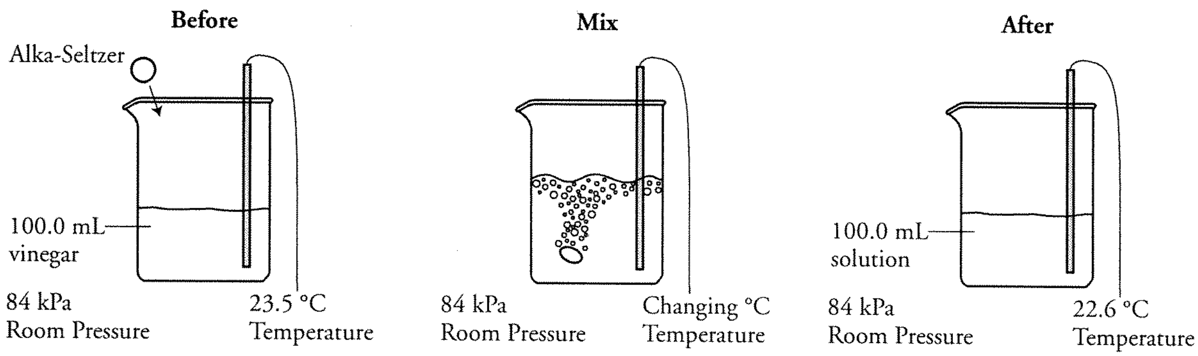
Fundamentals of Experimental Design

What is measured during a controlled experiment?

Why?

Working in the science lab can be a lot of fun. Mixing random chemicals and burning stuff just to see what happens can be entertaining (and possibly dangerous), but it doesn't lead to anything helpful to the scientific community. In order to be helpful to the community, a researcher's work in the lab must be systematic. A researcher usually asks a question and then designs an experiment to investigate that question. In this activity you will identify different types of variables that will help you design controlled experiments.

Model 1 – Alka-Seltzer® and Vinegar



1. Briefly describe the reaction illustrated in Model 1 in one or more complete sentences.

2. Did the room pressure change as the reaction occurred? If yes, was there an increase or decrease?

3. What two pieces of evidence observed during the "mix" phase of the reaction suggest that a chemical change is taking place?

4. Did the solution temperature increase or decrease during the reaction?

Model 2 – Results of Alka-Seltzer® Experiment

	Number of Alka-Seltzer Tablets	Volume of Vinegar (mL)	Room Pressure (kPa)	Initial Temp (°C) (Vinegar Solution)	Final Temp. (°C) (Final Mixture)
Trial 1	1	100.0	84	23.5	22.6
Trial 2	2	100.0	84	23.5	21.5
Trial 3	3	100.0	84	23.5	20.4
Trial 4	4	100.0	84	23.5	19.2
Trial 5	5	100.0	84	23.5	18.1

5. Which trial in the Model 2 data table corresponds to the reaction illustrated in Model 1?

6. Consider the five trials that produced the data in Model 2.
   a. What variable was purposefully changed in the experiment?

   b. What variable changed as a result of changing the variable listed in part *a*?

7. What variable(s) shown in the Model 2 data table remained constant among all the trials?

Model 3 – Boiling Points of Alcohols

Alcohol Name	Formula	Number of Carbons	Volume of Alcohol (mL)	Boiling Point (°C)	Room Pressure (kPa)
Methanol	CH_3OH	1	75	64.7	101
Ethanol	CH_3CH_2OH	2	75	78.4	101
Propanol	$CH_3CH_2CH_2OH$	3	75	97.1	101
Butanol	$CH_3CH_2CH_2CH_2OH$	4	75	117.7	101
Pentanol	$CH_3CH_2CH_2CH_2CH_2OH$	5	75	137.9	101

8. Describe the similarities and differences in the five alcohols used in the Model 3 experiment.

9. Consider the experiment that produced the data in Model 3.
   a. What variable was purposefully changed in the experiment?

   b. What variable changed as a result of changing the variable listed in part *a*?

10. What variable(s) in the Model 3 data table remained constant among all the trials?

STOP

Read This!

When designing an experiment, you need to consider three types of variables. The **independent variable** is changed by the experimenter by design. This variable is sometimes called the "manipulated variable." The **dependent variable** is what changes as a result of the change in the independent variable. This variable is sometimes called the "responding variable." In some cases more than one dependent variable is considered. The third category involves **controlled variables**. These are variables that you think might change the outcome of the experiment, but since you are not studying them, you need to keep them constant in each trial.

