

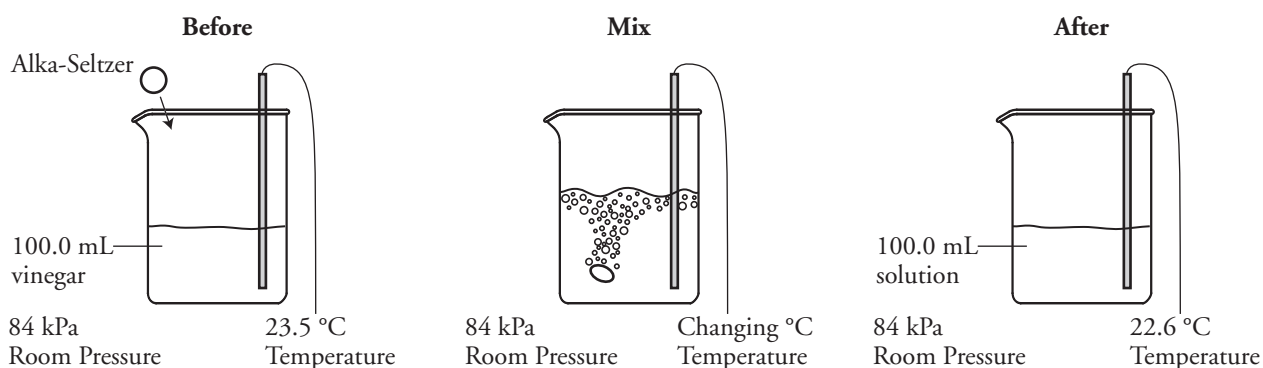
Fundamentals of Experimental Design

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 ₃ OH | 1 | 75 | 64.7 | 101 |
| Ethanol | CH ₃ CH ₂ OH | 2 | 75 | 78.4 | 101 |
| Propanol | CH ₃ CH ₂ CH ₂ OH | 3 | 75 | 97.1 | 101 |
| Butanol | CH ₃ CH ₂ CH ₂ CH ₂ OH | 4 | 75 | 117.7 | 101 |
| Pentanol | CH ₃ CH ₂ CH ₂ CH ₂ CH ₂ OH | 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?



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

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?



5. Consider the data in Model 1.
- How is the data organized?
 - 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 (cm³) | 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:

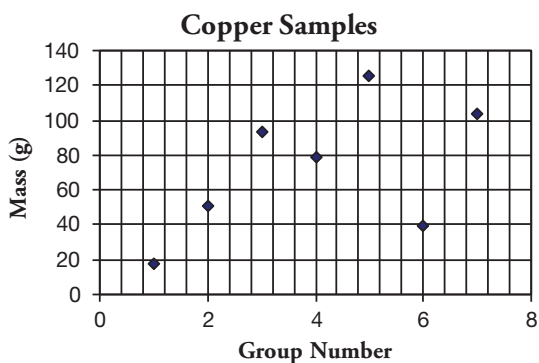
As the volume of copper increases, the mass of copper _____.

Read This!

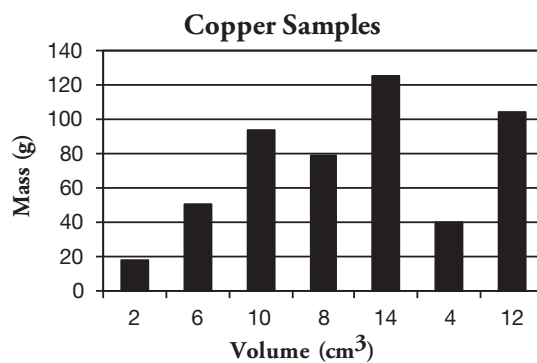
When scientists design an experiment they are usually looking for a cause-and-effect relationship between the independent variable and the dependent variable. Therefore, organizing the data by the independent variable is the easiest way to reveal a relationship. When the data is not organized, the relationships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

