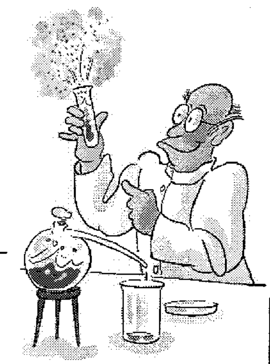
Performing Scientific Experiments

Section 2.1
Using the Scientific Method



Pre-View 2.1

- **Problem** – an observation that needs an explanation or a question that needs an answer
- **Hypothesis** – a possible explanation or answer to a scientific problem that can be tested
- **Experiment** – a step-by-step procedure used to test a hypothesis
- **Conclusion** – the interpreted results of an experiment based on the data; may prove or disprove the hypothesis
- **Theory** – an idea that is accepted as true because it is supported by repeated evidence

Just what is the scientific process, anyway? It's really just a series of steps in logical order that scientists use to help them solve a problem. The steps of the scientific process are shown below.

The Scientific Process

1. PROBLEM
- Start with an observation or a question. This is the "problem" to be solved.
- State the problem. What do you want to find out?
- Research the problem. What do we already know about it?

2. HYPOTHESIS
- Develop a testable statement that tells what you think will happen.

3. DESIGNING THE EXPERIMENT
- Develop a plan to test the hypothesis by determining the following:
  - the dependent and independent variables
  - the constants (or controls) in the experiment
  - the type(s) of data to gather and how to gather the data

4. CONDUCTING THE EXPERIMENT
- Set up the experiment.
- Perform the experiment.
- Record the experimental data.
- Perform calculations and/or organize the data into charts, graphs, or diagrams.

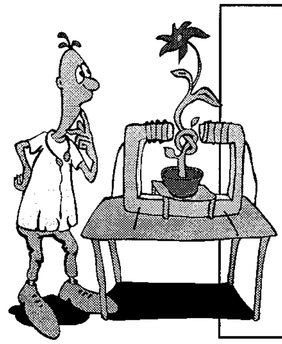
5. CONCLUSION
- Based on your data, was your hypothesis correct?
- If it was not correct, can you develop a new hypothesis to test?

6. THEORY
- If this experiment is repeated many times under similar conditions, then it may lead to a theory. A theory is an idea that is accepted as true because so much evidence supports it.

It may seem like a lot, but it's really not that bad. Let's look at the first two steps more closely in this sub-section, and then we will take a closer look at the other steps.

The Problem

The scientific process starts with a **problem**. Maybe a scientist makes an observation and wants to explain why it happens. Or maybe a scientist has a question that he or she wants answered. The first step is to state the problem and identify a question to be answered. Let's look at a few examples:



Examples of Scientific Problems

- The corn plants in my neighbor's garden grow taller than they do in my garden. Why?
- I've heard someone say that the length of a goldfish is determined by how large its tank or pond. Is this really true?
- In the game of baseball, what causes a curve ball to curve?
- What causes thunder?

The list of scientific questions that can be asked is endless. Can you think of a few?

Some of the observations and questions given above already have answers. For example, there is already a scientific explanation for thunder. If you wanted this question answered, you could research the answer without doing an experiment. On the other hand, you may not be able to research an exact answer as to why your neighbor's corn grows taller than yours. You may have to experiment to find an answer. Even so, doing some research can help you to narrow down possible explanations to be tested.

Example 1: Waldo's family has a vegetable garden, and his father always uses fertilizer. Waldo uses this observation as an idea for his science project. He decides to test the effects of 3 different fertilizers on corn plants. He will use brands X, Y, and Z. The first step in the scientific process is to identify a problem to be answered (or to state an observation to be explained). What questions does Waldo want to answer by his experiment? What kind of research should he do?

In this example, Waldo might ask, *"Which fertilizer, X, Y, or Z, causes corn plants to grow the fastest?"*

Waldo did some research and found that the numbers on a bag of fertilizer stand for the percentages of nitrogen, phosphorus, and potassium in the fertilizer. By doing a little more research, he might be able to come up with an even better question. Waldo looks on the Internet and finds that corn plants like growing in soil high in phosphorus.

What additional questions might he ask once he knows this information? For this example, Waldo comes up with the following question that he wants answered:

Will the fertilizer highest in phosphorus cause the corn plants to grow the fastest?

Many questions can be answered by doing research or by performing experiments, but not all questions can be answered that way. Some questions are based on opinions or are moral in nature. For example, how can you perform an experiment to answer the following questions? The answer is that you cannot!

Examples of Questions Not Answerable By Experiment

- What flavor of ice cream is the best?
- Who is the greatest super hero, Spider-Man, Superman, or Batman?
- Should scientists clone humans?
- Should seed companies modify the genetics of plants?

