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.

- **Engaging in Argument from Evidence**
  - Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
Exploration Teacher Guide: Wave Characteristics

Overview

Waves are caused by disturbances in a medium. Various factors like a wave’s frequency, wavelength, speed, and amplitude affect its motion in a medium. In this Exploration, students analyze different properties of a wave and observe its motion through different media.

Student Learning Objectives

- Analyze the motion and behavior of transverse and longitudinal waves.
- Observe the change in a wave’s speed and wavelength in different media.
- Understand how particle speed, frequency, wavelength, and amplitude affect a wave’s motion.
- Examine the behavior of electromagnetic waves in different media.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students examine transverse and longitudinal waves. Students select one of these waves using the available radio button options in the Select Wave section. If students select Transverse Waves, they can select the Electromagnetic Waves checkbox to analyze electromagnetic waves. Once the students have selected a type of wave they wish to analyze, they vary various parameters related to the wave using the sliders provided. Using these sliders, students vary particle speed, frequency, wavelength, and amplitude of a wave. Using options in the Select Medium 2 dropdown list, students select a second medium through which the wave propagates, the first medium being air.

Once the students click on the Start button, an animation of the motion of the selected wave based on the various selected wave parameters is shown. Students observe the values of frequency, wavelength, and wave speed for both media. Using the Reset button, students can reset the Exploration and examine the wave propagation with different parameters and for different wave parameters.

The Tracker tab displays a summary of the values for all the runs. Students observe the direction of equilibrium shift for the selected action.
Answers to Questions in the Student Worksheet

1. Explain the difference between a transverse wave and a longitudinal wave.

   **Answer:** In a transverse wave, the particle displacement is perpendicular to the direction of wave propagation. In a longitudinal wave, the particle displacement is parallel to the direction of wave propagation. A transverse wave is composed of crests and troughs and a longitudinal wave is formed by compression and rarefaction of the medium. All longitudinal waves require medium to propagate but electromagnetic waves, a type of transverse waves, can propagate through vacuum.

2. Calculate the wavelength of a wave, if its frequency is 2.4 Hz and its speed is 3.6 m/s.

   **Answer:**
   
   Frequency (f) = 2.4 Hz.
   Wave speed (v) = 3.6 m/s.
   Wavelength (λ) = v/f.
   Wavelength (λ) = 3.6/2.4.
   Wavelength (λ) = 1.5 m.

3. Define time period of a wave and determine the relation between time period of a wave and its frequency.

   **Answer:** The time period is the time taken by a wave to complete one full cycle. It can also be defined as the time taken by a wave to cover a distance equal to one wavelength. The time period of a wave is the reciprocal of its frequency.
   
   Time period (T) = 1/Frequency.

4. Describe a transverse wave using a real life example.

   **Answer:** Transverse waves are those waves in which motion of the particles is perpendicular to wave propagation. A wave traveling down a string is an example of transverse wave. If a string is plucked, the particles of the string move in the up and down directions, but the wave moves forward. Another example of a transverse wave is a ripple in a pond.

5. Explain why longitudinal waves do not propagate through vacuum.

   **Answer:** Longitudinal waves require a source and a medium to propagate. When a longitudinal wave propagates the particles in the medium vibrate in a direction parallel to the motion of propagation. Longitudinal waves do not propagate through vacuum, as there are no particles present in it.
6. Define wavelength and frequency and explain the relationship between them.

**Answer:** A wavelength is the distance between two adjacent crests or troughs in a wave. Frequency is defined as the number of vibrations per second. The product of wavelength and frequency gives wave speed.

\[ \text{Wave speed (} v \text{)} = \text{wavelength (} \lambda \text{)} \times \text{frequency (} f \text{)}. \]

7. Determine if the following statements are true or false. If a statement is false, correct it so that it is true.

   a. In a transverse wave, the particle displacement is parallel to the direction of wave propagation.
   b. Wave speed of a longitudinal wave increases as it travels from air to glass.

**Answer:**

   a. False. In a transverse wave, the particle displacement is perpendicular to the direction of wave propagation.
   b. False. Wave speed of a longitudinal wave decreases as it travels from air to glass.

8. Categorize the following into transverse or longitudinal waves.

   a. Ripples in a pond
   b. Motion of a spring
   c. Light waves from the Sun
   d. Sound waves from a speaker
   e. Stadium wave in a soccer match
   f. Vibration of a tuning fork

**Answer:**

   a. Ripples in a pond – Transverse wave.
   b. Motion of a spring – Longitudinal wave
   c. Light waves from the Sun – Transverse wave.
   d. Sound waves from a speaker – Longitudinal wave.
   e. Stadium wave in a soccer match – Transverse wave.
9. Wavelength and speed of a wave change as it travels from one medium to another but its frequency remains same. Explain.

**Answer:** Frequency is the property of the source whereas wavelength and speed are the property of the medium. As a wave travels from one medium to another, wavelength and speed change depending on the refractive index of the medium. Frequency of a wave will change only if the source of the wave is changed.

10. The distance between a speaker and a listener is 8.0 m. Determine the frequency of the sound wave if exactly 20 waves are formed before sound reaches the listener. (Speed of sound in air is 340 m/s.)

**Answer:**
Distance between the speaker and the listener = 8.0 m
Number of waves formed = 20.
Wavelength = total distance / number of waves.
Wavelength = 8.0 / 20.
Wavelength = 0.40 m
Speed of sound = 340 m/s.
Frequency = speed / wavelength.
Frequency = 340 / 0.40.
Frequency = 850 Hz.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.
- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Reflection and Refraction

Overview

Reflection and refraction are basic properties that govern the behavior of light waves. In this Exploration, students investigate laws of reflection and refraction of light using a slab and a lens.

Student Learning Objectives

- Observe reflection and refraction of light waves using a slab of different refractive indices.
- Understand the relation between angle of refraction and the refractive index of a material.
- Examine the formation of an image using a converging lens.
- Analyze the position and size of the image for different object positions.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students examine reflection and refraction using a rectangular slab and the formation of images when light rays are refracted from a lens. Students select either of the radio button options, Slab and Lens, provided. On selecting the Slab option, students can observe reflection and refraction of a beam of light through a slab. The students can select the angle of incidence using options in the Select Angle of Incidence dropdown list. Using options in the select refractive index dropdown list, students can select the refractive index of the slab through which the light passes. Once students click on the Start button, reflected and refracted beams are shown. The reflected beams are shown at both interfaces. The angle of reflection and refraction are also displayed. When the Lens option is selected, students can observe the image formation of an object on the other side of a converging lens. Students can select the focal length of the lens and the position of the object using options in the Select Focal Length and Select Object Position dropdown lists, respectively. The object is placed on the left side of the lens. Once students click on the Start button, an optical ray diagram is drawn and the formation of the image on the other side of the lens is displayed. The numerical values of the object position, object size, image position, and image size are displayed.

Students can use the Reset button to observe reflection and refraction with different values for the selected radio button option. Students can toggle between the two radio button options.

The Tracker tab is a summary of the values for all the runs. Students use the Select Setup dropdown list to select the data they want to examine. The tracker for Slab displays the angle of
reflection and refraction. The tracker for Lens displays the numerical values of the object position, object size, image position, image size, and magnification.

Answers to Questions in the Student Worksheet

1. Use the Slab section in this Exploration and describe the effect of the refractive index on the angle of refraction when the angle of incidence is constant.
   
   **Answer:** As the refractive index increases, the angle of refraction decreases.

2. List the laws of reflection of light.
   
   **Answer:**
   - The incident ray, normal, and reflected ray, all lie in the same plane.
   - \( \theta_{\text{incident}} = \theta_{\text{reflected}} \): These angles are measured between the ray and the normal.
   - The reflected ray and the incident ray are on the opposite sides of the normal.

3. In the Lens section, start at “Beyond 2F” and decrease the distance between the object and the lens using options in the Select Object Position dropdown list. For the same focal length, examine and describe the effect of the decreasing distance on the size of the image.
   
   **Answer:** As the distance of the object from the center of the lens decreases, the size of the image increases.

4. Explain why a piece of paper catches fire when a magnifying glass is held in direct sunlight at a certain distance from the paper. Comment on the distance at which the magnifying glass is placed and explain its significance.
   
   **Answer:** The paper is placed at a distance equal to the focal length of the magnifying glass. A magnifying glass is a converging lens. All the rays of light coming from the sun converge at one point; that is the focus of the lens. In the exploration you will observe that when the object position is infinity (a very large distance compared to the focal length of the lens) a point image is formed at the focus. This indicates that the image of the sun is formed at the focus (on the paper). All the rays of light converging at one point on paper produce enough heat to burn the paper.

5. A plane reflecting mirror A is placed horizontally and another plane reflecting mirror B is placed at an angle of 90.0˚ to it. If a beam of light incident at A makes an angle of 43.7˚ with the normal, determine the angle of reflection from B.
   
   **Answer:** The beam of light is incident at 43.7˚ at A
   The beam of light reflected from the surface of A = 43.7˚ (using laws of reflection)
   Angle at which this beam is incident at B = 90 - 43.7˚ (using geometry)
   Angle at which this beam is incident at B = 46.3˚
   So, the angle of reflection of this beam of light = angle of incidence = 46.3˚.
6. Determine the angle of refraction if a beam of light is transmitted from air to a medium of refractive index 1.6 and the angle of incidence is 37.0°.

**Answer:**

\[ n_1 = \text{refractive index of air} = 1 \]

\[ n_2 = \text{refractive index of medium} = 1.6 \]

Angle of incidence = 37°

According to Snell’s Law

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

\[ 1 \times \sin (37°) = 1.6 \times \sin (\theta_2) \]

\[ \theta_2 = 22°. \]

7. A beam of light transmitted from air to a material, undergoes reflection and refraction. Determine the refractive index of the material if the angle of reflection is 74.89° and the angle of refraction is 51.25°.

**Answer:**

Angle of reflection = 78.49°

Angle of refraction = 51.25°

Angle of incidence = 78.49° (using the laws of reflection)

According to Snell’s Law:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

\[ 1 \times \sin (78.49°) = n_2 \times \sin (51.25°) \]

\[ n_2 = 1.256 \]

8. Determine the position of an object on the left side of a converging lens if:
   a. a magnified image has to be projected on a screen on the right side of the lens.
   b. a point image has to be projected on a screen on the right side of the lens.
   c. an image of the same height has to be projected on a screen on the right side of the lens.
   d. a diminished image has to be projected on a screen on the right side of the lens.

**Answer:**

a. Between F and 2F.

b. Infinity.

c. At 2F.

d. Beyond 2F.

9. Explain why refractive index has no unit.

**Answer:** Refractive index is the ratio of two velocities or two wavelengths and the units cancel.
10. Wavelength and speed of light change when a beam of light travels from one medium to another but the frequency remains constant. A beam of green light travels through air and passes through a medium of unknown refractive index. If the velocity of green light in the medium is \(2.0 \times 10^8\) m/s, determine its wavelength in the medium and the refractive index of the medium. (Hint: wavelength of green light in air = \(5.2 \times 10^{-7}\) m. velocity of light = wavelength \times frequency)

**Answer:**

Refractive index \((n) = \text{velocity of light (in air)} / \text{velocity of light (in medium)}\)

Velocity of light in air = \(3.0 \times 10^8\) m/s

\[ n = (3.0 \times 10^8) / (2.0 \times 10^8) \]

\[ n = 1.5 \]

Since velocity of light = wavelength \times frequency

Using definition of refractive index

\[ n = \text{(wavelength (in air) \times frequency)} / \text{(wavelength (in medium) \times frequency)} \]

The frequency of wave does not change with the medium.

\[ n = \text{wavelength (in air)} / \text{wavelength (in medium)} \]

\[ 1.5 = (5.2 \times 10^{-7}) / \text{wavelength (in medium)} \]

wavelength (in medium) = \(3.5 \times 10^{-7}\) m.
Exploration Teacher Guide: Mirrors and Lenses

Overview

Mirrors and lenses are used to study properties of light. Understanding how images are formed using a mirror or a lens can expand their application. Some common applications of mirrors and lenses are microscopes, telescopes, and periscopes. In this Exploration, students analyze the nature of the images formed using a mirror or a lens by varying parameters like object distance and object size. Students also understand the formation of ray diagrams for mirrors and lenses.

