SCIENCE AND THE SCIENTIFIC METHOD

Purpose: To become familiar with the means by which scientific information is gathered.

Introduction

You’ve done investigations before, and likely done some controlled experiments. This is your opportunity to analyze another project, identify the components of a good investigation, and design one of your own in physics.

Science is more than a body of information. Science is dynamic - it constantly grows and changes. Scientists carry on an unending search for new information. With that new information, they re-evaluate old information to find out whether it is still valid.

The scientific method offers a means of testing ideas and solving problems. Investigation is the foundation upon which science rests, and investigation is the heart of the scientific method. This lab gives you the opportunity to develop skill in using the scientific method. In order to understand how to set up experiments, you must first become familiar with the following terminology:

Hypothesis - an idea used as the basis for experimentation. It expresses an educated guess about how changes in one (and only one) factor, the independent variable, will affect another factor, the dependent variable. The hypothesis should also include some justification for this ‘educated guess.’ The hypothesis might follow a format of: if _____, then _____, because _____.

Inference - a logical conclusion

Investigation - the procedure designed to determine whether an idea - the hypothesis - is false or not false

Manipulated (Independent) Variable - the single factor that the experimenter changes

Responding (Dependent) Variable - The single factor that the experimenter observes and measures

Controlled Variables - factors that are kept the same in an investigation

Control Group - the standard of comparison for the experiment. All factors in the control group are the same as in the experiment, except for the one factor changed in the experiment (which is not changed in the control)

Validity Measure - something you do in the investigation that ensures accurate results (such as calibrating the measurement tools)

Data - the observations (and measurements) collected during the experiment.

Conclusion – whether or not the hypothesis has been supported by the data. The conclusion of a controlled experiment is one of the following: "the data support the hypothesis" or "the data do not support the hypothesis." The conclusion should be accompanied by specific examples from the data and explanation to support the conclusion statement.
1. What two variables will you find included in a hypothesis?

2. A study was done of the concentration of bleach needed to change the color of cloth. Squares of cloth were soaked in a bleach solution for five minutes each. Concentrations of 100, 95, 90, 85, . . ., 5, and 0% bleach were used.

   a. Identify at least three variables you would want to control in the above investigation:

   b. Identify the manipulated variable: ________________________________

   c. Identify the responding variable: ________________________________

   d. Write a hypothesis for this investigation:

   e. What might be considered a control group for this investigation?

3. State whether each of the statements below is stated as a hypothesis (Y or N).

   a. ___ The rusty nail in the board is four inches long because I measured it.

   b. ___ The lighter the balloon, the higher it will climb because lighter things are less dense.

   c. ___ Plants grow toward light because they need light to conduct photosynthesis.

   d. ___ The more water in a tomato, the firmer it will be because water increases the pressure inside the tomato.

4. Hypothesis: The greater the horsepower, the faster the car will travel, because more power will lead to a higher acceleration.

   a. List four variables you would control if you were to test this hypothesis.

   b. If you were to make a graph of your data, which variable would go on which axis?

      Horsepower would go on the _________-axis

      Speed would go on the _________-axis
**Investigation 1:** Joe was interested in determining the effect the number of plants in an area has on growth rate. He planted radish seeds in several milk cartons. In the first carton, he planted 5 seeds 1 cm deep and no less than 5 cm apart, in the second 10 seeds were planted 1 cm deep and no more than 2 cm apart, in the third 15 seeds 1 cm deep and 1 cm apart, and in the fourth 20 seeds 1 cm deep and 1/2 cm apart. Each carton was watered daily and daily measurements of the length of the leaves were made.

6. What variables would you want to control (list at least 3)?

7. What variable was manipulated? ____________________________________________

8. Which variable was expected to respond? ___________________________________  

9. Write a hypothesis for this investigation.

10. Set up a labeled data table for the investigation.

**Investigation 2:** Is there a relationship between the amount of training received and the length of time a learned behavior persists in insects? Select a number of sowbugs which always turn right when entering the intersection of a T-shaped maze. Using the tendency of sowbugs to avoid light it is possible to train them to turn left by shining a strong light from the right as they enter the intersection. Subject an animal to 1, 5, 10, 15, or 20 training sessions. Test each animal once an hour by running it through the T-maze.

11. What variables are being controlled in this investigation?

12. What variable was being manipulated? _______________________________________

13. What variable was expected to respond? _____________________________________

14. Describe a possible control group for this investigation (none is listed in the description).

15. Set up a labeled data table for the investigation.
Organizing and Analyzing Data

**Data tables:** Data tables help organize your data, especially your quantitative measurements.

- Include a title with both the *Manipulated variable (MV)* and *Responding Variables (RV)*,
- Title the far left column of your table with the MV and list the levels below.
- The RV for each trial is titled in the columns to the right of the MV (include units) and your calculated value (like averages or best values) are titled in the far right column.