11. Identify the independent, dependent, and controlled variables for the experiments that produced the data shown in Model 2 and Model 3.

Model Experiment	Variables		
	Independent	**Dependent**	**Controlled**
Alka-Seltzer® and Vinegar			
Boiling Points of Alcohols			

Read This!

A well-written research question states the independent and dependent variables for an experiment. For example, a student investigated the effect of the deicer, magnesium chloride, on vegetation on the sides of highways. Her research question was, "What is the effect of magnesium chloride solution concentration on the growth of rye grass?"

12. Write a research question, using the format suggested in the *Read This!* box, for the experiments in Models 2 and 3.

    Alka-Seltzer® and Vinegar —

    Boiling Points of Alcohols —

13. A student wonders, "Will changing the volume of alcohol in a boiling point experiment change the boiling point of the liquid?" Identify the variables that should be considered in this experiment.

    Independent **Dependent** **Controlled**

Extension Questions

14. Many experiments designed to investigate the reaction of Mentos® with Diet Coke® have been documented on YouTube. Design and write an experiment that uses the knowledge gained in this activity to investigate this reaction. Include a research question; the independent, dependent and controlled variables; and a simple procedure.

15. Scientists may design an experiment with a **control group**, which is a set of organisms or samples that do NOT receive the treatment (the independent variable) that is being tested. Scientists can then compare normal changes in organisms or samples with those that might have occurred because of the treatment. The idea of a "control group" is not the same as a "controlled variable." Suppose a scientist is doing an experiment to determine the effect of a cancer drug on mice with lymphoma.

    a. What are some of the variables the scientist should control in the experiment?

    b. Describe the control group for this experiment.

Organizing Data

How is data displayed to make it meaningful?

Why?

Scientists rely on data to describe nature and uncover relationships. The raw data—measurements taken in the lab—are most useful when they are organized in a way that makes the relationships clear. In this activity you will explore two common ways that scientists organize data to help in analysis.

Model 1 – Copper Samples

Group Number	Volume (cm^3)	Mass (g)	Substance
1	2.0	17.92	Copper
2	6.0	50.89	Copper
3	10.0	93.45	Copper
4	8.0	79.30	Copper
5	14.0	125.44	Copper
6	4.0	39.80	Copper
7	12.0	103.85	Copper

Room Temperature: 21.7 °C

1. What substance were the students working with to obtain the data in Model 1?

2. What variables did the students measure to produce the data in Model 1?

3. Briefly describe an experiment that the class might have done on the day that the data in Model 1 was collected. Discuss your answer with your group members to be sure there is consensus.

4. Consider the data in Model 1.

   a. Which variable was the **independent variable** in the experiment, and why do you think it was the independent variable?

   b. Which variable was the **dependent variable** in the experiment, and why do you think it was the dependent variable?

   c. List two **controlled variables** in the experiment?

STOP

5. Consider the data in Model 1.

   a. How is the data organized?

   b. Is the table in Model 1 organized in a way that helps determine a relationship between the independent and dependent variables in the experiment? Explain.

6. Propose a better way to organize the data in Model 1, and transcribe the data into the table below.

Group Number	Volume (cm^3)	Mass (g)	Substance

7. The data table in Question 6 should allow you to state a relationship between the variables involved in the class's experiment. Complete the following statement:

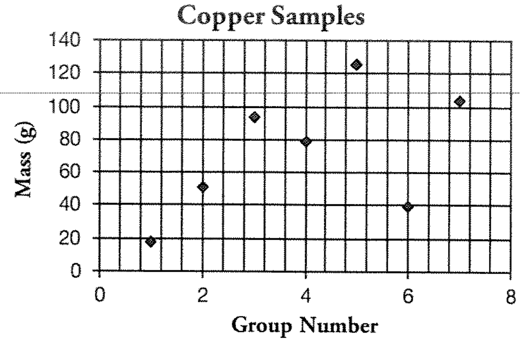
   As the volume of copper increases, the mass of copper ______________________________.

Read This!