Model 2 – Graphs for Copper Data

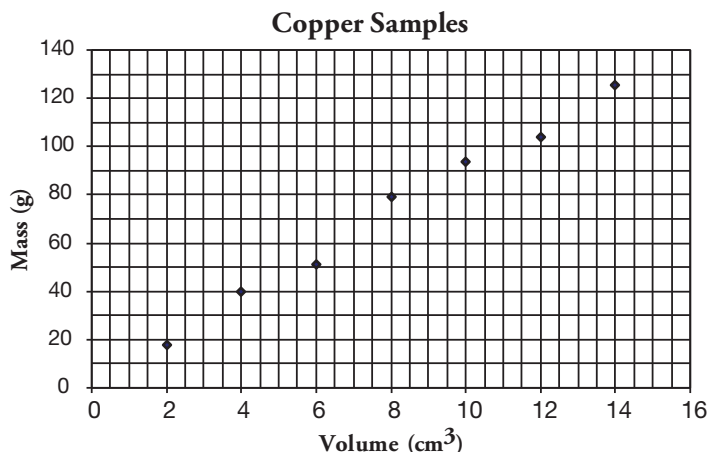
Graph A




Graph B



Graph C



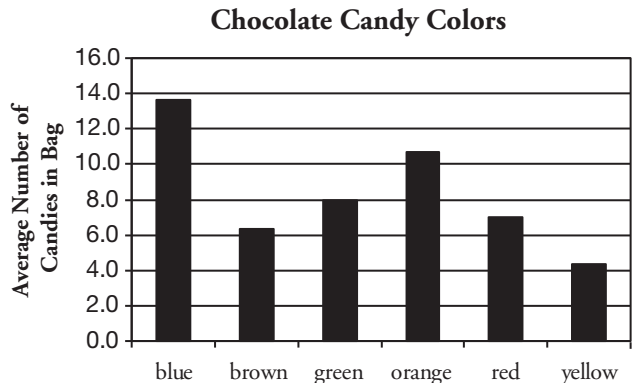
8. Identify each of the graphs in Model 2 as a bar graph or a scatter plot.
9. One of the data points in graph B indicates that a volume of 8 cm³ has a mass of 80 g. Which other graph in Model 2 shows this same data?
-  10. Of the three graphs in Model 2, which illustrates the relationship between the variables that you stated in Question 7 most clearly?

Read This!

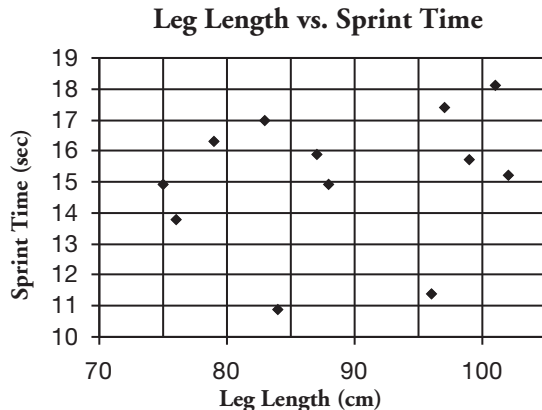
Scientists use graphs to clearly illustrate whether or not there is a relationship between variables. In most cases a scatter plot is used. Bar graphs are sometimes used if the independent variable is limited to specific numeric values (where the values in-between are not possible) or is non-numeric. 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.
- “Is the number of candies in a bag of chocolates dependent on the color of the candy?”
Graph _____
 - “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.

15. For each of the following experiments, choose “scatter plot” or “bar graph” as the most appropriate way to display the data. Justify your answer.

a. Students heated oil on a hot plate at the #4 setting for different amounts of time. They wanted to answer the question “How long do you need to heat an oil bath to reach a given temperature?”

| Volume Oil (mL) | Hot Plate Setting | Initial Temp. of Oil (°C) | Time Heated (min) | Final Temp. of Oil (°C) |
|-----------------|-------------------|---------------------------|-------------------|-------------------------|
| 250 | #4 | 21 | 0 | 21 |
| 250 | #4 | 21 | 5 | 30 |
| 250 | #4 | 21 | 10 | 38 |
| 250 | #4 | 21 | 15 | 47 |
| 250 | #4 | 21 | 20 | 57 |

b. Students measured the height of each student in class. They wanted to answer the question “What is the most common height among 10th grade students?”

| Height Range | Number of Students |
|----------------|--------------------|
| under 4' 0" | 1 |
| 4' 1" to 4' 6" | 3 |
| 4' 7" to 5' 0" | 5 |
| 5' 1" to 5' 6" | 9 |
| 5' 7" to 6' 0" | 3 |
| over 6' 0" | 1 |

c. The Fish and Wildlife agency measured the size of Pacific salmon for 1 year and recorded the average weight for each species.