The best flavor of ice cream can only be answered by opinion. Your favorite flavor will be different from others' favorites, so there is no way to "prove" a favorite scientifically. The greatest super hero is likewise an opinion, and since these characters are fictional, there is obviously no way to test which is the greatest.

The third and fourth example questions are moral questions. Some people believe that cloning and genetic modification are okay. Other people believe these practices are morally wrong. There is no way to answer "should" questions with an experiment.

Example 2: A group of science students performed an experiment using a particular variety of tomato plants that generally grows well in their area. Tomato growers have reported, however, that this variety is subject to heavy insect infestation. The students used two large groups of plants of this variety. Both groups were grown under identical conditions, including amount of sunshine, water, and fertilizer. In addition, one of the groups of plants was sprayed with a weak concentration of soap solution. While conducting research, two students had found information that said mild soap solution might act as an insect repellant.

Using the information above, what question are students most likely trying to answer by performing this experiment?

A. Should farmers use chemical insecticides when growing certain types of tomato plants?
B. Does weak soap solution prevent insect infestation on this variety of tomato plant?
C. Will soap solution application result in larger tomatoes for this variety?
D. Is soap a better insect repellent than a commercial insecticide?

To answer this type of question, read the information about the experiment carefully. What kind of research was performed? What was being tested and why? By answering these questions, hopefully you can see that the correct answer is B. The only thing being tested is the effect of a weak soap solution, so you know that the students wanted to test the effects of the soap solution. The research indicates the reason for using a soap solution is to repel insects. Putting the clues together, you can see that the students wanted to know whether a mild soap solution would prevent insect infestation on this infestation-prone variety of tomato plants.

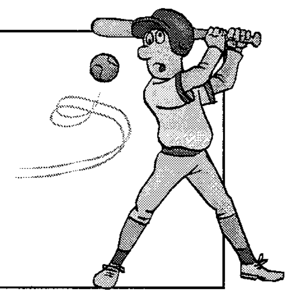
Remember, "should" type of questions cannot be answered by scientific experiments, so answer choice A is not correct. Answer choice C isn't likely because there is no mention of measuring the tomatoes. Answer choice D is also not correct because the students didn't test a commercial insecticide to compare to the mild soap solution, but this question may be something they want to test in a future experiment.

The Hypothesis

Once a scientist narrows down an observation to a specific problem to be answered, the next step is to form a hypothesis. A **hypothesis** is a possible answer or explanation to the problem that can then be tested. It is usually a question written in the form of a statement. Look at some examples below.

Examples of Hypotheses

- Corn plants that get more direct sunlight grow taller.
- Goldfish will grow longer in a larger aquarium.
- A curve ball curves because of the Bernoulli effect.



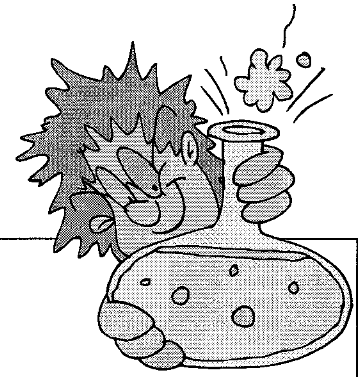
Example 3: Waldo has identified the problem and knows which question he would like answered. Now he needs to form a hypothesis. The hypothesis is a statement of what he thinks will happen. It is a question written in the form of a statement. Waldo comes up with the following hypothesis:

If corn plants are treated with fertilizer X, Y, or Z, then the plants that receive fertilizer Y will grow the fastest because fertilizer Y contains more phosphorus than fertilizer X or Z.

Notice that Waldo used his research about plant nutrients before forming his hypothesis. A hypothesis is sometimes called an *educated guess* because you have to research the problem first instead of making a blind guess without any background information.

Performing Scientific Experiments

Section 2.2
Setting Up Experiments



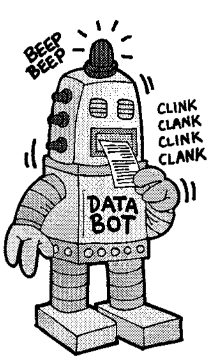
Pre-View 2.2

- **Experiment** – a set of steps used to test a hypothesis
- **Data** – observations, measurements, and other information gathered in an experiment
- **Quantitative data** – measured data; data associated with numbers or specific amounts
- **Qualitative data** – descriptive data; data not associated with numbers or amounts
- **Control group** – the group that is used for comparison; it does not receive the tested element
- **Experimental group** – a group that receives one element being tested
- **Bias** – a belief or opinion that may affect experimental results
- **Unbiased** – having no opinion or being impartial
- **Placebo** – a substance given to a control group that has no effect on the experiment but is used to eliminate bias
- **Constants** – factors that remain the same for all groups during an experiment
- **Variable** – a factor that is changed during an experiment in order to test its effect
- **Independent variable** – the variable used to produce an effect
- **Dependent variable** – the measurable change that occurs because of the independent variable

An **experiment** is a set of steps that are performed to collect data. The data can then be used either to prove or to disprove the hypothesis. The experiment must be designed carefully so that the data collected gives meaningful information. The following questions should be considered when designing an experiment.