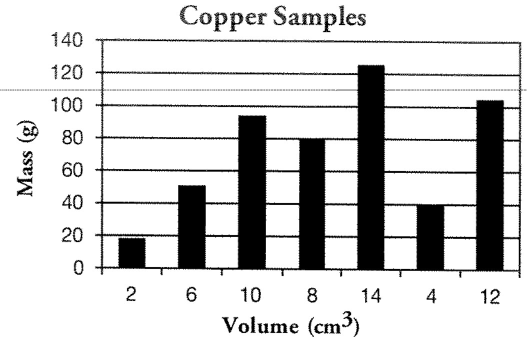
When scientists design an experiment they are usually looking for a cause-and-effect relationship between the independent variable and the dependent variable. Therefore, organizing the data by the independent variable is the easiest way to reveal a relationship. When the data is not organized, the relationships are not apparent.

Model 2 – Graphs for Copper Data

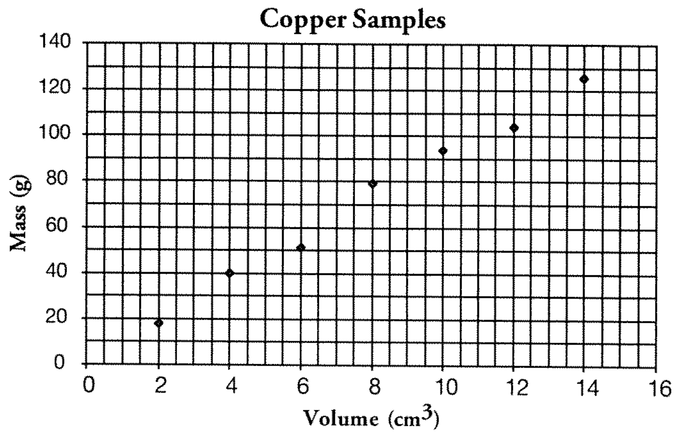
Graph A



Graph B



Graph C



8. Identify each of the graphs in Model 2 as a bar graph or a scatter plot.

9. One of the data points in graph B indicates that a volume of 8 cm^3 has a mass of 80 g. Which other graph in Model 2 shows this same data?

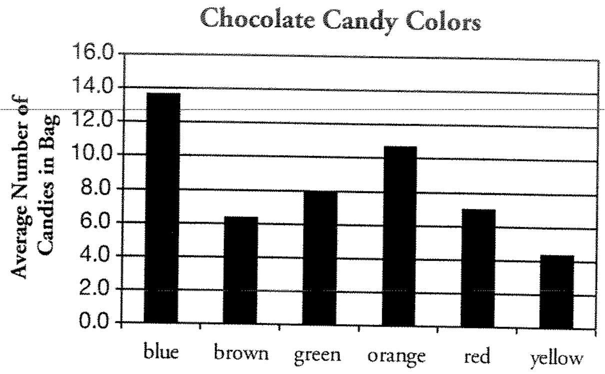
10. Of the three graphs in Model 2, which illustrates the relationship between the variables that you stated in Question 7 most clearly?

Read This!

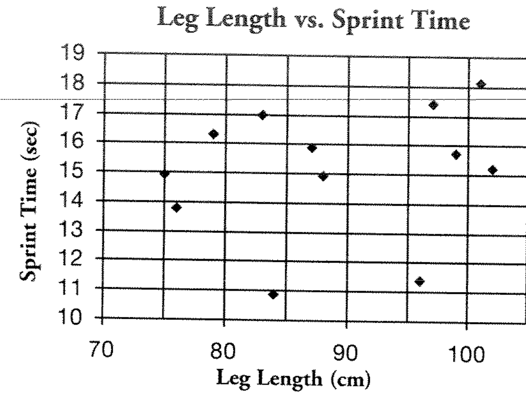
Scientists use graphs to clearly illustrate whether or not there is a relationship between variables. In most cases a scatter plot is used. Bar graphs are sometimes used if the independent variable is limited to specific numeric values (where the values in-between are not possible) or is non-numeric. A special type of bar graph called a histogram is used in cases where the scientist wants to show how often something happens.

Model 3 – More Examples of Graphs

Graph D



Graph E



11. Identify the independent variable and dependent variable for each of the graphs in Model 3.

	Graph D	Graph E
Independent Variable		
Dependent Variable		

12. Match the experimental questions below to the appropriate graph from Model 3.
    a. "Is the number of candies in a bag of chocolates dependent on the color of the candy?"
    Graph _____
    b. "Does the length of a person's leg affect the time it takes them to sprint 60 yards?"
    Graph _____

13. Why was the data for Graph D plotted in a bar graph?

14. Using the graphs in Model 2 and Model 3 as examples of proper graphs, identify the axis (*x* or *y*) where you would usually plot the independent variable.