Student Learning Objectives

- Observe the formation of images by a mirror and a lens.
- Understand how distance from a mirror/lens affects the nature of the image.
- Examine the effect of focal length of a mirror/lens on the type of image formed.
- Learn the sign conventions used to draw a ray diagram.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students use the radio button options to observe the formation of an image using a mirror or a lens in the setup. An Experiment View section is shown along with a Ray Diagram section. Students select the type of mirror (plane, convex, or concave) or lens (convex or concave) using the options in the Select Type dropdown list. They then select the focal length of the selected type of mirror or lens using the options in the Select Focal Length dropdown list. The focal length of a plane mirror cannot be selected. Students select the height of the object using the options in the Select Object Size dropdown list and the object's distance from the mirror or lens using the options in the Select Object Distance dropdown list. They use the Start button to observe the formation of the image for the selected set of values.

Students may use the Reset button to examine the formation of an image for different selections.

The Tracker tab displays a summary of all the previous runs. Students use the options in the Select Setup dropdown list to view the data for the mirrors and lenses they have observed in the Explore tab. Students also observe the images formed and the ray diagram for each case.
Answers to Questions in the Student Worksheet

1. Explain the difference between mirrors and lenses.

   **Answer:** Images formed by mirrors are because of the rays of light reflecting from its surface. On the contrary, a lens forms the images by refracting the rays of light.

2. Explain the difference between real and virtual images.

   **Answer:** Real images are those images that can be projected or captured on a screen. Virtual images can be observed, but these images cannot be projected or captured on a screen.

3. Explain why a convex lens is also known as a converging lens and a concave lens is known as a diverging lens.

   **Answer:** A convex lens is also called a converging lens because all the rays of light parallel to the principal axis get refracted at the surface of the lens and converge on its other side at the focus.

   In case of a concave lens, the rays of light also get refracted from the surface of the lens. The rays of light parallel to the principal axis appear to diverge from the focus on the same side.

4. List down the rays that may be used to draw a ray diagram.

   **Answer:** Three different rays can be used to determine the position and the size of an image formed. These three rays include

   a. The ray parallel to the principal axis which is reflected / refracted to pass through the focus.
   b. A ray passing through the focal point which is reflected / refracted to pass as a line parallel to the principal axis.
   c. A ray passing through the center and emerging undeviated on the other side in the case of lenses and reflects at an equal angle in the case of mirrors.

5. A car driver sees an image of a car behind him in a convex rear-view mirror. The focal length of the mirror is 1.2 m. The height of the car is 1.5 m and its distance from the mirror is 6.0 m. Determine the size of the image of the car formed.

   **Answer:**
   - Focal length (f) = -1.2 m
   - Height of the car = height of the object (o) = 1.5 m
   - Distance of the car from the mirror = distance of the object (u) = 6.0 m
1/f = 1/u + 1/v
1/-1.2 = 1/6.0 + 1/v
1/v = -1
v = -1 = -1.0 m

The distance of the image from the mirror is 1.0 m

Size of the object can be calculated using the following formula
v/u = -i/o
-1/6 = -i/1.5
i = 0.25 m

The size of the image is 0.25 m and the positive sign indicate that the image is virtual.

6. Explain why, when a magnifying glass is held over a paper in sunlight, the paper catches fire. Also, mention the distance at which the paper should be placed from the magnifying glass for this to happen.

Answer: The focal length of a magnifying glass is the distance at which all the rays of light converge. If the magnifying glass is held at this distance from the paper, the rays of light will converge at the surface of the paper. Due to the heat produced because of all the rays meeting at one point, the paper catches fire.

7. Explain the formation of images by mirrors using a real world example.

Answer: A metallic spoon can be used to explain the formation of images by a mirror. The side of the spoon that is curved outside acts as a convex mirror. This side forms erect and magnified images. The other side, which is the side that is curved inside acts as the convex mirror. This side forms diminished and inverted images.

8. Determine if the following statements are true or false. If a statement is false, correct it so that it is true.

   a. If an object is placed at 2F in front of a convex lens the size of the image formed is twice the size of the object.

   b. The point from which the rays appear to diverge in a concave lens is known as the focus.

Answer:

   a. False. If an object is placed at 2F in front of a convex lens the size of the image formed is equal to the size of the object.

   b. True.
9. An object of is placed at a distance of 20 cm in front of a convex lens of focal length 10 cm. Describe the nature of the image formed.

**Answer:**
Focal length \( f = 10 \text{ cm} \)
Distance of the object \( o = 20 \text{ cm} \)

\[
\frac{1}{f} = \frac{1}{u} + \frac{1}{v}
\]
\[
\frac{1}{10} = \frac{1}{20} + \frac{1}{v}
\]
\[
\frac{1}{v} = \frac{1}{20}
\]
\[
v = 20 \text{ cm}
\]

The distance of the image from the lens is 20 cm.

Size of the object can be calculated using the following formula:

\[
\frac{v}{u} = \frac{-i}{o}
\]
\[
\frac{20}{20} = \frac{-i}{o}
\]
\[
i = -o
\]

The size of the image is equal to the size of the object and the negative side indicates that the image is inverted.

10. The radius of a convex mirror is 30 cm. Calculate the distance at which the image is formed if the object is placed at 22 cm. (Hint: focal length = half of the radius of the mirror)

**Answer:**
Since the focal length = half of the radius of the mirror
Focal length = \( 30/2 = 15 \text{ cm} \)

\[
\frac{1}{f} = \frac{1}{u} + \frac{1}{v}
\]
\[
\frac{1}{15} = \frac{1}{22} + \frac{1}{v}
\]
\[
\frac{1}{v} = \frac{7}{330}
\]
\[
v = 47.14 \text{ cm} = 47 \text{ cm}
\]

The distance at which the image is formed is 47 cm.
Hands-On Lab
The Law of Refraction

Timing: one 90-minute class session

Objective(s):
The students will investigate refraction of light in water. By measuring the output beam and applying Snell’s law, the students will estimate the index of refraction of water.

Safety Precautions:
Do not put hands in aquarium, to avoid spillage. Do not use an optical laser to do this lab, as reflection from aquarium may cause injury.

Materials:
- power supply
- slide projector
- books to boost slide projector
- flat-sided aquarium or goldfish bowl, filled with water to a depth of five inches, about the diameter of a compact disc.
- two compact discs
- two meter sticks
- masking tape
- dark colored paper
- sticky notes
- pen

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- This lab is a demonstration lab, as the material setup is extensive, and things like an aquarium, slide projector and power supply are unique in a classroom. Students can independently perform their calculations and answer the questions, though.
- This lab repeatedly refers to an aquarium. Since this is only a large flat-sided translucent container of water, this can alternately be a flat-sided goldfish bowl if this is what is available. There may be other flat-sided translucent containers that can hold water that can be substituted as well (a glass vase in the shape of a rectangular prism, etc.).
Directed Instruction

An aquarium, placed in the center of a single lab bench, is the target for a light beam from a slide projector. As that projector is moved along a meter stick taped to the near side of this lab bench, students find and mark locations of the output beam near a second meter stick on the far side of the bench.

Students should be familiar with Snell’s Law. Students should also have graph paper in their notebooks, to allow them to sketch the lab setup very accurately. This will allow them to carefully calculate how light bends as it moves through the aquarium or goldfish bowl.

Procedure

1. Plug slide projector into power supply.
2. Tape one compact disc over the front of the slide projector’s front lens, aligning the hole in the center of the compact disc with the center of the lens. Use books to boost slide projector if required for the central hole to align.
3. Tape second compact disc on front of aquarium, and place this container in the center of the lab bench. Make sure second compact disc is positioned to allow light beam from the projector to go through central hole in compact disc.
4. Tape one meter stick on the side of the lab bench in front of students and behind the slide projector. Use tape to mark positions every five centimeters along length of meter stick.
5. Use second meter stick to measure lab bench and placement and dimensions of aquarium. Sketch and record these measurements in a lab notebook.
6. Use masking tape to tape second meter stick to back of lab bench, behind aquarium. Align end of second meter stick to be directly across lab bench from meter stick from Step 4.
7. Use pen to draw vertical arrows on several sticky notes.
8. On these notes, note projector positions, in terms of distance along the meter stick along the front of the lab bench.
9. Place slide projector at one marked position, and activate it.
10. Pivot slide projector in place to aim beam of light into hole in compact disc on front of aquarium.
11. While the teacher aims light beam from slide projector, a student should use the dark paper to find the bright center of the beam that emerges from the back of the aquarium.
12. When the position of this beam is found along the meter stick on the back of the bench, a sticky note should be placed on the lab bench at this position. Care should be taken to match position notations on each sticky note with the actual projector position that created the output beam position.
13. Turn off slide projector.
14. Move slide projector to next marked position along the front of the lab bench, and repeat Steps 9 through 13.
15. Repeat Step 14 until every marked position on the front of the lab bench has a corresponding sticky note along the back of the bench.
16. Students should use the second meter stick to note the output beam positions in terms of their corresponding slide projector positions. A chart might look like:
17. Students should use their accurate drawing of the setup to analyze how light was bent in the water. The drawing should be to scale, and a line (the “normal”) should be drawn perpendicular to the front and back of the aquarium, through the taped compact disc position.

a. Starting from one projector position, the student then draws a line to the center of the taped compact disc on the front of the aquarium in the drawing.

b. The student then constructs a line, parallel to the first, which extends from the beam endpoint to the back of the aquarium.

c. A line connecting these points on the front and the back of the aquarium will make a smaller angle with the normal than the exterior beamlines do.

d. Students then use geometry to accurately estimate each angle made by interior and exterior beamlines with the normal.

e. Plotting the sine of one angle against the other for several points will show a linear relationship between these data.

f. The slope of a line through the data will allow estimation of the index of refraction of water.
Analysis and Conclusions

1. What was the path of the light beam from the projector?
   Sample Response: We found that if the light beam entered the aquarium at an angle, the beam would be bent toward an imaginary line running straight through the aquarium. Upon emerging from the aquarium, the light would be bent back to its original angle.

2. Why do you think compact discs were used on the slide projector and the aquarium, and why did you have to use dark paper to find the bright center of the beam?
   Sample Response: Light diffuses in water, and the compact discs were used to produce a tight beam of light from the projector. Even this diffused, and so we had to find the output beam’s bright center. We used the dark paper to provide contrast to surroundings.

3. Was there any position of the slide projector for which an output beam did not emerge from the aquarium? If there was, what was this position, and why did an output beam not emerge?
   Sample Response: Any light beam that is incident on water or other translucent substance is both reflected and refracted by the material. If an incident beam is at too high an angle to a normal through the material, the beam is only internally reflected in it, and not refracted.

4. Why was it important for you to draw an accurate layout of the lab setup?
   Sample Response: The beam was bent in the water, and unbent when it emerged from the water. We used our accurate drawing to estimate the bent light path in the water. A ratio of the sines of the angles involved gave us an estimate of the index of refraction of water, about four-thirde, or 1.3.

5. If you repeated this lab with an empty aquarium, would you be able to figure out the index of refraction of the glass? Why or why not?
   Sample Response: The beam would bend from passing through the glass, but because the walls of the aquarium are thin, the path of the light would not change enough for us to be able to estimate the index of refraction of glass.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design or conduct field studies using:
    - Survey – collects multiple data points at one point in time.
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable – the one the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable.
  - Practice lab safety by:
    - Following lab safety procedures.

- **Gather Data**
  - Use Tools and/or the Use SI (metric) system) to accurately measure:
    - Length
  - Uses Senses to Observe:
    - Seeing (color, shape, size, texture, motion)
  - Chooses appropriate tools to conduct an investigation
    - Ruler/tape measure
  - Uses the appropriate format to record data:
    - Table
    - Graph or chart

- **Patterns and Systems**
  - Patterns and change:
    - Some small changes can be recorded by making measurements
    - Many patterns in nature contain symmetry
Hands-On Lab
The Law of Reflection

Timing: one 90-minute class session

Objective(s):
Students will investigate the relationship between the angle of incidence and reflection when a beam of light reflects from a mirror. They will shine a shrouded minilamp, i.e., a small socketed bulb, at a mirror and design a method of measuring the angles of incidence and reflection when the beam is directed on a mirror from different angles. Students will draw a conclusion about how light reflects off mirrors, and they will also evaluate the design of their experiment.

Safety Precautions:
Caution students not to shine lights or laser pointers directly into the eyes of another person. Some students may have allergies to chalk dust, so it may be wise to propose alternate materials (such as baby powder) if students wish to use a powder to observe the path of light. To control reflections of the laser pointer beam, have students hold the white paper near the mirror, so the reflected beam hits the paper with only enough distance to identify the direction of the reflected beam.