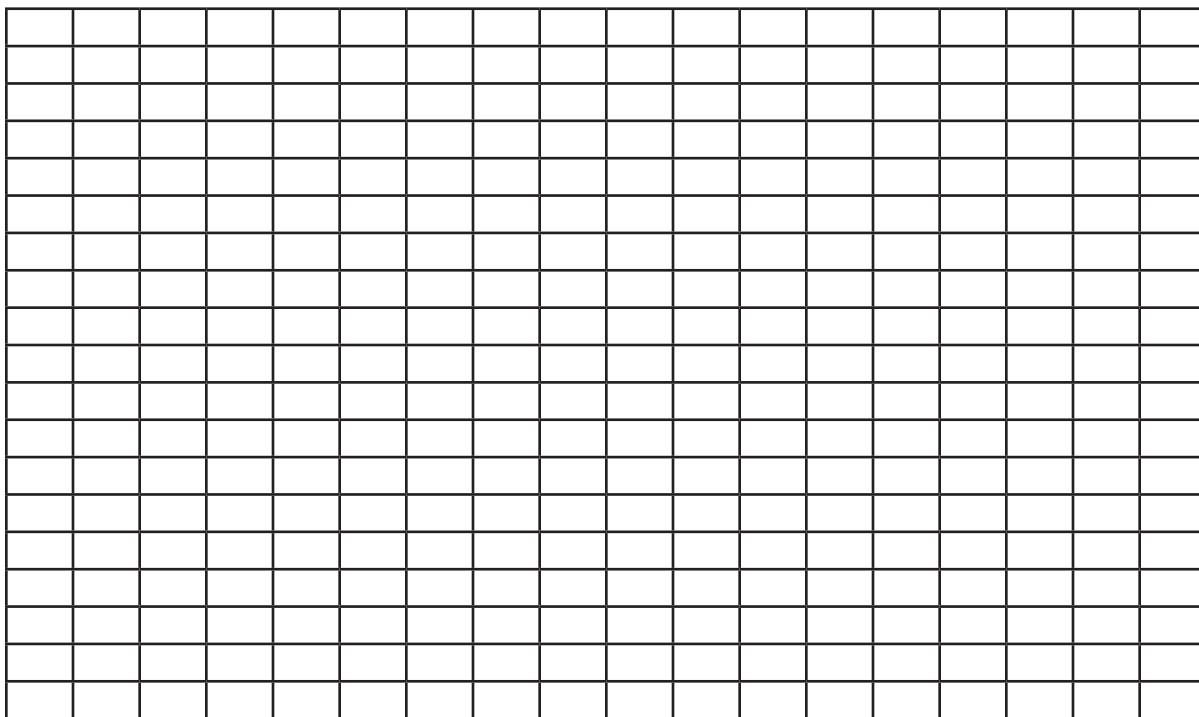
| Salmon Species | Average Weight (lbs) |
|----------------|----------------------|
| King | 15 |
| Sockeye | 8 |
| Silver | 12 |
| Chum | 15 |
| Humpback | 5 |

d. The National Oceanic and Atmospheric Administration measured the pressure of the atmosphere at various altitudes.