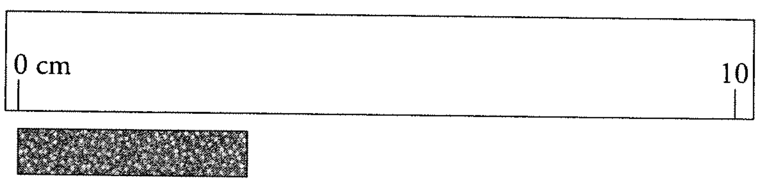
Significant Digits and Measurement

What digits are significant when recording a measurement?

Why?

Scientists do a lot of measuring. When scientists use an instrument (such as a ruler, graduated cylinder, spectrophotometer or balance) to measure something, it is important to take full advantage of the instrument. However, they can't cheat and record a better measurement than the instrument is capable of. There is an understanding among scientists of the proper way to record valid measurements from any instrument. When you are the scientist, you must record data in this way. When you are reading other scientists' work, you must assume they recorded their data in this way.

Model 1 – Ruler A



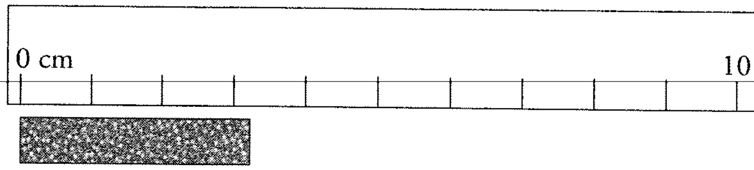
Susan	3 cm
Maya	2 cm
Jonah	2.5 cm
Tony	3.00 cm
Emily	3¼ cm
Dionne	3.33 cm

1. What distances can you be certain of on the ruler in Model 1?

2. Six students used the ruler in Model 1 to measure the length of a metal strip. Their measurements are shown at the right. Were all of the students able to agree on a single value (1, 2, 3…) for any digit (ones place, tenths place, etc.) in the measurement? If yes, which value and digit did they agree on?

3. The ruler in Model 1 is not very useful, but a measurement can be estimated. Discuss in your group how each student might have divided up the ruler "by eye" in order to get the measurement that he or she recorded.

Model 2 – Ruler B



Susan	3.2 cm
Maya	3.1 cm
Jonah	3.3 cm
Tony	3 cm
Emily	3.25 cm
Dionne	3.20 cm

4. The students obtained a better ruler, shown in Model 2. What distances can you be certain of on this ruler?

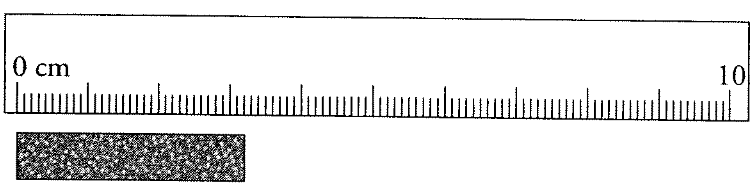
5. Were the students able to agree on a single value (1, 2, 3…) for any digit (ones place, tenths place, etc.) in their measurements using the ruler in Model 2? If yes, what value in what digit did they agree on?

6. What feature of the ruler in Model 2 made it possible for the students to agree on a value in that digit?

7. There will always be uncertainty in any measurement. This causes variation in measurements even if people are using the same instrument. Compare the variation in the measurements made by the six students using the rulers in Models 1 and 2. Which ruler resulted in greater variation? Explain why that ruler caused more variation.