**Example:**

<table>
<thead>
<tr>
<th>Effects of different types of exercise on Heart Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Heart Rate (beats / minute)</strong></td>
</tr>
<tr>
<td><strong>Types of exercise</strong></td>
</tr>
<tr>
<td>Trial 1</td>
</tr>
<tr>
<td>At rest</td>
</tr>
<tr>
<td>Walking 1 min.</td>
</tr>
<tr>
<td>Walking 5 min.</td>
</tr>
<tr>
<td>Running 1 min.</td>
</tr>
<tr>
<td>Running 5 min.</td>
</tr>
</tbody>
</table>

***If you are collecting data in intervals of time, you can list the times in the far left column instead and have a data table for each level.

**Example:**

<table>
<thead>
<tr>
<th><strong>Position vs. time (constant speed)</strong></th>
<th><strong>Position vs. time (accelerating)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (seconds)</strong></td>
<td><strong>Position (meters)</strong></td>
</tr>
<tr>
<td>0 seconds</td>
<td></td>
</tr>
<tr>
<td>5 seconds</td>
<td></td>
</tr>
<tr>
<td>10 seconds</td>
<td></td>
</tr>
<tr>
<td>15 seconds</td>
<td></td>
</tr>
</tbody>
</table>

**Analyzing Data:** After data is collected, it needs to be analyzed to see if there are any trends or relationships in your variables.

- **Graphs:** help you visualize trends in your quantitative data.
- **Written Analysis of the data:** Describes the trend(s) you see in your graph. **Cite specific data (numbers)** to support your trend statement. Your cited data should cover the full range of your levels. A discussion of the **reliability and possible sources of error** in your data is also important to address.
- **A conclusion** or summary statement can also be made for your data. It is important that you do not use inferences in your trend statements.

More detail about the written portions of your analyses are addressed in the “Guide to writing lab reports.”

**Graphs:** They are used to help interpret and visualize any trends in your quantitative data. There are different types of graphs, and it’s important to know which one to use.
**Bar graphs:** Usually not used in science. It is used when one of your variables is grouped into categories instead of numbers. There may be no relationship or trend between the categories. A few examples are given below:

![Bar graph example](image)

**Scatter Plots:** This graph is very frequently used in science to show relationships between manipulated and responding variables. Tips for creating scatter plots:

- Title the graph appropriately. Include both your MV and your RV in the title. This will usually be in the format of “Y vs. X.” Example: For the temperature graph below, a good title would be “Global Average Temperature vs. Year.”

- Scale the graph appropriately. Determine your increments for each variable. Look at your maximum values and make sure the graph will be big enough to include the data and interpret the trend it represents. Make sure the numbering is consistent (evenly spaced) on each of your axes. Example: Each square on the x-axis represents an increase of 5 ml, each square on the y-axis represents 10 g.

- Decide whether the origin, (0, 0) needs to be included in the data (and on the graph). Do not put breaks in your graph just to include the origin. This can lead to an inaccurate interpretation of the data. If none of your data is near the origin, just scale the graph at a starting point that makes sense. Example: Graph starting at 13.5°C is fine. Example: Do not put breaks in your scales. This should just start at 30 kg and 134 cm.

![Scatter plot example](image)

- Do not connect the dots! A best-fit line or curve is better. Do not put breaks in your scales!

- The X-axis (horizontal) represents the manipulated (independent) variable, the Y-axis (vertical) measures the responding (dependent) variable. Exception: time is almost always plotted on the x-axis, even though it is often the responding variable.

- Label the X and Y axes with both a label for what is being measured, and the unit (label) it is being measured in. The units are usually put in parentheses. Example: Mass of pendulum (g)

- If you have run several trials for a single manipulated variable value, average your results for a single data point on your graph, unless there is so much variability between your trials that you want to show all of the data. Example: For a string length of 20 cm, the period was measured during 5 trials to be 1.01 sec, 1.20 sec, 0.99 sec, 1.01 sec, 1.3 sec. Average period = 1.10 sec. Plot only the point (20 cm, 1.10 sec) on the graph.
Trendlines and curves: Look to see if there is a pattern in the data. The pattern is usually going to be either a straight line (linear), or a curve (square root $x^2$, $x^3$, etc). If there is a pattern, draw a best-fit line or best-fit curve through the data. For drawing a best-fit line:

- Use a ruler (clear ones work best) to draw a line that comes closest to all your points. The best-fit line does not have to go through any of the actual data points, it just needs to be close to all of them. The line also does not have to go through the origin $(0, 0)$.

Example:

![Graph of Arm Span vs. Height]

Do not force your line through the origin $(0, 0)$!

- Do not force your line or curve to go through the point $(0, 0)$, unless you are sure that it has to. Many best-fit lines will not go through the origin.