Designing an Experiment

- What data should be collected and how?
- How many groups will be used?
- How many subjects per group should be used?
- What will be the control group?
- Will there be a placebo used?
- What are the important constants?
- What is the independent variable?
- What is the dependent variable?



Data

Data is any information gathered during an experiment. Measured data, such as length, mass, pH, temperature, or time of day is called **quantitative data.** Remember, a quantity is an amount of something, so quantitative data deals with numbers or amounts. The data recorded in most experiments is quantitative. Descriptive data, on the other hand, is called **qualitative data**. Color, odor, taste, feel, or any other described quality is considered qualitative data.

Many kinds of information can be recorded during an experiment. However, the only data that should be collected in an experiment is the information that can be used to prove or disprove the hypothesis. The scientist must decide which information is important to record and which isn't.

Section 2.2, continued
Setting Up Experiments

Example 1: Waldo wants to determine which fertilizer, X, Y, or Z, will cause corn plants to grow the fastest. His hypothesis is that the corn plants fertilized with brand Y will grow the fastest because it contains the most phosphorus. What kind of data should Waldo collect in his experiment?

Since his hypothesis is based on the fertilizer that will cause the fastest growth, Waldo must collect data on plant growth. What will he measure to determine growth? The obvious answer is that he should measure and record the height of the plants. He might also record other data such as soil temperature, plant appearance and color, or room temperature, but these types of data are not going to help him prove or disprove his hypothesis. Only growth data will do that.

Waldo decides to measure the height of the corn plants in millimeters every two days for three weeks.

Control and Experimental Groups

Next, how many groups should be used in an experiment? There are two types of groups.

First, an experiment should have a **control group**, which serves as a standard for comparison. The control group is treated exactly the same as the experimental group or groups except it will not receive the element being tested.

Second, there are one or more **experimental groups**. Experimental groups also receive the same treatment except for the one element being tested. Remember, each experimental group should receive only one different element. If an experimental group receives more than one different element, it is not possible to determine how each element affected the group.

Each group usually will be made up of more than one member. In general, the more members in each group, the better. By having multiple members in a group, individual differences among members average out.

Example 2: Now that Waldo knows he's going to measure the heights of corn plants in his experiment, he needs to answer the following questions to design his experiment.

What will be his control group?
How many experimental groups will he have?
How many plants should he put in each group?

The Control Group: The control group will be a group of corn plants that get the same amount of light and water as the other plants and are grown in the same type of soil but will not get any fertilizer.

The Experimental Groups: The experimental groups will be the groups of corn plants that get fertilizer. One experimental group will receive fertilizer brand X, a second will receive fertilizer brand Y, and a third will receive fertilizer brand Z. Notice that each experimental group will receive only one brand of fertilizer, and the fertilizer each group receives will be the ONLY different element added to that group.

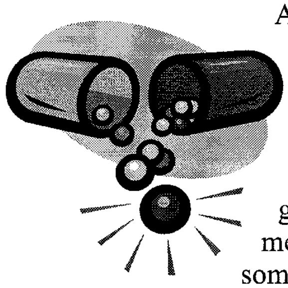
Plants Per Group: He decides to include five corn plants in each group for a total of 20 corn plants.

Bias in an Experiment

When performing an experiment, a scientist should be unbiased, or impartial. A **bias** is a belief or a preference for a specific outcome. Being **unbiased** means the person does not let his or her personal opinions affect the results.

For example, let's say a research scientist believes she found a new drug that will cure cancer. The scientist will have a strong belief (a bias) that this drug works, and her belief (bias) may influence her own experimental results.

Placebos for the Control Group



A **placebo** is an inert substance given to the control group that should have no effect on the control group. The purpose of a placebo is to eliminate biases. Placebos are often given in experiments involving people because the attitudes of people can be a factor in the experiment. For example, a pharmaceutical company may want to test the effects of a blood pressure medication. The experimental group would receive a pill with the medication, but the control group would receive a placebo, a pill that does not contain any medication. The group members would not know if they received a pill with the medication or a pill with no medication. People who think they have been given a medication, even if it is a placebo, can sometimes improve a health condition just because they believe that the medicine they receive will help them. This phenomenon is called the *placebo effect*. Using a placebo can help to eliminate these attitude biases since all the participants believe the same, that they received the medication.

In many cases, the doctors performing the experiment will also not know which members received which pill. Only the pharmaceutical company would know. When both the administrator of the experiment and the participating members of the experiment do not know what each group is receiving, the experiment is said to be a *double-blind experiment*. Using this double-blind method in an experiment keeps the doctors from treating patients differently depending on which group they are in. Double-blind experiments decrease any additional biases.