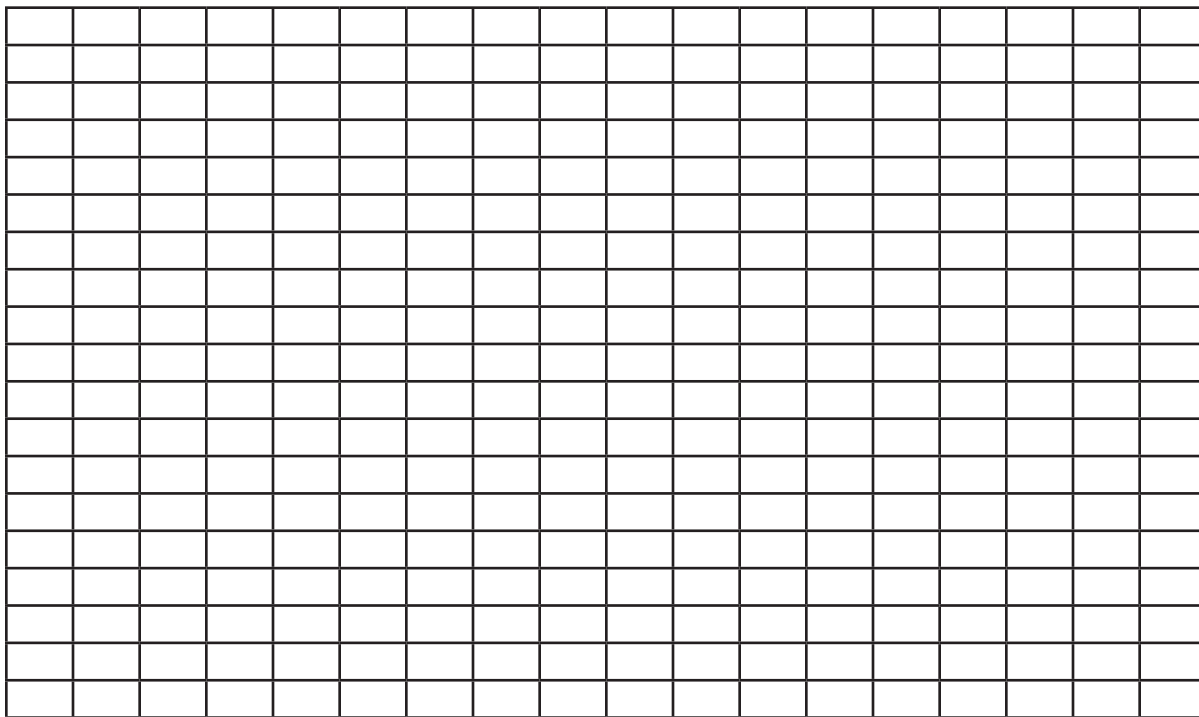
| Altitude (m) | Atmos. Pressure (atm) | Altitude (m) | Atmos. Pressure (atm) |
|--------------|-----------------------|--------------|-----------------------|
| 0 | 1.000 | 16,132 | 0.100 |
| 2750 | 0.750 | 30,901 | 0.010 |
| 5486 | 0.500 | 48,467 | 0.001 |
| 8376 | 0.333 | | |



16. Choose one of the data sets in Question 15 that you selected as appropriate for a scatter plot and graph it here. Remember to label the axes.



17. Choose one of the data sets in Question 15 that you selected as appropriate for a bar graph and graph it here. Remember to label the axes.

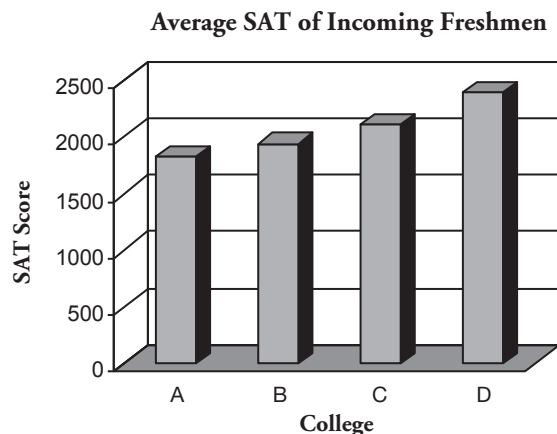


18. Send one representative of your group to another table to share the two graphs constructed in Questions 16 and 17. Does the other group agree that your graphs are properly constructed? If not, what adjustments do you think need to be made?

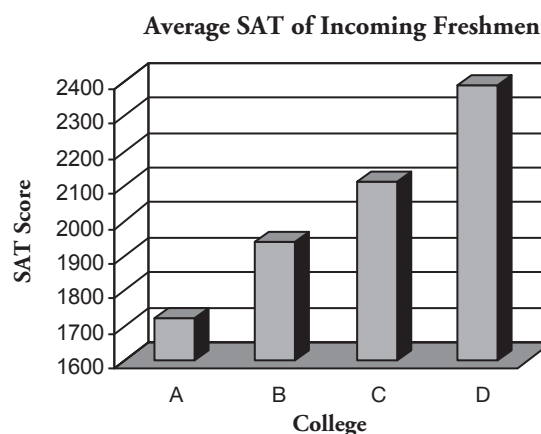
Extension Questions

Model 4 – SAT Scores

Graph F



Graph G



19. Describe the independent and dependent variables for the data that is displayed in Graphs F and G in Model 4.
20. When you look at Graph F, what message is communicated by the relative lengths of the bars to prospective students about College D's average SAT scores compared to the other three schools?
21. When you look at Graph G, what message is communicated by the relative lengths of the bars to prospective students about College D's average SAT scores compared to the other three schools?
22. For each of the graphs in Model 4, estimate the average score for each college represented by the height of the bar. Is the data being displayed in the two graphs the same or different? Support your answer with evidence from the graph.
23. A student takes a quick look at Graph G and says "Based on the size of these bars, it looks to me as though College D had entering freshman with SAT scores nearly four times higher than College A." Explain to this student what mistake he has made in processing the information presented in Graph G.