- Trendlines or curves are more powerful than just "connecting the dots." Example: Look at the temperature vs. time graph above. If you wanted to know the average rate of temperature increase with time, a best-fit line would enable you to calculate this by finding the slope of the best-fit line.

Outliers:
- Data points that fall well outside the pattern of your other points. They may be present for 2 reasons: a) unusual data--data that is real but doesn’t fit the pattern. You should always keep this data. b) inaccurate data -- data that is false, i.e. obtained through human error. This data shouldn’t be used in your analysis.

- You must use your judgment in deciding whether an outlier should be discarded or not. Never discard data unless you are sure it is due to error.

- If you are not going to use an outlier, leave it in your data table, but note that it is an outlier due to error, and that you are going to discard it. Explain the reason(s) why in the analysis section of your lab.

Practice questions:

1. Indicate by writing the word “bar” or “scatter” indicating which type graph should be used for the following data sets:

   a. Favorite movie genre vs. gender _______________

   b. Weight of 9th graders vs. their height. _______________

   c. Distance a ball rolls down a hill vs. time. _______________

   d. The height a ball bounces vs. the brand of ball _______________

   e. The height a ball bounces vs. the height it is dropped _______________
2. Practice Data Tables and Graphs: Make a blank data table and graph for the following experiments, using the guidelines given to you. Be sure to include Titles, labels, units, and appropriate scales on the graphs.

a. Measuring the audio volume (in decibels-dB) of a guitar string as you increase the force (in Newtons-N) you use to pluck it. The force will be increased from 0N to 3N in increments of 0.5 Newtons.

Data Table: 

<table>
<thead>
<tr>
<th>Force (N)</th>
<th>Volume (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Graph:

b. You are measuring the time it takes (in seconds-s) for an object to hit the ground from various heights (in meters-m). The heights range from 0 meters to 5 meters (increments of 1 meter).

Data Table: 

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Graph:
c. You are measuring how far a car travels, in meters, over different increments of time (every 2 seconds for a total of 20 seconds).

Data Table:

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>35</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>130</td>
</tr>
<tr>
<td>60</td>
<td>150</td>
</tr>
<tr>
<td>65</td>
<td>175</td>
</tr>
<tr>
<td>70</td>
<td>200</td>
</tr>
</tbody>
</table>

Graph:

3. For the following two sets of data tables, graph each and put a best-fit line through the data.

a. Data for Quartz: Mass is measured (RV) at different volumes (MV).

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>Mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>30</td>
<td>180</td>
</tr>
<tr>
<td>35</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>130</td>
</tr>
<tr>
<td>60</td>
<td>150</td>
</tr>
<tr>
<td>65</td>
<td>175</td>
</tr>
<tr>
<td>70</td>
<td>200</td>
</tr>
</tbody>
</table>

b. Balloon Expansion: Volume is measured at different temperatures (3 trials per temp).

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Volume (liters)</th>
<th>Avg. Vol. (l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>20</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>3.3</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>4.2</td>
<td>3.9</td>
</tr>
<tr>
<td>50</td>
<td>3.9</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>5.9</td>
<td>5.9</td>
</tr>
<tr>
<td>75</td>
<td>5.8</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>8.3</td>
<td>8.4</td>
</tr>
<tr>
<td>100</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>8.3</td>
<td></td>
</tr>
</tbody>
</table>
How to calculate Slope of a Best-Fit Line

The slope of a best-fit line represents the “best value” for the trend in your data.

**Steps:**
1. Put a best-fit line through the data.
2. Select 2 points on your best-fit line. These do not have to be your data points. Circle the points on your graph. Use open circles, so it is clear that they are not data points. It is best if the points are widely separated on the graph. Write down the 2 points in the form (x,y).
3. Use the 2 points you selected to calculate the slope:
   
   **NOTE:** The symbol Δ is the greek letter Delta, and stands for “Change in.”

   \[
   \text{Slope} = \frac{\Delta y}{\Delta x} = \frac{\text{Rise}}{\text{Run}} = \frac{y_2-y_1}{x_2-x_1}
   \]

   **Example:** If your 2 data points are (2 sec, 10 m) and (12 sec, 60 m), then the slope will be:

   \[
   \text{Slope} = \frac{\Delta y}{\Delta x} = \frac{60m - 10m}{12s - 2s} = \frac{50m}{10s} = 5 \text{ m/s}
   \]

4. Label the units for your slope. The units will be y-units/x-units.

**Practice:** Put a best-fit line through each graph, calculate the slope, and then interpret the results:

1. Beach visitors vs. Average Daily Temperature

   **Point 1 coordinates:**

   **Point 2 coordinates:**

   \[
   \frac{\Delta y}{\Delta x} = \frac{y_2-y_1}{x_2-x_1}
   \]

   **Interpretation:**

2. Final exam score vs. Hours spent studying:

   **Point 1 coordinates:**

   **Point 2 coordinates:**

   \[
   \frac{\Delta y}{\Delta x} = \frac{y_2-y_1}{x_2-x_1}
   \]

   **Interpretation:**

/10
Best-Fit Lines and Slope

Put a best-fit line through the data, calculate slope, and interpret the results. Circle the two points (they do not have to be data points) you use for your calculation. SHOW YOUR WORK. Also be sure to label your answer with the appropriate units.