Materials:
Per group:
- 1 minilamp in a socket, loosely covered with duct tape with a small slit
- 1 plane mirror
- 5 sheets of drawing or chart paper (or more)
- 1 piece white paper
- protractor
- laser pointer
- ruler

Teacher Preparation:
Prepare a copy of the Student Investigation Sheet for all students. Create circuits of batteries and minilamps, loosely shroud the minilamp in duct tape, and cut a small slit to create a beam. Test all shrouded minilamps to ensure that the beams are strong and visible in a dark room. Replace any old batteries, if necessary.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
1. Divide students into groups and distribute materials. Review with students the definitions of incident and reflected angles when light reflects from a mirror. (Be sure to define the term “normal line.”) Explain to students that they will investigate the relationship between the incident and reflected angles of light when it strikes a mirror.
2. Ask students to develop a hypothesis for the investigation. For example, do students believe that the incident angle of light is equal to, less than, or greater than the reflected angle of light? Allow students the opportunity to experiment briefly with the flashlights and mirrors when formulating their hypotheses. Caution students not to shine light directly into another person’s eyes.
3. Once groups have formulated a hypothesis, have them set up the experiment. Have students first place chart paper flat on the floor (or a table). Then, have students place the base of the mirror on top of the chart paper so that it stands up vertically. Then, have students in each group hold the minilamp, mirror, and white paper so that the light strikes the mirror and reflects onto the paper. It may help to dim the lights so that students can observe the path of the beam more clearly. This system should be set up so that the entire path of the light travels over the chart paper below it.
4. When the minilamp/mirror system is set up, have students sketch on the chart paper the path of the beam from the minilamp to the mirror to the white paper. They should also be sure to draw the location of the mirror on the chart paper.
5. Once the light path is sketched, students can turn off the minilamp and put the mirror and white paper aside. They should use the ruler and protractor to draw in the normal line to the mirror. Students should use the protractor to determine the angle of incidence and angle of reflection. Students should record these data in a chart.
6. Have students repeat steps 3–5, though in each case they should change the angle at which
the light strikes the mirror. Students can choose to sketch the paths of each test on the same chart paper (using different colored pens or pencils). Alternatively, they can use a separate sheet each time. A sample data chart with sample data is provided:

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Angle of Incidence (degrees)</th>
<th>Angle of Reflection (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>4</td>
<td>66</td>
<td>66</td>
</tr>
<tr>
<td>5</td>
<td>79</td>
<td>78</td>
</tr>
</tbody>
</table>

7. Repeat Steps 1-6 using a laser pointer instead of a minilamp. Control the reflection from the mirror by initially holding the white paper near the mirror when the laser pointer is pointed at the mirror and activated. Once the reflected beam hits the paper, students should back the paper away only so far as to be able to identify the direction of the reflected beam.

Guided Inquiry
Students will develop their own experiment to investigate the relationship between the angle of incidence and the angle of reflection. Ask the students some guiding questions to help them focus their inquiry:

- What do you think is the relationship between the angle of incidence and the angle of reflection?
- How will you arrange the minilamp and mirror?
- How will you observe and measure the incident and reflected angle of the light? What measuring tools will you use?
- What variables will you control and change in the experiment?
- What will you do to ensure that you can observe the path of the light?
1. Divide students into groups but keep all materials located in a central area of the classroom. Review with students the definitions of angle of incidence, angle of reflection, and normal line.
2. Then, demonstrate to students that a minilamp and mirror can be used to analyze the angles at which a beam reflects. Show students that when the lights are on, the beam path is not easily observed. However, the beam path can be observed better when the lights are dimmed.
3. Explain to students that they can use any combination of the materials provided to observe and measure the angles at which the light strikes and reflects off the mirror. Allow students to obtain different materials and experiment with different techniques for observing and measuring the beam path.
4. Once students have experimented briefly with the materials, have them develop a set of procedures that they will follow. Students should also develop a data table that will be used to collect measured values. It is a good idea to approve these procedures for each group before allowing them to proceed.
5. Allow students to carry out their investigations. Be sure to offer assistance to any groups that are struggling. Refer to the Directed Inquiry option for a sample procedure, data table, and sample data.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How did the angle of incidence compare to the angle of reflection in each test? Was your hypothesis correct?
   **Sample Response:** The angles of incidence and reflection were very similar, and in most cases equal to one another. My hypothesis was correct.

2. The law of reflection relates the angle of incidence and the angle of reflection of a wave that reflects off a flat surface. Based on the results of this experiment, what do you think the law of reflection states?
   **Sample Response:** When light waves reflect off a flat mirror, the angle of incidence is congruent to the angle of reflection.

3. What problems did you encounter when trying to measure the angles of incidence and reflection?
   **Sample Response:** It was difficult to hold the beam still while sketching the path of the beam. Also, it was not easy to vary the angle of incidence in a systematic way; it was rather random.

4. How could you make modifications to this experiment to reduce any problems that you encountered?
   **Sample Response:** I could modify the experiment by creating a stable surface, such as a tripod, to hold the minilamp. This way the beam path would remain still, and the light angle could be turned and modified more easily.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if–then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
    - Independent variable—the one variable the investigator chooses to change
    - Dependent variables—what changes as a result of, or in response to, the change in the independent variable
    - Constant—identify variables that must remain unchanged
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist

- **Gather Data**
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape measure
    - Mirrors
  - Use the appropriate format to record data:
    - Table
    - Chart

- **Interpret Data**
  - Identify and interpret patterns using:
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
- Comparing results to hypothesis
- Answering the testable question
- Examining how investigations can be improved
- Formulating scientific explanations/arguments

- Communication in Science
  - Report results using:
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
Exploration Teacher Guide: Mirrors and Lenses

Overview

Mirrors and lenses are used to study properties of light. Understanding how images are formed using a mirror or a lens can expand their application. Some common applications of mirrors and lenses are microscopes, telescopes, and periscopes. In this Exploration, students analyze the nature of the images formed using a mirror or a lens by varying parameters like object distance and object size. Students also understand the formation of ray diagrams for mirrors and lenses.

Student Learning Objectives

- Observe the formation of images by a mirror and a lens.
- Understand how distance from a mirror/lens affects the nature of the image.
- Examine the effect of focal length of a mirror/lens on the type of image formed.
- Learn the sign conventions used to draw a ray diagram.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students use the radio button options to observe the formation of an image using a mirror or a lens in the setup. An Experiment View section is shown along with a Ray Diagram section. Students select the type of mirror (plane, convex, or concave) or lens (convex or concave) using the options in the Select Type dropdown list. They then select the focal length of the selected type of mirror or lens using the options in the Select Focal Length dropdown list. The focal length of a plane mirror cannot be selected. Students select the height of the object using the options in the Select Object Size dropdown list and the object's distance from the mirror or lens using the options in the Select Object Distance dropdown list. They use the Start button to observe the formation of the image for the selected set of values.

Students may use the Reset button to examine the formation of an image for different selections.

The Tracker tab displays a summary of all the previous runs. Students use the options in the Select Setup dropdown list to view the data for the mirrors and lenses they have observed in the Explore tab. Students also observe the images formed and the ray diagram for each case.
Answers to Questions in the Student Worksheet

1. Explain the difference between mirrors and lenses.

   **Answer:** Images formed by mirrors are because of the rays of light reflecting from its surface. On the contrary, a lens forms the images by refracting the rays of light.

2. Explain the difference between real and virtual images.

   **Answer:** Real images are those images that can be projected or captured on a screen. Virtual images can be observed, but these images cannot be projected or captured on a screen.

3. Explain why a convex lens is also known as a converging lens and a concave lens is known as a diverging lens.

   **Answer:** A convex lens is also called a converging lens because all the rays of light parallel to the principal axis get refracted at the surface of the lens and converge on its other side at the focus.

   In case of a concave lens, the rays of light also get refracted from the surface of the lens. The rays of light parallel to the principal axis appear to diverge from the focus on the same side.

4. List down the rays that may be used to draw a ray diagram.

   **Answer:** Three different rays can be used to determine the position and the size of an image formed. These three rays include
   a. The ray parallel to the principal axis which is reflected / refracted to pass through the focus.
   b. A ray passing through the focal point which is reflected / refracted to pass as a line parallel to the principal axis.
   c. A ray passing through the center and emerging undeviated on the other side in the case of lenses and reflects at an equal angle in the case of mirrors.

5. A car driver sees an image of a car behind him in a convex rear-view mirror. The focal length of the mirror is 1.2 m. The height of the car is 1.5 m and its distance from the mirror is 6.0 m. Determine the size of the image of the car formed.

   **Answer:**
   
   Focal length \((f) = -1.2\) m
   Height of the car = height of the object \((o) = 1.5\) m
   Distance of the car from the mirror = distance of the object \((u) = 6.0\) m
\[ \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \]
\[ \frac{1}{-1.2} = \frac{1}{6.0} + \frac{1}{v} \]
\[ \frac{1}{v} = -1 \]
\[ v = -1 = -1.0 \text{ m} \]

The distance of the image from the mirror is 1.0 m

Size of the object can be calculated using the following formula

\[ \frac{v}{u} = -\frac{i}{o} \]
\[ -\frac{1}{6} = -\frac{i}{1.5} \]
\[ i = 0.25 \text{ m} \]

The size of the image is 0.25 m and the positive sign indicate that the image is virtual.

6. Explain why, when a magnifying glass is held over a paper in sunlight, the paper catches fire. Also, mention the distance at which the paper should be placed from the magnifying glass for this to happen.

**Answer:** The focal length of a magnifying glass is the distance at which all the rays of light converge. If the magnifying glass is held at this distance from the paper, the rays of light will converge at the surface of the paper. Due to the heat produced because of all the rays meeting at one point, the paper catches fire.

7. Explain the formation of images by mirrors using a real world example.

**Answer:** A metallic spoon can be used to explain the formation of images by a mirror. The side of the spoon that is curved outside acts as a convex mirror. This side forms erect and magnified images. The other side, which is the side that is curved inside acts as the convex mirror. This side forms diminished and inverted images.

8. Determine if the following statements are true or false. If a statement is false, correct it so that it is true

   a. If an object is placed at 2F in front of a convex lens the size of the image formed is twice the size of the object.

   **Answer:**
   a. False. If an object is placed at 2F in front of a convex lens the size of the image formed is equal to the size of the object.

   b. The point from which the rays appear to diverge in a concave lens is known as the focus.

   **Answer:**
   b. True.
9. An object of is placed at a distance of 20 cm in front of a convex lens of focal length 10 cm. Describe the nature of the image formed.

**Answer:**
Focal length (f) = 10 cm  
Distance of the object (o) = 20 cm  

\[ \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \]
\[ \frac{1}{10} = \frac{1}{20} + \frac{1}{v} \]
\[ \frac{1}{v} = \frac{1}{20} \]
\[ v = 20 \text{ cm} \]

The distance of the image from the lens is 20 cm.

Size of the object can be calculated using the following formula
\[ \frac{v}{u} = -\frac{i}{o} \]
\[ \frac{20}{20} = -\frac{i}{20} \]
\[ i = -o \]

The size of the image is equal to the size of the object and the negative side indicates that the image is inverted.

10. The radius of a convex mirror is 30 cm. Calculate the distance at which the image is formed if the object is placed at 22 cm. (Hint: focal length = half of the radius of the mirror)

**Answer:**
Since the focal length = half of the radius of the mirror  
Focal length = \( \frac{30}{2} = 15 \text{ cm} \)

\[ \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \]
\[ \frac{1}{15} = \frac{1}{22} + \frac{1}{v} \]
\[ \frac{1}{v} = \frac{7}{330} \]
\[ v = 47.14 \text{ cm} = 47 \text{ cm} \]

The distance at which the image is formed is 47 cm.
Hands-On Lab
Build a Seismograph

Timing: one 90-minute class session

Objective(s):
Students will design and build a seismograph.

Safety Precautions:
Offer safety reminders to students relevant to the modeling materials they are working with. For example, if using wire cutters, pliers, scissors, cutting knives, hammers, staple guns, or screwdrivers, review instructions for proper use and safety procedures. When working with any of these tools, students should wear lab aprons and eye protection.