STOP

Model 3 – Ruler C



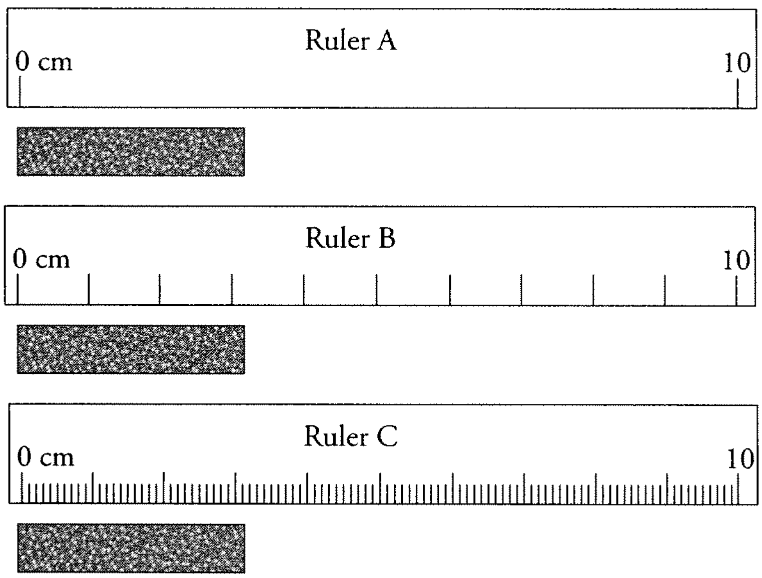
Susan	3.21
Maya	3.20 cm
Jonah	3.22 cm
Mark	3.2 cm
Emily	3.215 cm
Dionne	3.205 cm

8. The students obtained an even better ruler, shown above in Model 3.
   a. Were the students able to agree on a single value for any of the digits in their measurements using the new ruler? If yes, what value(s) did they agree on in which digits?
   b. What feature of the ruler in Model 3 made it possible for the students to agree on the values in those digits?

Read This!

When humans use measuring instruments, variation is expected. Everyone will estimate differently between marks on the instrument. On the other hand, digits that are certain (based on marks on the instrument) should not vary from person to person.

Model 4 – Valid Measurements



Valid Measurements	Invalid Measurements
3 cm	2.5 cm
2 cm	3.00 cm
	3¼ cm
	3.33 cm
3.2 cm	3 cm
3.1 cm	3.25 cm
3.3 cm	3.20 cm
3.21 cm	3.2 cm
3.22 cm	3.215 cm
3.20 cm	3.205 cm

9. The measurements taken in Models 1–3 have been combined in Model 4. The measurements that follow the rules of measurement agreed upon by scientists are in the "Valid Measurements" column. Those that do not follow the rules are in the "Invalid Measurements" column. For each valid measurement shown in Model 4, draw a square around the certain digits (if any) and circle the digits that were estimated (if any).

10. Based on the examples in Model 4, circle the best phrase to complete each sentence below.

    a. In a valid measurement, you record (zero, one, two) estimated digit(s).

    b. In a valid measurement, the estimated digit is the (first digit, second to last digit, last digit) in the measurement.

    c. In a valid measurement, the estimated digit corresponds to (the largest marks, the smallest marks, one tenth of the smallest marks) on the instrument.

11. Using Ruler B from Model 4, Tony recorded a measurement of 3 cm. Explain why this was an invalid measurement.

12. Using Ruler B from Model 4, Dionne recorded a measurement of 3.20 cm, which was invalid. But when Maya made the same measurement using Ruler C, it was considered valid. Explain why the zero was acceptable when using Ruler C, but not when using Ruler B.

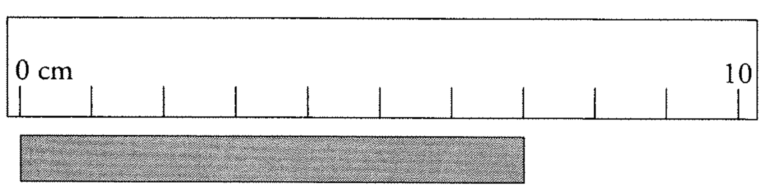
13. A student recorded the length of a test tube as 5.0 cm. Which ruler in Model 4 was the student using? Explain.

14. In Model 4, Ricky recorded his measurement 3.19 cm using Ruler C. His classmates thought he was wrong because his second digit was not "2." However, Ricky's recorded measurement is perfectly valid. Explain.

Read This!

When a measurement is recorded properly, all of the digits that are read directly (certain) and one estimated (uncertain) digit are called **significant digits**. The number of allowable significant digits is determined by the marks or gradations of the instrument. Sometimes a "0" is the estimated digit and must be recorded.

15. Record the length of the wooden splint to the proper number of significant digits.



16. Record the length of the wooden splint to the proper number of significant digits.