1. Slope = \( \frac{\Delta y}{\Delta x} \)

2. Slope = \( \frac{\Delta y}{\Delta x} \)
3. Slope $= \frac{\Delta y}{\Delta x}$

4. Slope $= \frac{\Delta y}{\Delta x}$
Circle Lab

Purpose: You are going to discover the relationship between circumference and diameter by measuring a variety of circular objects, graphing your data, and finding the slope of your line.

Materials: Circular objects       String       Ruler or meter stick

Procedure:
1. Find at least 6 circular objects of different sizes.
2. Measure the circumference (in cm) of each object using string.
3. Measure the diameter (in cm) of each object using a ruler or meter stick.
4. Graph the data, putting circumference on the y-axis, and diameter on the x-axis.
5. Draw a best-fit line through your data.
6. Find the slope of your best-fit line. **Circle the two points on your line that you are going to use to calculate slope.**
7. Describe what the slope of the best-fit line represents.

Data:

<table>
<thead>
<tr>
<th>Name of Object</th>
<th>Circumference (cm)</th>
<th>Diameter (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

\[
\text{Slope Calculation} = \text{Rise} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{--}{--} = \\
\text{Run} = \frac{\Delta x}{\Delta x} = \frac{x_2 - x_1}{x_1} = --
\]

What does the slope represent?
Guide to Writing Lab Reports

TITLE
The title must specifically describe the investigation
Instead of using “Spring Lab”, use “Effect of Mass on the Stretch of a Spring”

QUESTION
(Purpose or Objective): A brief question that can be answered scientifically.
Use your own words about why you are doing this lab and what you expect to learn by doing it.

After writing the Question include in a separate paragraph some background information, observations, and/or research on the topic.

HYPOTHESIS
(Prediction): An expected, observable relationship.
A testable explanation about how or why something happens, followed by a statement of explanation or reason.
You may use IF...THEN..., BECAUSE...... format:
IF (explanation of what you are going to do or cause), THEN (prediction of results or effect), BECAUSE (reason you are predicting the expected result).

MATERIALS: List of everything needed to perform the investigation in multiple columns to save space

PROCEDURE: The logical steps needed to perform the investigation.
Use numbers for each step. You must include:
Manipulated (Independent) Variable: the variable that experimenter changes
Responding (Dependent) Variable: variable that is measured as a result of changing the Manipulated Variable.
Controlled Variables: the variables that are kept the same throughout the investigation (should be at least three).

1. How all the materials are used.
2. How often measurements are taken and recorded.
3. Specific information (including values for controlled variables)
4. Labeled diagram(s) with specifics (including values for controlled variables) pertaining to the procedure.

(Make sure a 9th grader could do the exact same experiment by following your procedure)

DATA/ANALYSIS: Data reported in a table and an analysis of the results. Include the following:
1. Data Table(s): with labels and units on the columns and rows
2. Graph: if appropriate (including descriptive title, labels, units, etc.)
3. Description of the data: What can you infer from the data? Is there a pattern? If so, what is it? Be specific and use data to help illustrate your findings. For example, if there is a linear relationship, what is the slope? What does the slope mean?
4. Reliability of the data: Do you believe your data? What is the uncertainty (or range) within each set of trials, and do you think the uncertainty is large or small? Should you disregard any data points? If so, why?
5. Error Analysis: Describe possible errors in your experiment. How might the errors have affected the data?
6. Assigned Questions (if applicable): Answer in complete sentences.

CONCLUSION: An answer to your question using specific data from your investigation.
This is where you explain the BIG IDEAS (important concepts) that you learned. Make sure to relate any important ideas from readings/lectures to what you observed in the lab. Conclusions should always be written in your own words in paragraph form.

To help you in writing the Conclusion, revisit your Question and Hypothesis sections. What were you supposed to learn in this investigation? What did you think would happen and, more importantly, why? What actually happened? Explain how you know from your results that your original hypothesis and ideas were correct (or incorrect). Restate your hypothesis along with any corrections you would make based on what you know now.