Materials:
Per small group:
- A selection of building materials and fasteners suitable for constructing seismograph frame, such as:
  - Thin pine boards
  - Sturdy cardboard boxes
  - Balsa wood
  - Dowels
- A selection of building materials and fasteners suitable for constructing weighted pen holder, such as:
  - 3- to 5-in. metal springs
  - String or twine
  - Hooks
  - Sturdy plastic cups and pebbles
  - Heavy washers
  - 100- to 500-gm masses
- Cutting and fastening tools appropriate to the choice of materials (e.g., screws and screwdrivers; heavy-duty staples and staple gun; hammers and brads or nails; scissors or cutting knives; duct tape or wood glue)
- Fresh felt-tip pens or soft charcoal pencils
- Paper roll

Teacher Preparation:
Before the lab, gather supplies sufficient for each group to have a choice of materials suitable for building a working seismograph. To estimate material needs, consider the approximate sizes of the boxes or frames necessary to accommodate the paper rolls. If materials are in short supply, you may wish to limit the sizes of the seismographs. For example, for an 11-in. paper roll, a limit of 2 ft. × 2 ft. × 2 ft. should be more than sufficient for student designs.
Prepare a copy of the Student Investigation Sheet for each student.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Regardless of which level of inquiry students follow, divide the class into groups of about 5 students each. Explain that the goal of the lab is to design and build a working seismograph that is capable of recording shaking and distinguishing the strength of shaking. Encourage students to think of the seismograph as a system. A system is made up of interacting parts, each of which performs a certain task relevant to the function of the whole.

**Directed Inquiry**
Lead the class through the design process. Begin by brainstorming a list of design requirements. To elicit students’ ideas, ask questions such as:

- What does the seismograph need to do? *(It must record shaking and distinguish between different strengths of shaking.)*
- What parts will be needed in order for the seismograph to perform its task? *(A seismograph requires a writing instrument that moves freely in response to shaking; paper that moves under the writing instrument; and a frame that holds the writing instrument.)*
- What function does each part need to perform? *(The writing instrument needs to touch the paper firmly enough to record markings of its motion on the paper; this may require students to weight the instrument. The material that holds the writing instrument needs to move back and forth freely in response to shaking; the paper needs to be able to move freely beneath the writing instrument; the frame needs to support the whole apparatus while allowing the paper room to move freely beneath the writing instrument.)*
What limitations do we need to place on the design? (*We are limited by the available materials. Also, our seismographs must function in classroom conditions, and they must be safe to operate.*)

Guide discussion toward a group consensus on a list of design requirements, and write the list on the board; if some groups want to include additional requirements for their designs, they may do so.

Explain that the next step in the design process is figuring out how to design each part of the system to meet the requirements. The product of this step is a plan for a preliminary design. Have students work in their groups to come up with their preliminary designs. At this stage, distribute the available materials to each group. Students may explore the properties of the different materials for ideas, but they should not build anything yet. Remind students that in the design process, planning precedes building a prototype. For their plans, students should draw detailed designs of the whole seismograph, along with close-ups of parts as necessary to convey their ideas. As students plan, circulate from group to group to answer questions and clarify misconceptions. If time restrictions necessitate, you may wish to assign this part of the lab for homework.

After groups have completed their preliminary designs, pair each group with another group. Instruct each group to present its design to its partner group, and instruct each partner group to provide feedback in the form of aspects of the design they like and aspects of the design that could be improved. Groups should justify their feedback with specific reasons and explanations. Then as a class, instruct each group to identify the most helpful piece of feedback it received from its partner group. Then, have students work in their groups to incorporate feedback and produce a final design and materials list. As part of their final designs, students should:

- Write a list of safety procedures they will follow while constructing their prototypes.
- Outline a plan to test their designs. Emphasize that the test must demonstrate that the seismograph accomplishes its two main goals:
  - Record shaking
  - Distinguish between different strengths of shaking

Have groups bring you their final designs and plans for approval. Once you approve a group’s design, allow its members to use the available materials to construct its prototype. As groups work, circulate around the classroom offering building tips and checking for safety awareness.

When a group completes its prototype, have its members test its seismograph as outlined in its plan. Instruct students to make adjustments to their prototypes as necessary and to record any changes to their design on their original plans. Instruct groups to write a conclusion about whether or not their prototypes were successful, citing evidence and data from their tests.
Finally, have group members share their prototypes, test results, and conclusions with the class. Instruct classmates to offer feedback as to whether a group’s conclusions are sufficiently supported by results and to make suggestions for improving designs.

Guided Inquiry
Groups can develop their own plans for approaching the task of designing, building, and testing their prototypes. You may also allow them to bring in their own (approved) materials from home; if you do this, however, you will need to break this activity into two class sessions so that students have an opportunity to plan their designs in the first session and to build their designs, based on their chosen materials, in the second session. Ask the students some guiding questions to help them focus their planning:

- What steps are part of the engineering design process?
- How can you apply each step to the design of a seismograph?
- What materials can you use for each part of your seismograph, and how will you assemble these materials?
- How will you know whether your seismograph is capable of performing its two main functions of recording shaking and distinguishing between different strengths of shaking?
- How will you test your seismograph in the classroom?
- How will you stay safe while building and operating your seismograph?

Have students bring their designs and plans to you for final approval. Once you approve designs, distribute the necessary materials and have students construct their prototypes. When students are building their seismographs, circulate around the classroom offering building tips and checking for safety awareness.

After students have planned, constructed, and tested their prototypes, have groups write a conclusion about whether or not their prototypes were successful, citing evidence and data from their tests. Each group should share its prototype, test results, and conclusions with the class. Instruct classmates to offer feedback as to whether a group’s conclusions are sufficiently supported by results and to make suggestions for improving designs.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Why is it important to develop a clear list of requirements before beginning a design? Sample response: It is important to know what each of the parts of the design must do in order to start thinking about how to design each part. It is important to know what the limitations are so you don’t design something that can’t be built.
2. Did getting feedback at the preliminary design phase help you to improve your design or construction methods? Explain. Students’ responses will vary.

3. Did you encounter any surprises when you tried to build a 3-dimensional prototype from your 2-dimensional plan? Did you need to change any part of your design as you were building your prototype? Sample answers: Yes, when we weighted the spring it hung lower than we thought it would, which made the pen stick to the paper too much. We had to make the legs of our stand a little longer so the whole frame was raised up, lifting the pen enough so it would swing freely.
Inquiry and Nature of Science Skills in this Lab:

- Design and conduct investigations using:
  - Fair test - changing only one variable at a time makes comparisons valid
  - Independent variable - the one variable the investigator chooses to change
  - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
  - Constant - identify variables that must remain unchanged in
  - Multiple trials - repeated tests with the same variables to check for variability of results

- Make or use models that:
  - Simulate a real thing that cannot easily be studied or manipulated
  - Have as many details as possible replicated from the real thing
  - Function exactly like or similarly to the real thing
  - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
  - Apply mathematical operations and principles to replicate the real thing
  - Have been revised as new knowledge and information has been obtained
  - Are based on logic and evidence

- Explain the investigative processes by:
  - Describing the logical sequence that was used to conduct the investigation
  - Properly citing all equipment and materials
  - Describing it so that it can be easily repeated by a fellow scientist

- Practice lab safety by:
  - Following lab safety procedures
  - Recognizing safety equipment and materials and knowing their proper use
  - Incorporating laboratory safety practices into the investigation design

Gather Data

- Use tools and the SI (metric) system to accurately measure:
  - Length/distance/depth

- Choose appropriate tools to conduct an investigation:
  - Other Laboratory equipment

- Use senses to observe:
  - Seeing (shape, motion)
  - Touching (vibration, motion)
  - Kinesthetic (position)

- Use the appropriate format to record data:
  - Writing
  - Sketch
  - Diagram
Interpret Data
  o Identify and interpret patterns using:
    ▪ Trends in data
    ▪ Repeating physical or data patterns
    ▪ Analysis of data collected during an investigation

Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Using data to determine the cause-effect relationship observed in the investigation
    ▪ Reporting trends and patterns in the data
    ▪ Identifying alternative explanations
    ▪ Examining how investigations can be improved
    ▪ Formulating scientific explanations/arguments
    ▪ Explaining how technology can be used to enhance the investigation
    ▪ Showing the application of the scientific concept or process being investigated

Communication in Science
  o Report results using:
    ▪ Peer presentation
    ▪ Scientific illustration with proper labeling
    ▪ Scientific explanations/arguments

Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
    ▪ Evaluating a conclusion
    ▪ Identifying alternative explanations
    ▪ Analyzing scientific explanations
    ▪ Analyzing scientific arguments

Patterns and Systems
  o Patterns and Change:
    ▪ Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    ▪ Some small changes can be detected by taking measurements.
    ▪ Things that change may do so in steady, repetitive or irregular ways.
  o Systems:
    ▪ A system, such as the human body, is composed of subsystems.
    ▪ A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
• In some systems, it may not always be possible to predict accurately the result of changing some part or connection.

• Scientific Investigation
  o Scientific Data and Outcomes:
    ▪ People are more likely to believe ideas if good reasons are given for them.
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
    ▪ It is important in science to keep honest, clear, and accurate records.
    ▪ Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientists are curious about wanting to know how things work.
    ▪ Scientific claims can be substantiated using data and observation.
    ▪ An important part of science is the critical review and analysis of any idea or conclusion.

• Engineering and Technology
  o Uses of Technology:
    ▪ An invention can be used in different ways, such as a radio being used to get information and for entertainment.
    ▪ Technology extends the ability of people to make positive and/or negative changes in the world.
    ▪ Each part of a mechanical device contributes to the purpose of that device.
    ▪ Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.
    ▪ Any invention may lead to other inventions.
    ▪ Human beings have made tools and machines, such as x-rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
    ▪ Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
    ▪ Even a good design may fail even though steps are taken ahead of time to reduce the likelihood of failure.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

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How to Use the Data/Graph Tool

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Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Activity
Model Seismic Waves

Objective:
Students will use a spring toy to model P waves, S waves, and surface waves.

Estimated time to complete: 20 minutes

Materials:
For each student pair:
• A large spring toy (Slinky™ or similar)
• About 24 square feet (6 ft. × 4 ft.) of open table space

Procedure:
Have students work in pairs. If table space is limited, consider setting up this activity as a station that students rotate through.

Instruct students to stand about 6 ft. apart holding opposite ends of the spring toy. The spring should be stretched so that it does not dip low in the center, but caution students not to stretch the spring so far that it deforms. First, instruct students to use the spring to model compressional waves; allow partners to experiment without describing for them the correct process. (To model a compressional wave, one student should give a quick inward push on the end of the spring in the direction of the other student. A compressional wave should visibly travel along the length of the spring. If students cannot see such a wave, they may need to increase the force of the push, though not to the point at which they may injure each other. Laying the spring on the table may also help.) Encourage students to verbalize their observations of how the wave travels along the spring. Point out that the wave does not carry matter from one end of the spring to the other. The spring coils move only back and forth as energy travels from one end to the other.

Then, instruct students to identify the seismic waves that move in this way. (Students should note that P waves are compressional waves, as are certain surface waves.)

Next, instruct students to stand away from the table, about 6 ft. apart from each other, and use the spring toy to model transverse waves. Again, allow partners to experiment without describing for them the correct process. (To model a transverse wave, one student should gently shake the spring from side to side or up and down.) Encourage students to verbalize their observations of how the wave travels along the spring. Point out that the wave does not carry matter from one end of the spring to the other. The spring moves only side to side (or up and down) as energy travels from one end to the other. Next, have students change the plane of their transverse waves (i.e., if they were shaking their spring up and down, they should now shake it side to side, and vice versa).
Then, instruct students to identify the seismic waves that move in this way. (Students should note that S waves are transverse waves, as are certain surface waves.)

Remind students that seismic waves can travel in different planes as they propagate through Earth’s interior. Encourage students to investigate modeling waves—both transverse and compressional—in a variety of planes, including diagonals.

Finally, remind students that surface waves have longer wavelengths than P or S waves. Encourage students to experiment with the spring to figure out how to model long wavelengths. (The student shaking the spring side to side will need to move the spring more slowly—i.e., decrease the frequency of the wave. Students should do this carefully to avoid injuring each other.)

Ask the following questions to help guide students’ observations and make connections between the models and the propagation of actual seismic waves:

- **How does a compressional wave travel along the spring? How is this like a P wave traveling through the body of Earth?**
- **How does a transverse wave travel along the spring? How is this like an S wave traveling through the body of Earth?**
- **What do you have to do in order to increase the wavelength of a transverse wave? What does this indicate about surface waves?**

After each pair has had a chance to model all of the waves, bring the class back together for a concluding discussion. Ask the following questions to help students reflect on the use of models to represent seismic waves:

- **Why is it useful to study seismic waves with spring models? How was the modeling experience different than reading about seismic waves or looking at diagrams?**
- **What are some of the limitations of the spring models? In what ways are the models different than actual seismic waves?**
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
    - Are based on logic and evidence

- **Gather Data**
  - Use senses to observe:
    - Seeing (motion)
    - Touching (motion)
    - Kinesthetic (position)

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Extrapolating results beyond the investigation
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated
Use your knowledge of earthquake magnitude to solve the problems below.