At a minimum, a good conclusion includes:
1. Restatement of the Hypothesis and whether or not it was correct.
2. Answer to the question or explanation about why they experiment did not answer the question.
3. Support for the answer with data (specific numbers) from the investigation.
4. What you believe are the Big Ideas for the investigation. Why did the results come out the way they did? What is the science behind your results? Why is this investigation important? What are some applications for your investigation? How does your investigation tie in with other knowledge about the topic you studied?
Pendulum Lab

**Purpose:** You will design an experiment to determine how one variable affects the period (T) of a pendulum. You will get the choice of testing the effect of angle, length, or mass.

**Vocabulary:**
- **Period (T):** the amount of time it takes for one wave cycle. For a pendulum, the period is the time it takes for the pendulum to swing back and forth once.
- **Manipulated (Independent) Variable:** a variable that is changed during an experiment
- **Responding (Dependent) Variable:** a variable that is being measured (to see possible effects from changing the manipulated variable)
- **Controlled Variables:** variables that are kept the same during an experiment

**Available Materials:**
- Pendulum Stands
- Masses
- String
- Meter Sticks or Rulers
- Timing Devices
- Protractors
- Tape
- Clamps
- Scissors

**Procedure and Lab Write-Up:**
This is a formal lab report. Use the provided Lab Report Template with the embedded grade rubric. Reports should be neat, preferably typed.

Your write-up should include: (see the Guide to Writing Lab Reports and the template for more detail)

1. **Title**
2. **Question**
3. **Hypothesis**
4. **Materials**
5. **Procedures:** Write a thorough description of your procedures. Try to reduce the error of your experiments where possible. Include a list of your manipulated variable, responding variable, and at least 3 controlled variables.
6. **Diagram:** Draw a diagram of your experimental set-up, which shows some detail about your procedures.
7. **Data:** Create a data table for your experiment. Make sure it is labeled appropriately.
8. **Graph:** Represent your data with a graph: be sure to follow appropriate graphing formatting. Put a best-fit line or curve through your data.
9. **Analysis:** What does your data seem to indicate about the effect of mass on the period of the pendulum?
   A. description of data
   B. description of reliability of the data.
   C. analysis of possible sources of error
10. **Conclusion:** Compare your hypotheses to your data and analysis. Do your data support your hypotheses? Why or why not? Use data from your lab to support your conclusion.
Finding the Best Value and Uncertainty for Data

When you do several trials in an experiment, or collect data for analysis, you want to know 2 things: the best value for your data, and the uncertainty in your data. Why are you interested in the uncertainty? Uncertainty will give you an idea of how consistent your data is (how close all your data is to your best value). If your data has a large uncertainty, it can be due to one of 2 things:

a. your experimental procedure may have a lot of error in it, which will reduce the validity of your best value;
b. your data might have a lot of natural variability, which is important to consider when analyzing the significance of your best value.

To find the best value and uncertainty:
1. Check the data to see if there are any outliers. Outliers may be present for 2 reasons:
   a. unusual data: data that is real but well outside the range of your other values.
   b. inaccurate data: data that is wrong, usually due to human error in the experiment.

2. Discard outliers that you believe are due to inaccurate data. Do not discard outliers if you are not sure if they are inaccurate. Leave outliers in your data table, but indicate whether you are discarding them.

3. To find the best value: find the average of the good data. Record this number in a separate column in your data table.

4. Find the range in the data: mark the highest and lowest values in your data (not including outliers).

5. Find the differences between your average value and the highest and lowest data values.

6. Take whichever difference is larger. This is the uncertainty in the data. Record it as a ± value after the best value. It means that all your data falls within this uncertainty value either above or below your best value.

Examples:
1. Jody records the amount of time it takes for a ball dropped from 2 meters to hit the floor. She records the data in the following table:

   | Time (sec) | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6
   |------------|---------|---------|---------|---------|---------|---------
   |            | 0.24    | 0.30    | 0.88    | 0.21    | 0.25    | 0.19    |

   outlier (discard)

   Best Value = 0.24 + 0.30 + 0.21 + 0.25 + 0.19 = 1.19 sec/5 trials = 0.24 sec

   Range = 0.19 sec (lowest) to 0.30 sec (highest)

   Differences between high and low values and the best value:
   Lowest: 0.24 - 0.19 = 0.05 sec
   Highest: 0.30 - 0.24 = 0.06 sec

   this difference is the largest

   Uncertainty: ± 0.06 sec (all the data are no more than 0.06 sec above or below 0.24 sec)

   Final Answer: Time for a ball to hit the floor from a height of 2 meters = 0.24 ± 0.06 sec
2. Kurt took a survey to see how much TV his teachers watch each week. He got the following information from 20 teachers:
Hours TV watched/week: 20, 3, 0, 5, 7, 32, 12, 30, 5, 8, 13, 4, 2, 18, 41, 10, 7, 0, 2, 14

Note: 41 is an outlier, but is not inaccurate data (just a teacher who's a serious TV junkie), so it will be included. Values of zero are also counted since they are important data.