1. Calculate the difference in energy released by a magnitude 5 earthquake and a magnitude 7 earthquake.
   [answer: A magnitude 7 earthquake releases about 900 times more energy than a magnitude 5 earthquake.]

2. Earthquake A has a magnitude of 3. What magnitude earthquake would release 810,000 times more energy than earthquake A?
   [answer: A magnitude 7 earthquake releases about 810,000 times more energy than a magnitude 3 earthquake.]

3. Joules are a unit of energy. Because earthquakes result from a sudden release of energy in Earth’s crust, the amount of energy released by an earthquake can be estimated based on the magnitude of the earthquake. An earthquake with a magnitude of 1 releases about $1.99526 \times 10^6$ joules of energy. Approximately how many joules of energy does a magnitude 4 earthquake release? Write your answer in scientific notation. (Hint: Each whole number increase in magnitude on the Richter scale represents an increase of about how many times more energy?)
   [answer: A magnitude 4 earthquake releases about $5.3872 \times 10^{10}$ Joules of energy.]

4. What magnitude earthquake releases approximately 50 trillion joules of energy?
   [answer: a magnitude 6 earthquake]
Overview

In this Exploration, students will learn about the types of seismic waves and how they provide evidence for Earth's interior structure. Students will also investigate how seismograms are generated and how they can be used to interpret the features of an earthquake.

Student Learning Objectives

- Learn about the types of seismic waves.
- Observe and understand the propagation of seismic waves through Earth’s interior.
- Examine the record of seismic waves in a seismogram.
- Interpret the features of an earthquake, including magnitude, from a seismogram.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Apparatus tab, students select the Seismometer radio button to learn about the features and operation of the seismometer and about how it generates a seismogram. Students select the Seismogram radio button to view a seismogram with an example earthquake trace.

In the Explore tab, students use the radio button options in the Select Seismic Wave section to select the type of seismic waves they want to examine. Students use the Select Magnitude radio button options to select the magnitude of the earthquake and then use the Record button to observe the propagation of the selected seismic waves through Earth’s layers. Students examine the seismograms recorded at all four stations in the Seismogram panel. They can use the Reset button to select other seismic waves.

In the Compare tab, students select a seismogram from the two options in the Select Seismogram section. For the selected seismogram, they may use the Select Time slider to indicate the time interval from the beginning of the trace to the arrival of the maximum amplitude wave. The Select Time slider automatically updates the distance of the station from the epicenter indicated on an adjacent scale. They use the Select Amplitude slider to indicate the maximum amplitude of the S waves. Students then use the Interpret button to validate the arrival time and amplitude. After they have correctly identified the time and amplitude, the earthquake magnitude is displayed. Students can repeat the same procedure for the other seismogram.

Students may use the Reset button to start again with the same set of seismograms. After correctly identifying the time and amplitude for both seismograms, students the Proceed button to compare the energies released by the earthquakes.
Students can use the Start Over button to analyze additional pairs of seismograms.

**Answers to Questions in the Student Worksheet**

1. Explain the term seismic waves.

   **Answer:** Seismic waves result from elastic strain energy that is released during an earthquake. These are responsible for the ground movements associated with an earthquake.

2. Compare and contrast P and S waves.

   **Answer:** P waves are the fastest seismic waves while S waves are the slowest seismic waves. The velocity of P wave is about 8 kilometers per second while the velocity of S wave is about 5 kilometers per second. P waves propagate through solids and liquids while S waves propagate only through solids. In P waves, the particles of the medium alternately compress and expand, and move parallel to the direction in which the wave propagates. In S waves, the particles of the medium have alternate transverse motions and move perpendicular to the direction in which the wave propagates.

3. Explain how a seismometer records ground movements caused by seismic waves, during an earthquake.

   **Answer:** A seismometer consists of a heavy weight suspended from a frame. The frame’s base is set in the ground. A pen is attached to the heavy weight. The pen’s movement is recorded on a rotating paper drum on the base. During an earthquake, seismic waves cause ground movement, which makes the frame vibrate. However, the suspended heavy weight remains stationary due to its inertia. The pen attached to the stationary heavy weight records relative motion between the heavy weight and the ground on the rotating paper drum.

4. In the Exploration, select P and S waves in the Select Seismic Waves section and low in Select Magnitude section. Observe and explain the seismogram’s recording at station 4.

   **Answer:** The seismogram at station 4 shows record of P waves but not of S waves. P waves can propagate through both solids and liquids while S waves propagate through solids only. The outer core of Earth is in a liquid state. Only P waves can propagate through the outer core and reach station 4.

5. Compare and contrast the particle motion caused by Love and Rayleigh waves.

   **Answer:** In a Love wave, the particles of the medium move horizontally and perpendicular to the direction of wave propagation. In a Rayleigh wave, particles of the medium move elliptically in the vertical plane and move parallel to the direction of wave propagation.
6. Explain the term shadow zones.

   **Answer:** Zones in which no seismic body waves can be detected for a particular earthquake are called shadow zones.

7. Identify the parameters used to calculate the magnitude of an earthquake. Name the scale on which earthquake magnitude is measured.

   **Answer:** Magnitude of an earthquake is calculated from the arrival time and the amplitude of the largest seismic wave. Magnitude is measured on the Richter scale, which is a logarithmic scale.

8. Calculate the approximate time taken for a P wave to reach a point A, which is 320 km away from the epicenter.

   **Answer:**
   
   \[
   \text{Time} = \frac{\text{Distance}}{\text{Velocity}} \\
   \text{Distance} = 320 \text{ km} \\
   \text{Velocity} = 8 \text{ km/s} \\
   \text{Time} = \frac{320 \text{ km}}{8 \text{ km/sec}} = 40 \text{ s}
   \]

   The time taken by the P wave to reach point A is approximately 40 seconds.

9. Compare the energy released by an earthquake of magnitude 7.3 with that of an earthquake of magnitude 5.9.

   **Answer:** The energy released by an earthquake of magnitude 7.3 is \(10^{7.3}\). The energy released by an earthquake of magnitude 5.9 is \(10^{5.9}\). The energy released by the two magnitudes can be compared by finding their ratio.

   \[
   \frac{10^{7.3}}{10^{5.9}} = 10^{7.3 - 5.9} = 25.12 \approx 25
   \]

   The energy released by a 7.3 magnitude earthquake is 25 times greater than a 5.9 magnitude earthquake.
10. Determine the magnitude of the earthquake using the data and the image given below:

**Data**
Earthquake a. Distance: 20 km, Amplitude: 2 mm
Earthquake b. Distance: 100 km, Amplitude: 1 mm

**Answer:**
Earthquake a. Magnitude: 2
Earthquake b. Magnitude: 3
Exploration Teacher Guide: Causes of Earthquakes

Overview

Strain, caused by stress, is the deformation, or change in an object's size or shape. In this Exploration, students examine how stress and strain are related. Students examine the types of faults formed due to stress and then relate faulting and earthquakes to plate tectonics. Students will also examine the world map that shows the earthquakes along plate boundaries associated with different types of stress.

Student Learning Objectives

- Examine the relationship between stress and strain.
- Examine the types of faults formed due to different types of stress.
- Examine the types of stress associated with different types of plate boundaries.
- Examine the locations of some faults and earthquakes on the world map.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students first match the text cards for the three different types of stress with the corresponding picture cards showing illustrations of strain. They can do this by clicking on a text card and then clicking on a picture card to pair stress with its strain. Students may use the Reset button at any time in the Exploration to undo what they have done. Students may also use the Start Over button to begin over. After all the cards are matched correctly, students use the Proceed button to go to Step 2 and examine the effects of different types of stresses.

In the second step, students select a type of stress from the radio button options in the Apply Stress section and then select the type of fault from the Select Fault section. Students then use the Trigger button to observe the type of fault formed due to the selected applied stress and how the energy released at the focus travels to Earth's surface. Students may use the View Location button to see an example of this type of fault. The Reset button can be used to select another type of stress. The Start Over button can be used to go back and pair a new set of cards.

In the Boundaries tab, students investigate the world map to examine earthquakes caused by compression, tension, and shear stress. These are color-coded. Students may use the Interactive Key buttons to hide or unhide locations of earthquakes associated with the different types of stress along plate boundaries on the map. They roll over different parts of the map to view locations of some significant fault systems and earthquakes. Alternately, they can use the View All button to examine all marked locations of faults and earthquakes. After examining the
map and the locations, students use the Proceed button to view an animation of plate tectonic movements. After viewing the animation, they use the radio button options to identify the stress with the plate movement associated and type of faulting that will form.

**Answers to Questions in the Student Worksheet**

1. Define the terms stress and strain. Explain how they are related.

   **Answer:** The force per unit area acting on a body is called stress. The deformation of a body’s size or shape, caused by stress, is called strain. Strain is the outcome or the effect of stress on a body.

2. Infer the type of stress that has caused changes in the original shape of the object given below.

   **Answer:**

   ![Diagram of original and deformed shapes with labels for tension stress and compression stress.](image-url)

   - Tension Stress
   - Tension Stress
   - Compression Stress
3. Compare and contrast normal and reverse faults.

**Answer:** Normal fault is formed due to tension stress while reverse fault is formed due to compression stress. In a normal fault, the hanging wall falls down relative to the footwall. In a reverse fault, the hanging wall is thrown up relative to the footwall.

4. In the Exploration, select the *Shear* radio button option in the *Apply Stress* section and then click *Trigger* button. Observe and explain what happens.

**Answer:** Strike-slip fault is formed due to shear stress. The displacement of the crustal blocks occurs along the strike of the fault plane.

5. Identify the type of fault and the type of stress that has caused the offset of strata in the image below. Label the hanging wall, foot wall, and the direction of movement. What could have caused the stress that formed the fault?

**Answer:** The strata are offset along a normal fault, which was caused by tension stress. This stress could have been a result of plate movements.
6. Define the terms focus and epicenter.

   **Answer:** The focus is the point within Earth from where the energy is released radially outward during an earthquake. The focus is where the rocks start to break and slip against each other. The epicenter is the point on Earth’s surface which is directly above the focus, often where the most destruction during can occur.

7. Describe the types of stress associated with each of the three types of plate boundaries. What types of earthquake movements and faults do you expect at these boundaries?

   **Answer:** Movements along plate boundaries are caused by stress. The movement of plates toward each other associated with convergent plate boundaries is associated with compressive stress. The movement of plates away from each other associated with divergent plate boundaries is associated with tension stress. The movement of plates past each other in a horizontal direction associated along transform plate boundaries is associated with shear stress. We would expect to find reverse or thrust faults along convergent plate boundaries, normal faults along divergent boundaries, and strike-slip faults along transform boundaries.

8. Which type of plate boundary is associated with very strong and deep earthquakes? What type of stress is associated with these earthquakes? What types of faults?

   **Answer:** Convergent plate boundaries are associated with very large and deep earthquakes. There is a large amount of compressive stress along these boundaries, causing reverse and thrust faults.

9. Earthquakes are caused by plate movement and displacement along faults. What are some other causes of earthquakes?

   **Answer:** Earthquakes can also be caused by magma movement, volcanism, isostatic rebound, and human activities like pumping water from the ground.

10. What type of stress is associated with the San Andreas Fault System? Describe how rocks move relative to each other during earthquakes along the San Andreas. What type of fault is the San Andreas?

    **Answer:** Shear stress is associated with the San Andreas Fault System. When an earthquake happens, rocks move horizontally past each other. The San Andreas is a strike-slip fault.
11. While mapping an area, a geologist finds that there are a significant number of normal faults. The geologist uses relative dating methods to figure out that the faults are about 180 million years old. What do these faults tell the geologist about what was happening in the area 180 million years ago? What might the geologist infer about the tectonic environment of the region at that time?

**Answer:** The faults tell the geologist that, 180 million years ago, the area was experiencing tension stress. Earthquakes were occurring as blocks of crust separated. This could be evidence that the area was undergoing tectonic extension, that it was part of a continental rift system.
Data/Graph Tool
Teacher’s Guide

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Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
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There are several elements to enter on this screen.

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- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

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The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

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A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

![Graph Image]

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Pressure Along Faults

**Timing:** one 90-minute class session

**Objective(s):**
This lab will allow students to visualize how pressure builds at faults and then releases suddenly to cause an earthquake.

**Safety Precautions:**
Rubber bands may snap if students pull them too quickly or hard. Students should wear safety gloves and goggles to protect their fingers and eyes from snapped rubber bands.

**Materials:**
Per group:
- 2 blocks of wood (2” \( \times \) 4”), approximately 10 cm long
- 10 thin rubber bands
- 2 meter sticks or 1 tape measure
- Sharpened pencil
- A length of stretch fabric, at least 2 m long
- Duct tape
- A flat working surface at least 2 m wide
- Graph paper

**Teacher Preparation:**
Groups will need to “loop” their 10 rubber bands together to form a kind of chain, so practice the technique prior to class to ensure you can lead students through the process. To loop together two rubber bands, lay them as in the following diagram, so that one (Band B) overlaps the other (Band A):
Pull Point C (of Band A) through Band B and back toward Point D (of Band A). Weave Point C beneath Point D. Continue to pull Point C until you have knotted together both rubber bands, as shown in the following diagram:
Repeat this process to create a chain of 10 rubber bands approximately 16 cm long.

Prior to class, practice pulling the wood blocks along the fabric and aligning each movement with the meter sticks, as described in the Procedure. As the block moves along the fabric it should “stick,” build up pressure, and then “slip” forward as the rubber band is stretched. If the surface is too smooth, then the block will tend to slide instead. Stretching a length of fabric across the length of the working surface and duct-taping the ends in place should allow for the necessary friction. Alternatively, attach sand paper to the bottoms of the blocks and slide them along a board (so as not to scratch the working surface). Place two meter sticks (laid end to end) or a tape measure locked at least 2 m along the length of the fabric. Tape the ends of the meter sticks in place to keep them from getting knocked out of position during the experiment.

In addition to the other materials needed for each group, prepare a copy of the Student Investigation Sheet found at the end of this lab for each student.
**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Divide class into groups of 3–4 students, and distribute materials to each group. Instruct students to loop the rubber bands together to make a chain about 16 cm long. (See Teacher Preparation for instructions.) Then, instruct students to loop the rubber band on one end of the chain completely around one of the wood blocks. Have students cover their work surface with the band of stretch fabric, and then try to pull the block along the fabric by pulling on the other end of the rubber band chain. Instruct the students to experiment with different pulling speeds (e.g., very slowly, slowly, moderately, quickly, very quickly), and to note in an observations table the effect of each pulling speed on the motion of the block. Students should then place the second wood block on top of the first block to add additional weight. Students can place a loop of duct tape between the two blocks to secure them together, but they should *not* wrap the tape around the blocks. (Doing so would create a smooth portion in the middle of the bottom block that will affect its motion along the work surface.)

After students have experimented for a few minutes, instruct them to place the wood block at one end of the fabric, with the rubber band chain extending along the length of the fabric. (If students were experimenting with two blocks taped together, they should remove the top block and the tape.) Students should align the meter sticks end-to-end and parallel to the fabric. Students should loop the free end of the rubber band chain around a sharpened pencil; this can be used as a pointer to help them align the rubber band chain with the meter stick. The following diagram illustrates this setup:
Assign one student in each group to be the Puller, one student to be the Observer, and one or two to be Recorders. Recorders should divide their observation tables into two columns: one for the position of the free end of the rubber band chain (again, using a pencil will make the position easier to identify) and one for the position of the pulling end of the block.

To begin the investigation, instruct the Puller in each group to stretch the chain of rubber bands as far as possible without putting any tension on the wood block. The Observer should determine the initial position of the pulling end of the wood block with respect to the meter sticks, as well as the initial position of the free end of the rubber band chain with respect to the meter sticks, and announce these numbers to the recorders. The recorders should then write these data in their observation tables. (Recorders may want to set up their notes in advance, creating a row for each 1-cm interval and leaving a space in the second column for the block position at each interval.)
Once the initial positions of the block and rubber band strings have been recorded, instruct the Puller to stretch the end of the rubber band string 1 cm from the initial position. The Observer should wait for the wood block to move in response to the stretching of the rubber band string, then announce the new position of the pulling end of the wood block with respect to the meter sticks. The recorders should then write these data in their observation tables. The Puller should then move the end of the rubber band string 1 more cm; the Observer should wait for the wood block to move and announce the new position of the pulling end of the wood block with respect to the meter sticks. The recorders should then write these data in their observation tables.

The investigation will proceed in this way until the block has reached the end of the meter sticks (or traveled at least 1 m, preferably more). At each step in the investigation, the Puller should stretch the rubber band chain 1 cm from the previous position, and the Observer will announce how far the wood block has moved in response to the stretching. A sample set of data for teacher reference only is located at the end of this procedure.

When groups have collected all their data for this part of the investigation, they should proceed to the Guided Inquiry.

**Guided Inquiry**
Students will require graph paper for the Guided Inquiry. Using the data the Recorders have collected, each student should create a graph plotting the movement of the block relative to the pull of the rubber band chain. Students can develop their own plans for organizing and displaying their data graphically, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- Was there consistent movement of the wood block at each 1-cm pull of the rubber band chain?
- How will you display this data graphically? Which data will you plot on the x-axis? Which data will you plot on the y-axis?

When the students have created their graphs, they should write a paragraph answering the following questions:

- How does friction affect the movement of the wood block?
- Would you expect to obtain the same data if the experiment were repeated?

Then, instruct the students to return to their small groups. Have the group members switch assignments so that there is a new Puller, Observer, and Recorder(s). Instruct students to repeat the experiment two or three more times, until each group member has gotten a chance to play each role in the experiment. After each run of the experiment, students should graph their data using the same method they developed after the initial run of the experiment.
A sample graph is located at the end of this procedure. For teacher reference only, here is a sample set of data for the first 40 pulls:

<table>
<thead>
<tr>
<th>Position of pulling end of rubber band string (cm)</th>
<th>Position of pulling end of wood block (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>10.0</td>
</tr>
<tr>
<td>31</td>
<td>10.0</td>
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<td>10.0</td>
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<td>33</td>
<td>10.2</td>
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<td>34</td>
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<td>41</td>
<td>19.0</td>
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<td>43</td>
<td>21.4</td>
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<td>43.8</td>
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<tr>
<td>69</td>
<td>43.8</td>
</tr>
<tr>
<td>70</td>
<td>47.4</td>
</tr>
</tbody>
</table>
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Were the data from each repeat of the experiment identical? *No, the overall motion of the block was similar each time, but the block “slipped” in different positions each time.*

2. How does the movement of the block represent earthquakes that occur along faults? *Friction holds fault blocks in place, just as friction holds the wood block in the experiment in place for a given time. As pressure builds, the block slips to release the pressure, just as pressure builds along a fault block until the pressure is released as an earthquake.*
3. How does a change in the data from one run of the experiment to the next represent the unpredictability of earthquakes? Through experiment, it is not possible to predict when the block will slip. Even though the interval remains the same, the block slips at different times. The same is true for earthquakes. It is impossible to predict when the pressure on a fault or plate boundary will release as an earthquake.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Design and conduct field studies using:
    - Survey - collects multiple data points at one point in time
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged
    - Multiple trials—repeated tests with the same variables to check for variability of results.
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated.
    - Applies mathematical operations and principles to replicate the real thing.

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
  - Chooses appropriate tools to conduct an investigation:
    - Ruler/tape measure
    - Meter stick
  - Use senses to observe:
    - Kinesthetic (balance, position)
  - Uses the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identifies and interprets patterns:
    - Trends in data
    - Repeating physical or data pattern
    - Graphed data points
    - Tables and graphs
    - Based on an analysis of data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause effect relationship observed in the investigation
    - Reporting trends and patterns in the data.
- Comparing results to hypothesis
- Identifying alternative explanations
- Examining how investigations can be improved
- Formulating scientific explanations/arguments
- Explain how technology can be used to enhance the investigation
- Show the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Formulating scientific explanations/arguments
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy

- Patterns and Systems
  - Patterns and Change
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- Scientific Investigation
  - Scientific Investigation
    - Science takes place in many locations including labs, offices, fields, and under the ocean.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - It is important in science to keep honest, clear, and accurate records.

- Scientific Endeavor
  - Characteristics of Science
    - One way to make sense of something is to think of how it relates to something more familiar.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory* leads to looking at old observations in a new way.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
The Doppler Effect

Timing: one 90-minute class session

Objective(s):
Students will experience the Doppler effect through changes in sound as a sound source is moved past them.

Safety Precautions:
Students should be careful not to run into anything or anyone when riding the bicycle. The cyclist should wear a safety helmet.

Materials:
For the class:
- A repeating sound source, such as a battery-operated piezo electric buzzer alarm clock or if these are not available music player programmed to repeatedly play the same short track and connected to a portable, battery-operated stereo
- A bicycle and cycle helmet.

Teacher Preparation:
Teachers should prepare a source of repeating sound; a battery powered piezo electric buzzer is ideal, but anything that beeps with the same repeating tone will work. Be sure that the sound is loud enough for all students to hear at various distances from the source. This sound source should be placed on a bicycle provides. If a bicycle is not available then a cart may be used, but it will have to be moved at high speed. This lab should be performed in a large open space or outside.
Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate

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variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Instruct students to write a paragraph defining the Doppler effect and describing several examples of it (e.g., the redshift or blueshift of stars; the changes in pitch of sounds). When students have finished, write the term *Doppler effect* on the board, and come up with a working definition on which the entire class can agree. Explain to students that human eyes are not sensitive enough to detect the Doppler shift of visible light when everyday objects are moving toward or away from us. However, we can easily sense a Doppler shift in sound waves.

Use a repeating sound source, such as a piezo electric buzzer, on a bicycle at one end of a field or other flat area. Have the students position themselves on the opposite side of the field from the sound source. Play the repeating sound with the bicycle remaining stationary until the students get used to the sound. Instruct students to imagine that the pitch of this sound rates a 5 on a scale from 1 to 10 (1 being the lowest pitch; 10 being the highest pitch). Students should keep in mind their initial experience of the sound (i.e., when it rates 5 on the scale) throughout the lab.

Then, instruct students to write down a hypothesis about what they think will happen to the sound as the bicycle is moved toward them; remind students to explain their reasons for their hypotheses by referring to the *Core Interactive Text* and other Discovery Education resources. Then, have a student ride the bicycle toward the students while the sound source is playing, stopping when the bicycle is about 1 m from the students. Have the students record their observations about how the sound’s pitch changed as it moved toward them, comparing their observations to their hypotheses. Instruct students to rate the pitch of the sound again on a scale from 1 to 10, using their previous rating as a baseline, and to explain in their own words what is causing the change. (*Students should note that the pitch grows higher as the sound source approaches them. That is, they should rate the sound as higher than a 5 on their scale. The reason is that the sound waves are compressing as the sound source moves closer—as wavelength decreases, wave frequency increases, and as frequency increases, pitch increases.*)

Then, instruct students to write down a hypothesis about what they think will happen to the sound as the bicycle is moved away from them and back to its original position; remind students to explain their reasons for their hypotheses by referring to the *Core Interactive Text* and other Discovery Education resources. Then have a student ride the bike away from the students while the sound source is playing, stopping when the cart has returned to its starting point. Have the students record their observations about how the sound’s pitch changed as it moved away from them, comparing their observations to their hypotheses. Instruct students to rate the pitch of the sound again on a scale from 1 to 10, using
their previous rating as a baseline, and to explain in their own words what is causing the change. (Students should note that the pitch grows lower as the sound source moves away from them. When the sound source has returned to its starting point, the sound should again rate a 5 on students’ scales. The reason is that the sound waves are elongating as the sound source moves away—as wavelength increases, wave frequency decreases, and as frequency decreases, pitch decreases.)

Finally, have a student ride the bike toward and away from the students several more times in succession so that students have an opportunity to confirm their initial observations, adding to or revising them as necessary.

Students’ observations will be qualitative, rather than quantitative, so there will be no direct mathematical data to graph. Instruct the students to work in pairs or small groups to create a general diagram illustrating the relationship between the motion of the sound source relative to themselves and the apparent change in the pitch of the sound. Here is an example of what students might create:
Students should then proceed to the Guided Inquiry part of this lab.

**Guided Inquiry**

In Directed Inquiry, students observed the Doppler effect as a source of sound was moved in a straight line toward and away from them; students remained stationary and faced the sound directly. In this part of the lab, students will form and test new hypotheses involving changes to the previous setup.

Begin by dividing students into groups of 4 or 5. Instruct groups to discuss the following questions and form hypotheses based on their responses:

- a. How would your experience of the sound change if the sound source remained stationary and you moved in a straight line toward and away from the sound source?
- b. How would your experience of the sound change if you faced away from the sound source as it moved in a straight line toward and away from you? (You remain stationary throughout.)
c. How would your experience of the sound change if you remained stationary as the sound source moved toward and then past you in a separate line, as illustrated in the following diagram?