**Best Value:** Total TV watched = 233 hours/20 teachers = **12 hours/week per teacher**

**Range:** 0 hours/week (lowest) to 41 hours/week (highest)

**Differences** between high and low values and the best value:
Lowest: **12 - 0 = 12 hours/week**
Highest: **41 - 12 = 29 hours/week**

this difference is the largest

**Uncertainty:** ± 29 hours/week

**Final Answer:** Average TV watched in one week by teachers = **12 ± 29 hours/week**

**Note:** The very large uncertainty in the data reflects the large natural variability in how much TV teachers watch. You would not conclude from your data that if someone is a teacher, then that person will watch approximately 12 hours of TV each week.

**Problems:**

1. Christina measures how long it takes a beaker filled with water to heat to 100°C. She uses 7 beakers of water, each one starting with 100 ml of 22°C water in it. She got the following data: 5 min, 11 min, 9 min, 16 min, 14 min, 13 min, 8 min. What is the best value and uncertainty for Christina's data?

2. Steve measures his heart rate after sprinting 100 m. Before each trial, he measures his resting heart rate, which is always 60 beats/min. He gets the following data for 8 trials: 80, 77, 92, 55, 100, 75, 104, 96 beats/min. What is the best value and uncertainty for Steve's data?

3. Bob decided to measure how many drips of water were coming out of his kitchen sink each minute. He got the following data over a 10 minute period: 4, 6, 7, 7, 8, 10, 14, 17, 22, 26 drips/min. What is the best value and the uncertainty for Bob's data?

Why do you think Bob's uncertainty is as large as it is? What might be a better way to analyze Bob's data?
Issues with Measurement: Blood Alcohol Content (BAC):

As you reflect on the following specific situation or questions, consider issues, questions, and concerns that you have regarding the nature of measurement. Be prepared to discuss them in class.

Suppose a person, over 21 years of age, is suspected of driving while under the influence of alcohol (DUI). The person has blood withdrawn for the purpose of doing a blood alcohol content (BAC) test. Five people independently run the BAC test from portions of the same original sample and acquire the following results:

- Trained assistant: 0.10 (\% BAC)
- Nurse: 0.07
- Resident Intern (new MD): 0.0713
- Laboratory Technician: 0.06
- Head Doctor (MD): 0.17

1. What would you report as the BAC for the individual being tested? Give the best value and uncertainty for your answer.

2. Did you discard any data? If so, why? If not, explain why you think all the data is valid.

3. Give several reasons why five trained individuals might come up with different readings from the same blood sample.

4. Do you believe the person is guilty of a DUI, according to the information given in the Washington State Laws (see following page)? Explain why or why not.

5. If the State of Washington decided to pursue a DUI conviction for this person, and you were this person’s lawyer, do you think you could get an acquittal? Why or why not?

6. What is the danger of only doing one trial in an experiment? What if the head MD was the only measurement taken? What if the laboratory technician was the only measurement taken?
The following excerpts from the Motor Vehicle Laws for the State of Washington might help in your decisions about whether the person described above is legally guilty of a DUI:

**From RCW 46.61.502: Driving under the influence**

(1) A person is guilty of driving while under the influence of intoxicating liquor, marijuana, or any drug if the person drives a vehicle within this state:

(a) And the person has, within two hours after driving, an alcohol concentration of 0.08 or higher as shown by analysis of the person’s breath or blood made under RCW 46.61.506; or

(b) The person has, within two hours after driving, a THC concentration of 5.00 or higher as shown by analysis of the person’s blood made under RCW 46.61.506; or

(c) While the person is under the influence of or affected by intoxicating liquor, marijuana, or any drug; or

(d) While the person is under the combined influence of or affected by intoxicating liquor, marijuana, and any drug.

**From RCW 46.61.503: Driver under twenty-one consuming alcohol or marijuana**

(1) Notwithstanding any other provision of this title, a person is guilty of driving or being in physical control of a motor vehicle after consuming alcohol or marijuana if the person operates or is in physical control of a motor vehicle within this state and the person:

(a) Is under the age of twenty-one; and

(b) Has, within two hours after operating or being in physical control of the motor vehicle, either:

(i) An alcohol concentration of at least 0.02 but less than the concentration specified in RCW 46.61.502, as shown by analysis of the person’s breath or blood made under RCW 46.61.506; or

(ii) A THC concentration above 0.00 but less than the concentration specified in RCW 46.61.502, as shown by analysis of the person’s blood made under RCW 46.61.506.

**From RCW 46.61.506: Persons under influence of intoxicating liquor or drug — Evidence — Tests — Information concerning tests.**

(5) Withdrawal of blood for the purpose of determining its alcoholic or drug content may be performed only by a physician, a nurse, or certified technician.
Chapter 1 Reading Questions

Read Chapter 1, p. 5-16 and p. 22-24 in your Physical Science Textbook. Then answer the following questions.

1. Why do you think it is important to research and gather information before running your own experiment in science?

2. Write the definition of dependent and independent variable given in your textbook below:
   Dependent variable:
   What is the other name we use for dependent variable? __________________________

   Independent variable:
   What is the other name we use for independent variable? ________________________

3. What is a constant?

   What is the other name we use for constant in an investigation? __________________

4. Describe what bias is in science.

5. Give three examples, either ones we discussed in class, or your own, of how a scientist’s bias might affect their treatment of the data.

6. Describe the steps that scientists can use to reduce bias and validate experiments.

7. What is the difference between a scientific theory and a scientific law?
8. Which question cannot be answered by science?
   A. How do birds fly?  
   B. How does a clock work?  
   C. Is this a good song?  
   D. What is an atom?

9. What is precision?

   When reporting the best value and uncertainty in data, which part indicates the precision?

10. What is accuracy?

   When reporting the best value and uncertainty in data, which part indicates the accuracy?

11. Give an example of experimental results that are precise but not accurate.

12. Give an example of experimental results that are accurate but not precise.

13. Two students measure the speed of sound in a lab. Student A obtains 344 ± 12 m/s. Student B obtains 339 ± 8 m/s. The actual speed of sound is 343 m/s. Which student was more accurate, and which was more precise?

14. In figure 18 on p. 23, there is a graph that shows a “break in the vertical axis.” I’ve told you to not use a break in your scale on your graphs in class. Why?

15. Instead of using a break in the scale, what should you do if you want to spread out your scale so you can more easily see variation among data that are close in value to each other? (For example, data that ranges from 16°C to 25°C like in the graph shown in Figure 18).

16. In the section on constructing line graphs, what does the text say is the most important factor in making the graph? Do you agree or disagree? Why?

17. The text also states that when the points are related, you should connect the points. I’ve told you that you should not connect the points if there is a relationship between them. What are some better ways to show relationships within a data set?
What Went Wrong in Flint Article Questions

Go to the Investigations link under the Physics Documents section of my Website, and/or on Schoology. http://www.mercerislandschools.org/Page/7844. Find the Article called “What went wrong with Flint” and answer the questions below.

1. What were some of the early symptoms that residents of Flint started having after the city switched the drinking water supply to the Flint River?

2. Why was corrosion control needed to be put in Flint’s water?

3. In science classes, you are taught the importance of careful procedures and doing many trials to obtain accurate results. The Department of Environmental Quality (DEQ) made two mistakes detailed in the second bullet point in the article. What were they, and how did this affect their lead data?

4. The city threw out two data points. How did this affect the results of their analysis of the level of threat from lead contamination in Flint’s water?

5. One of the two data points the DEQ threw out was a clear outlier. What is the procedure they should have followed when deciding whether or not to throw out an outlier?

6. Why did Flint switch their water source from Detroit’s water to the Flint River water?
7. List four other mistakes the DEQ made in their lead testing protocol that led to their underestimation of the lead levels in the water?

8. What level of lead did Walters find in her water at home? How much higher was this than the allowed amount?

9. What are the effects of lead on people, especially children?

10. Why do you think the DEQ threw out the two data points and used the protocols that they did? Do you think they were innocent mistakes, sloppy protocols based on laziness or ignorance, a move to cover up the results, a combination of these things, or something else? Use example(s) from the article and material you have learned during the Investigations Unit to justify your answer.

11. Read the update from the *Washington Post* at the end of the article and find out the status of the criminal charges that have been filed in this case, and who they were filed against. List the jobs of people who are being charged, and what they are being charged with. Be sure to read the entire article to get a complete list.
Best Value and Uncertainty Exercises

Calculate the best value and the uncertainty for the problems below. Determine whether there are any outliers that should be discarded (remember not all outliers should be thrown out) before you find your best values. If you discard data, state the reason why.

1. Susan is trying to figure out her “weight.” She has a bathroom scale that is digital and goes to the tenths place. One morning she “weighs” herself 5 times. The values she records are: 120.0, 128.2, 125.5, 152.5, and 123.7 pounds. Determine the best value and uncertainty for Susan’s weight.

2. Sophie keeps track of her car’s gas mileage. She divides the number of miles she drives by the number of gallons she puts in her car during each gas station fill-up. These are the values she calculates for her gas mileage after 10 fill-ups at the gas station: 25.3, 26.2, 24.1, 23.4, 27.5, 25.4, 15.2, 26.4, 22.1, 24.4 mi/gal. What is the best value and uncertainty for the gas mileage of Sophie’s car?