![Diagram of sound source moving toward and then past a student](image)

**Sound source at start**

**Student**

**Sound source at finish**

d. In addition, instruct each group to develop its own question involving the changing position of a sound source with respect to a hearer and to hypothesize an answer to that question.

If resources permit, allow each group to test its hypotheses using its own set of materials in its own space; most likely, though, you will need to combine groups or continue to work as a full class. Even if you have enough materials, groups must be separated by walls (or at least sufficient distances); otherwise the sounds made by other groups will interfere with each group’s own investigation. Walk students through the first three scenarios described above (questions a, b, and c), giving students time to record their observations in their notes; then, allow each group a chance to describe for the rest of the class the scenario it developed for question d, above. Students not in that group should form their
own hypotheses in response to the scenario; then, allow the group to test its hypothesis by working through its scenario in front of the class.

Students may wish to refine their investigations by using a laptop with a built-in microphone, and software to look at changes in pitch. Free software is available on the internet to that records changes in pitch.

Analysis and Conclusions:
1. Describe the changes in your perception of the sound source as the source:
   a. Moved toward you (Pitch increased)
   b. As it moved away from you (Pitch decreased)
   c. As the bike sped up and slowed down as it moved toward you. (As the bike increased in speed the pitch rose, as it slowed down the pitch fell.)

2. Use diagrams and words to explain your observations in terms of the sound waves that were reaching your ears. (Students should include reference to the waves being compressed as the source move toward them, or attenuated as the source moves away from them. They should relate the change in compression with change in speed as the source moves toward them.)

Further Questions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. You have observed how the Doppler effect acts on sound waves. How does the Doppler effect act in a similar way on light waves?
   The Doppler effect is the apparent change in the frequency of a wave caused by the changing distance between the observer and the object emitting the wave. When the sound source is moving toward an observer, the sound it produces is a higher pitch (i.e., a shorter wavelength) than when the sound source is moving away (i.e., a longer wavelength). This is similar to how electromagnetic waves are shortened when an object in space is moving toward an observer or lengthened when an object in space is moving away from an observer.

2. How can people observe the Doppler effect in visible light waves? That is, what is the visible light equivalent to the changing pitch of sound waves?
   Redshift is the apparent shift of wavelengths of visible light toward the red end of the electromagnetic spectrum; it happens when a luminous object is moving away from Earth. Blueshift is the apparent shift of wavelengths of visible light toward the blue end of the electromagnetic spectrum; it happens when a luminous object is moving toward Earth. Both of these phenomena are examples of the Doppler effect.

3. How is the Doppler effect used as evidence for the Big Bang theory?
The redshift of most galaxies in the universe is evidence for the expansion of the universe because redshift is associated with objects that are moving away from an observer (i.e., on Earth). If the universe is expanding in all directions, it stands to reason that at some distant time in the past, all the objects in space were packed tightly together. The Big Bang theory resulted from this inference.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process.
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship.
    - Require the changing of one variable at a time.
    - Can be answered with a science investigation or observational study.
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction).
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis).

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Study - compares changes in data points over time.
    - Interventional Study - adjusts one or more elements and observes resulting changes over time.
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid.
    - Independent variable - the one variable the investigator chooses to change.
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable.
    - Constant - identify variables that must remain unchanged.
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated.
    - Function exactly like or similarly to the real thing.
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing.

- **Gather Data**
  - Use senses to observe:
    - Hearing (pitch, volume, reflection, direction).

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause effect relationship observed in the investigation.
    - Comparing results to hypothesis.

- **Communication in Science**
  - Report results using:
    - Written report.
    - Scientific illustration with proper labeling.

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
Hands-On Lab
Explaining the Big Bang

Timing: one 90-minute class session

Objective(s):
Students will construct an explanation of the Big Bang Theory based on reliable evidence they obtained. Their explanation will be based on laws that operate in our natural world. They then will compile the evidence and display it in Builder Board to share with their classmates.

Safety Precautions:
Remind students to follow all general lab safety rules.

Materials:
Per pair:
- science journal
- writing tools
- access to a computer and the Internet

Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Ensure students will have access to DE resources, like Board Builder.

Procedure
1. Review the main elements of the Big Bang Theory on the board. Write the main categories scientists use to support the theory. You should supply the terms: singularity, expansion of the universe (redshift of light), cosmic background radiation, and nuclear fusion (or nucleosynthesis).
2. Remind students that they will be constructing their own explanation for this theory and giving examples of the evidence that confirms it from their research on the Internet. They will use Board Builder to display and present their explanations.
3. In pairs, students should share the information they gathered in their science journals about the Big Bang Theory. They should create a chart in their notebooks with the same headings that are displayed on the board.
4. With their partners, students should begin filling in their chart with examples of this evidence.
5. Allow students the opportunity to review the DE resources on this subject, if necessary.
6. Once students have a completed their chart and feel they have covered all of the different pieces of evidence to support the theory, allow them to work in Board Builder to decide how best to present their results.
7. Once students have completed their Board Builder explanation of the Big Bang Theory, allow them time to share their explanations with the rest of the class.
8. As students view the other explanations, have them write down which parts or methods of other explanations they found clear.

**Analysis and Conclusions**

1. Which part of the Big Bang Theory was the most difficult to explain. Why?
   *Answers will vary, but some pairs may have found it most difficult explaining the point of singularity, others explaining light years, or explaining the timeline of the Big Bang. Some of the concepts involve questions for which scientists don’t have all of the answers; others require a sense of vastness and numbers that are much larger than can be illustrated.*

2. In which order did you present the evidence? Why?
   *Answers will vary but students may consider presenting evidence that was easiest to understand first, or to present it sequentially or historically. They may have chosen to present the pieces first that had physical evidence, such as the redshift.*

3. Which piece of evidence was most convincing for you? Why?
   *Answers will vary, but students may name the evidence of elements found in stars by spectral analysis to be convincing, or they may find the redshift associated with the light from stars to be more persuasive.*

4. Why is nuclear fusion (or nucleosynthesis) so important to an explanation of the Big Bang Theory?
   *Nucleosynthesis explains how different elements are formed in stars. The life cycle of a star and its eventual supernova explain further how heavier elements are formed. This information explains how these different elements, such as iron and gold, could be found on Earth.*
In this lab, students will demonstrate the following Inquiry Skills:

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.

- **Gather Data**
  - Uses the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Identifying alternative explanations
  - Communication in Science
    - Peer presentation

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Identifying alternative explanations

- **Engineering and Technology**
  - Uses of Technology
    - Technology extends the ability of people to make positive and/or negative changes in the world.
Overview

Although scientists have to work out many details of the nature of the universe and its origin, they agree that the Big Bang Theory explains the key observation that the universe is expanding. Scientists use a variety of methods to study the expansion. The most important method is the Doppler shift. In this Exploration, students apply the concept of Doppler shift to determine the motions of various stars.

Student Learning Objectives

- Understand the concept of Doppler shift.
- Compare wavelengths of stars of different velocities.
- Examine the emission spectra of stars.
- Identify the type of Doppler shift exhibited by various stars.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Doppler tab, students select a star using the options in the Select Star section. The intrinsic frequency and intrinsic wavelength of the selected star are displayed. Students then choose to analyze the wavelength/frequency data or the emission spectrum of the selected star. They use the radio button options in the Select Analysis section to make their selection. Students use the Start button to begin their observation. They note the observed frequency, observed wavelength, and the spectrum of the selected star. Students analyze this data to decide first whether the star is approaching or receding. They then identify the type of shift. They use the radio button options to make their selections and the Submit button to validate them. Students may use the Reset button to undo what they have done and select another star.

In the Stars tab, students select a star using the options in the Select Star dropdown list. The reference spectrum and the position of the star are displayed. Other characteristic features such as the constellation the star belongs to, its distance from Earth, and its peak wavelength are also displayed. Students use the Observe button to observe a shift in the selected star’s spectrum. They note its observed frequency and identify the type of Doppler shift using the radio button options. Students may use the Reset button to undo what they have done and select another star.

In the Tracker tab, students view a summary of the activity performed in both the tabs, Doppler and Stars. They select a tab using the options in the Select Tab dropdown list. For the Doppler tab, the tracker displays the direction, velocity, selected analysis, intrinsic frequency, intrinsic
wavelength, observed frequency, and observed wavelength of the stars. For the Stars tab, the tracker tab displays the constellation, distance from Earth, known wavelength, observed wavelength, speed, direction, and Doppler shift of the stars.

**Answers to Questions in the Student Worksheet**

1. Explain the term Doppler shift.

   **Answer:** Doppler shift is a difference between the observed wavelengths of a wave due to relative motion of the generating source with respect to the observer.

2. Describe the use of Doppler shift in astronomy.

   **Answer:** Doppler shift is used to establish the speed of a star relative to Earth and whether the star is moving toward or away from Earth.

3. Describe how Doppler shift observations imply the continuous expansion of the universe.

   **Answer:** A star approaching Earth exhibits blueshift because of a decrease in the apparent wavelength of its light waves compared with a reference wavelength. Similarly, a star or a galaxy moving away from Earth exhibits redshift because of an increase in the apparent wavelength of its light waves. All galaxies in the universe appear to be redshifted, which implies that the universe is expanding.

4. Determine whether the following statements are correct. If incorrect, modify the statement such that it is correct.

   a. The observed frequency of light from a star moving closer to Earth is higher than its intrinsic frequency.

   b. The spectrum of a star moving away from Earth appears to have shifted toward the blue end.

   c. The Big Bang theory states that billions of years ago, a huge explosion began the expansion of the universe.

   d. Vega belongs to the constellation Gemini.

   **Answer:**

   a. Correct.

   b. Incorrect. The spectrum of a star moving away from Earth appears to have shifted toward the red end.

   c. Correct.
d. Incorrect. Vega belongs to the constellation Lyra.

5. Describe how the emission spectrum of a star can be used to determine whether the star is approaching or receding from Earth.

**Answer:** If a star is moving away from Earth, the apparent wavelength of light emitted by the star or galaxy lengthens, which is observed as a shift in emission spectra toward the red end of the spectrum. This is known as redshift. Similarly, a star approaching Earth will exhibit blueshift because of an increase in the apparent wavelength of its light waves, and shift of its emission spectra toward the blue end of the spectrum.

6. A star has an intrinsic frequency of 457.12 THz and an observed frequency of 472.88 THz. Identify the type of shift exhibited by the star.

**Answer:** As the observed frequency has increased relative to the intrinsic frequency so the type of shift is blueshift.

7. Identify the type of shift of the star based on the data provided.
   a. This star has an intrinsic frequency of 421.12 THz and an observed frequency of 434.59 THz.
   b. This star has an intrinsic wavelength of 670.34 nm and an observed wavelength of 692.89 nm.
   c. This star has an intrinsic frequency of 446.28 THz and an observed frequency of 438.19 THz.
   d. This star has an intrinsic wavelength of 667.89 nm and an observed frequency of 650.23 nm.

**Answer:**
   a. Blueshift
   b. Redshift
   c. Redshift
   d. Blueshift

8. This Exploration explains the Doppler shift of four stars. State one star that exhibits blueshift.

**Answer:** Sirius is receding from Earth at the speed of 19000 m/s. It exhibits blueshift.
9. This Exploration explains the Doppler shift of four stars. State one star that exhibits redshift.

   Answer: Canopus is receding from Earth at the speed of 21000 m/s. It exhibits redshift.

10. Use this Exploration to identify whether the star Pollux is approaching Earth or receding from Earth.

   Answer: Pollux exhibits a redshift. This means that it is receding from Earth.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- **Name the data table**: select a descriptive title or name for the data table.
- **Name each of the columns in the data table**: Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Model A Star’s Life Cycle

**Timing:** one 90-minute class session

**Objective(s):**
Students will model the stages through which stars progress during their life cycles.

**Safety Precautions:**
Offer safety reminders to students relevant to the modeling materials and tools they are working with. For example, if using craft knives, remind students of safety procedures for working with sharp objects.

**Materials:**
Per group:
- A selection of modeling materials appropriate for students’ plans. Useful materials may include cardboard, card stock, modeling clay, and a selection of materials in white, blue, yellow, and red.