3. John’s growing a Chia Pet. He measures the amount of growth in millimeters that he sees each day in his pet. He gets these numbers for each of the following 20 days:

<table>
<thead>
<tr>
<th>Day</th>
<th>Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>0</td>
</tr>
<tr>
<td>19</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

What is the best value and uncertainty for the growth rate of John’s Chia pet?

4. Marlena sets up a science experiment where she is trying to determine the effects of tension and length on the pitch (frequency) of a guitar string. She does 5 tests. In each test she increases the force she applies to the string by 10 Newtons, and she increases the length by 10 cm. What is wrong with Marlena’s experimental set-up, and how can she fix it?

5. Geoff needs to know the length of his spring when there is no mass on it. Laying it on the table, he measures it 6 times and records the following data: 23, 23.2, 22.4, 24.1, 29, and 23.25 cm. What is the best value and uncertainty for the length of Geoff’s spring?
6. Geoff now measures how his spring stretches when he hangs various masses from it. These are the data he collects:

<table>
<thead>
<tr>
<th>Mass (g)</th>
<th>Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>24.5</td>
</tr>
<tr>
<td>20</td>
<td>25.2</td>
</tr>
<tr>
<td>20</td>
<td>24.3</td>
</tr>
<tr>
<td>50</td>
<td>28.4</td>
</tr>
<tr>
<td>50</td>
<td>30.3</td>
</tr>
<tr>
<td>50</td>
<td>27.9</td>
</tr>
<tr>
<td>100</td>
<td>30.0</td>
</tr>
<tr>
<td>100</td>
<td>30.6</td>
</tr>
<tr>
<td>100</td>
<td>31.1</td>
</tr>
<tr>
<td>200</td>
<td>64.3</td>
</tr>
<tr>
<td>200</td>
<td>36.0</td>
</tr>
<tr>
<td>200</td>
<td>32.2</td>
</tr>
<tr>
<td>400</td>
<td>45.7</td>
</tr>
<tr>
<td>400</td>
<td>24.5</td>
</tr>
<tr>
<td>400</td>
<td>82.0</td>
</tr>
<tr>
<td>500</td>
<td>54.6</td>
</tr>
<tr>
<td>500</td>
<td>56.3</td>
</tr>
<tr>
<td>500</td>
<td>55.1</td>
</tr>
</tbody>
</table>

Find the best value for each measured mass and graph the data. Follow the format given in this workbook. Then, draw a best fit line through the data.

6a. What is the slope of the best fit line through Geoff's data and what does it represent?

6b. Why doesn't the best fit line go through the point (0,0)? What does the Y-intercept represent?

6c. Are there any values that you think are outliers that should be discarded? If so, which one(s) and why?

6d. Are there any other data that you have concerns about? If so, why?

6e. Based on this data, predict what the length of the spring would be if 300 g were hung from it. What would the length of the spring be if 1000 g were hung from it? Which of these do you feel more comfortable predicting and why?
Study Guide for the Investigations, Data, and Ethics Test

Understand and identify the parts to a scientific investigation, including:
- An appropriate hypothesis
- Manipulated variable, Responding variable, and Controlled variables
- Control group
- Validity measure
- Importance of clear, specific procedures and diagrams
- A well-written analysis and conclusion

Know how to construct a graph, including:
- Placing manipulated variable on the x-axis, and the responding variable on the y-axis
- Using appropriate labels, units, and a title
- Choosing an appropriate scale (each square worth the same amount and using as much of the space available as possible
- Plotting only the best value for each set of trials on the graph

Understand how to analyze data on a graph, including:
- Identifying a trend in a data set on a graph
- Placing a best-fit line or curve through a trend in data on a graph
- Finding the slope of a best-fit line (including using two points on the line, calculating the slope, and labeling the slope with the correct units).
- Interpreting what the slope of a best-fit line says about the data

Know how to find the best value and uncertainty in data, including:
- Identifying outliers
- Deciding whether to keep or discard an outlier and justifying that decision
- Finding the average of the good trials (best value)
- Finding the uncertainty of the data, and reporting that as a ± value
- Reporting the answer in the format “Best value ± uncertainty” with units (example: 3 ± 0.2 m/s as the best value and uncertainty for the speed of a toy car)

Understand the difference between precision and accuracy, including:
- The best value, when compared to a known answer, can indication the accuracy of the experiment
- The uncertainty gives an idea of the precision of the experiment (reliability of data)
- The rules and use of significant figures when reporting data (honors only)

Understand the Issues and Ethics in Science, including:
- That science is inherently full of uncertainty, and that no data set is ever perfect or can prove a hypothesis or theory as a “fact.”
- Different ways scientists might represent data to highlight results (i.e. scales, trend lines or curves, averaged data, bars, color)
- Bias in scientific reporting and in scientists
- Reasons why having rigorous protocols to follow when conducting scientific investigations is important
- The peer review process and why it is important
- Reasons for unethical scientific behavior and potential consequences for scientists and society