**Teacher Preparation:**
You may wish to split the lab so that you and students can gather necessary materials after the planning phase. Have students submit materials lists with their plans. Gather materials before the modeling phase of the lab.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to
ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Explain that the goal of the lab is to model the life cycle of a star. Lead the class in brainstorming a list of phases that a star might experience during its life cycle. List each phase on the board; students should also place the phases in chronological sequence. Be sure to include:

- Birth
- Main sequence
- Giant
- Planetary Nebula
- White Dwarf
- Black Dwarf
- Supernova
- Neutron Star
- Black Hole

Divide students into small groups of 4 or 5, and task groups with planning their models. First, have students work together to diagram the possible life cycle paths. Students can use a concept map or divided flow chart to organize the phases of the life cycle and the diverging paths by which stars with different masses die. An example diagram is shown below:
To help them plan, ask groups the following questions:

- How do the characteristics of main sequence stars vary? (*Stars in the main sequence can vary in temperature, color, size, and brightness.*)
- What influences the characteristics of a main sequence star? *(the star’s mass)*
- What determines the path a star will take as it dies? *(the star’s initial mass)*
- How can you model the effects of mass on the different characteristics of a star as well as the star’s path through its life cycle? *(Answers will vary. Ideas may include a web-based model in which the user chooses the star’s initial mass and then views a slide show illustrating the life cycle appropriate to that mass, or a game in which players choose cards with different initial masses and proceed down appropriate paths on a game board.)*

Next, have groups brainstorm ways to represent the stages and divergent paths in their models. You may suggest possible approaches, such as a game, a skit, or an interactive computer model built using Web 2.0 tools. Whatever approach groups select, their models must meet the following criteria:
• Represents each of the main phases in the life cycle of a typical low-mass star, from birth through death as a black dwarf.
• Represents each of the main phases in the life cycle of a typical high-mass star, from birth through death in a supernova followed by either a neutron star or a black hole. Note that the initial mass of a star that ends its life as a neutron star is substantially less than the initial mass of a star that ends its life as a black hole; therefore, each group should indicate the initial mass of its example star and select the appropriate final phase, given that initial mass.
• Explains the main characteristics of a star (e.g., mass, temperature, color, size, brightness) at each phase in its life cycle.

Once groups have decided on an approach, instruct them to write a plan for constructing the model and submit the plan for your approval. The plan should include a materials list. Then, have groups build their models and demonstrate them for the class. Encourage students to offer constructive feedback on each other’s models. If time permits, have students make revisions to their models based on the feedback they receive from their peers.

Guided Inquiry
Students can develop and implement their own plans for creating a model of a star’s life cycle. Divide students into small groups of 4 or 5 and instruct them to plan and create a model that represents the following:
• Characteristics of a star at each phase in its life cycle
• Major processes that occur during each phase
• The several paths that a star can take during the death phase, depending on the star’s initial mass

Encourage students to brainstorm in their groups to list the phases of star life cycles and use diagrams or pictures to represent the different paths through the star’s death phase. You may wish to ask guiding questions such as:
• How do the characteristics of main sequence stars vary? (*Stars in the main sequence can vary in temperature, color, size, and brightness.*)
• What characteristic determines how a star will proceed through its death phase? (*the star’s initial mass*)
• How can you represent in a model the different possibilities for death phases given the star’s initial mass? (*answers will vary*)
Have groups develop and submit plans for their models. Plans should include a materials list. Then, have students build their models and demonstrate them for the class. Encourage students to offer constructive feedback on each other’s models. If time permits, have students make revisions to their models based on the feedback they receive from their peers.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What were the challenges in designing a model of a star’s life cycle? *Sample response: The characteristics of a star in the main sequence and the phases of a star’s death vary depending on the star’s initial mass. Accounting for this difference was a challenge.*

2. How did you choose to represent the differences in main sequence star characteristics? *Answers will vary.*

3. How could you improve your model to include more details of life cycles for various stars? *Sample answer: Link differences in luminosity and surface temperature of main sequence stars to the star’s initial mass.*
Inquiry and Nature of Science Skills in this Lab:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
    - Apply mathematical operations and principles to replicate the real thing.
    - Have been revised as new knowledge and information has been obtained
    - Are based on logic and evidence
  - Practice lab safety by:
    - Following lab safety procedures

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
    - Applying a classification scheme to objects, substances or organisms

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Extrapolating results beyond the investigation
    - Identifying alternative explanations
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Scientific explanations/arguments

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating a conclusion
- Identifying alternative explanations
- Analyzing scientific explanations

- Patterns and Systems
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
  - Systems:
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.

- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - An important part of science is the critical review and analysis of any idea or conclusion.
Hands-On Lab
Monitoring Solar Activity

**Timing:** one 90-minute class session

**Objective(s):**
Students will design and conduct an investigation to determine whether the significance of aurora activity on Earth is dependent on the scale, proportion, and quantity of the solar activity of the Sun. They will need to track and collect solar and aurora activity data, and compile it, so they may analyze it for patterns or correlations of cause and effect.

**Safety Precautions:**
Remind students to follow all general lab safety rules and not to eat or drink anything in the lab.

**Materials:**
Per group:
- 30 days of solar activity records
- the same 30 days of recorded aurora activity
- graph paper or a computer graphing program
- writing tools
- poster paper
Teacher Preparation:

- You may have students collect the aurora and solar activity data themselves, or you can collect it in advance and share it with the students. A minimum of thirty days of activity is necessary. Many Internet sites offer daily readings of solar activity and aurora activity (Kp-index), including NASA and other government sites. Using data from the same sites over the course of the 30 days is necessary to allow comparison and reduce variables in the investigation.
- Review with the class the different types of graphs used for communicating data and how they are useful for comparing two sets of data.
- Ensure students know the terms aurora, solar flare, sunspot, sunspot cycle, and non-cyclical variations. Share images, video segments, and glossary terms to help students with their understanding.
- **Auroras** are the colored light displays that occur most frequently near the poles and are caused by charged particles from the Sun colliding with the magnetosphere around Earth.
- **Solar flares** are sudden eruptions that release bursts of electromagnetic energy and charged particles from the surface, or near the surface, of the Sun.
- **Sunspots** are temporary areas that form on the surface of the Sun where the magnetic energy prevents solar energy from circulating freely. These areas, or spots, have a lower temperature than the rest of the Sun’s surface and appear dark in comparison. But the area around these spots is hotter, and there is a correlation between more sunspots and a greater release of solar radiation.
- Scientists discovered that the varying levels of energy released by the Sun repeat in a pattern called the **sunspot cycle**. This cycle lasts about eleven years. Some cycles are a little longer, and some are shorter.
- Even larger eruptions, called **Coronal Mass Ejections (CMEs)**, also blast high levels of energy and particles into space, which hit Earth’s magnetosphere and are deflected to the poles causing auroras—shimmering, colored lights in the night sky. High-energy particles and radiation can also damage power stations, satellites, and radio transmissions. The scale and quantity of the bursts determine the type of problems Earth experiences.

Procedure

1. As a group, have students design an investigation to determine whether aurora activity on Earth is dependent on the scale, proportion, and quantity of solar activity of the Sun, using daily aurora and solar readings. Encourage students to collect at least thirty days of activity in their investigation.
2. Have students write down their design and submit it for your approval.
3. Students will then need to compile their two sets of data in a form so that it may be compared and analyzed. Graphs or charts are useful to help compare sets of data.
4. Once students are ready to compare data sets, they should analyze them for patterns or trends.
5. Have students record the patterns they see in their science journals.
6. Ask groups to write down their answers to the investigation question: Is aurora activity on Earth dependent on the scale, proportion, and quantity of the solar activity of the Sun?
7. Ask groups to share their conclusions with the class.
Analysis and Conclusions

1. How long do you think you would need to collect data so that your conclusions would be considered valid? Explain.
Because solar cycles last, on average, 11 years, it would be important to collect data for several cycles before reaching a solid conclusion about the trends seen in solar activity affecting aurora activity.

2. During periods of low solar activity, are there matching low periods of aurora activity? Explain.
Because auroras are caused by solar particles bombarding Earth’s magnetosphere, it makes sense that if there is less solar activity there would be fewer particles to hit Earth and therefore cause the aurora lights.

3. During periods of high solar activity, are there periods of more frequent or brighter auroras? Why do you think this is?
Because auroras are caused by solar particles bombarding Earth’s magnetosphere, it makes sense that if there is more solar activity there would be more particles to hit Earth and therefore cause greater intensity or frequency of the aurora lights.

4. Did all groups find the same patterns and make the same conclusions? Why or why not?
Changes in the data might have been too small to make an accurate conclusion. Or, because it takes some time for solar particles to travel to Earth (sometimes several days), it may have been difficult to correlate each rise in activity on the Sun with aurora activity.

5. How might the data you collected be used in real-world applications?
Because large solar eruptions can cause disruption to satellites and power stations, it might be important to collect enough information to determine if it is possible to predict solar events and prevent any disruptions on Earth.
In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Study - compares changes in data points over time
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation

- **Gather Data**
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)
    - Table
    - Graph or chart

- **Interpret Data**
  - Identifies and interprets patterns
    - Trends in data
    - Repeating physical or data pattern
    - Graphed data points
    - Tables and graphs
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting out trends and patterns in the data.
  - Assessing the conclusion by:
    - Answer the testable question
    - Extrapolating results beyond the investigation
  - Communication in Science
    - Peer presentation

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Things that change may do so in steady, repetitive or irregular ways.
    - Many patterns in nature occur in cycles.
    - Cycles may be short, such as the second hand of a clock, or long such as the cycle of a year.
Hands-On Activity
Nucleosynthesis

In this activity, students will model the process of nucleosynthesis in three stars of different size. Their models will communicate the mass and different elements produced by three different-sized stars. Student will decide on the best way to create their models, build them, and then present them to the class.

Suggested Materials
Per Group:
- paper
- drawing supplies
- paints
- graph paper
- clay
- scissors
- glue

To introduce the activity, share the glossary term nucleosynthesis. If students are not confident about its meaning, have them revisit the material in Stars and Galaxies. Before beginning this Hands-On Activity, students should also be aware of these facts and have them recorded in their science journals:

- the larger the original mass of a star, the hotter it burns
- hotter stars appear blue
- cooler stars appear red
- the larger the mass, the quicker hydrogen burns and therefore the shorter the life cycle
- nucleosynthesis cannot produce elements heavier than iron
- as temperature and pressure rise, nuclear fusion can take place
- the first element produced by nucleosynthesis is helium
- helium is heavier than hydrogen and gravity pulls it into the core
- stars bigger than the Sun can produce heavier elements like oxygen and nitrogen

Part 1: Brainstorming Design

Procedure

Explain to students that they need to create a way to model three different-sized stars—one the size of our Sun, one 8 times bigger, and one 20 times bigger than the Sun. Their model must also show the different process of nucleosynthesis that takes place in each star during its life cycle, including the types of elements that are produced. Students should record the necessary information in their science notebooks. Then have students meet in small groups to brainstorm the way they wish to present the information. They may choose diagrams, graphs, 3D models, or a combination of all three.
1. Have students share with their group what they know about the role the size of a star plays on the kinds of elements that are produced during nuclear fusion.
2. Have students discuss ways in which they can share this information in a model. Remind students that they need to show relative size of the stars, temperature, and the different elements that are produced.
3. Have students create a plan on paper for your approval. The plan should list the materials they will need and the information they need to display. They may decide on additional materials.
4. Once their design is approved, have students gather the materials they will need.
5. Have students create their model.
6. Circulate and encourage students to verbalize their process. Guide students to ensure they are including the relative size of the stars, temperature, and the different elements produced by nuclear fusion.
7. Give students the opportunity to present their model to the class. Allow them to discuss the different ways groups chose to model the information.

Analysis and Conclusions

1. What difficulties were there in modeling the relative difference in size of the three stars?
   Answers may vary, but students may have found it difficult to show the size difference between the stars while still having a model that was both big enough, and small enough, to communicate the many different pieces of information for each star.

2. Would pictorial representations or graphs be easier to use to communicate this process? Why?
   Answers may vary, but it would require several different graphs for each star to show all of the information. A drawing or 3D shape with labels could show color, size, and content at a glance.

3. How does nucleosynthesis relate to a star going supernova?
   Nucleosynthesis is nuclear fusion that occurs in a star during most of its life cycle. Iron is the heaviest element that can be produced by nucleosynthesis. Once a core becomes too heavy with iron and collapses on itself, the star may go supernova.

4. What is the heaviest element that can be produced by nucleosynthesis? How are heavier elements produced?
   Iron is the heaviest element. Heavier elements are the result of the intense heat and pressure present when a star goes supernova.
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Identifying alternative explanations

  - Communication in Science
    - Peer presentation

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Identifying alternative explanations