Example 3: Should Waldo use a placebo in his experiment? How would a placebo be helpful? What would the placebo look like in his experiment?

Waldo may or may not choose to use a placebo in his experiment on corn plants. The plants in the control group won't know that they aren't getting fertilizer and that the others are! However, if Waldo wants to eliminate his own biased opinion, he may want to have someone else add the fertilizer and perform the measurements. In this case, he would want to give a placebo to the control group so that the person adding the fertilizer will not know which group is the control group. A placebo could be a material that does not add any nutrients to the soil.

Constants/Controls

In a well-performed experiment, it is extremely important that all the groups are treated exactly the same except for the experimental element. All the other elements that are the same are called **constants** (also referred to as *controls*). Constants are elements in an experiment that must be considered and kept the same or else they may affect the results of the experiment. Some elements are important to control; others are not important. The key to getting meaningful data is to determine the important constants before beginning the experiment.

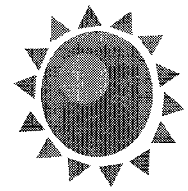
Example 4: What are important constants in Waldo's experiment? What factors are not important to keep constant?

The following are important constants in Waldo's experiment. Before you turn the page, can you come up with reasons why they are important?

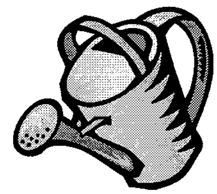
- type of soil
- sunlight
- amount of water
- the number of plants in each group

If any one of these factors is not kept constant, it could affect the data. If a factor affects the data, it is important to keep constant.

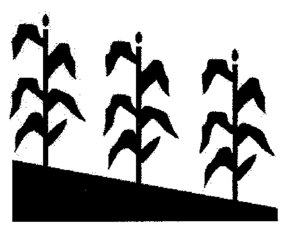
Soil: If Waldo plants the control group plants using one brand of potting soil, and the experimental group plants are planted in soil from his back yard, he has introduced a factor into the experiment that may affect plant growth from the beginning.



Sunlight: Sunlight is another factor that can affect plant growth. If he keeps one group of plants in direct sunlight in front of a window, but all the other groups of plants receive only indirect light, the amount of sunlight each plant receives could affect the growth of the plants.



Water: What do you think would happen if Waldo gives different amounts of water to each group of plants? Could the water affect the plants differently? Sure it could, so he should be careful to give each group of plants the same amount of water.



Number of plants in each group: Each group should always have the same number of members, and that number should be more than one per group. What if Waldo put 5 plants in his control group and only 1 plant in each experimental group? Now what would happen if one of the plants in an experimental group died? Could he say the fertilizer caused the plant's death? Of course not. By having multiple members in each group and by having the same number of members in each group, Waldo can better interpret results.

Unimportant factors: Would Waldo need to buy all three fertilizers at the same store? No, this is not an important factor to keep as a constant. *Where* the fertilizers are purchased would not normally affect the plant growth.

Independent and Dependent Variables

Variables are the things that change during an experiment. One variable is tested in each experimental group. No more than one variable should be tested per group at one time. There are two types of variables that are important in an experiment: independent variables and dependent variables. The **independent variable** is what the experimenter uses or changes to produce results. The **dependent variable** is the measured change due to the independent variable. These definitions might seem confusing, but just remember that the dependent variable *depends* on the independent variable. Fill in the following sentence, "____ depends on _____." The first blank is the dependent variable.

Example 5: In Waldo's experiment, can you determine the independent and dependent variables?

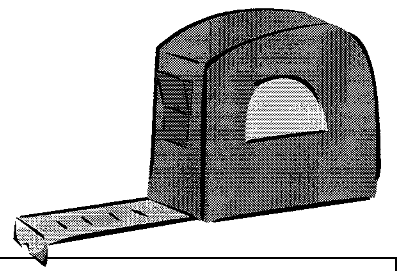
If you can fill in the sentence, "____ depends on ____," the answer to this question is easy. To help you fill in this statement, ask yourself, "What data is being collected?" In this case, plant height is the data collected. Now, what in the experiment is being tested? The different fertilizers are being tested. Using "plant height" and "the fertilizer," fill in the blanks.

Plant height depends on the fertilizer.

Plant height is the dependent variable since it *depends on* the fertilizer. The fertilizer must be the independent variable.

Performing Scientific Experiments

Section 2.3
Using Tables to Organize and Interpret Data



Pre-View 2.3

- **Data table** – a way to format and organize data into rows and columns
- **Raw data** – information ("data") gathered during an experiment before it has been analyzed
- **Optimum** – the best

In biology, tables are used to record data during an experiment and to organize and present information. Tables can give both quantitative data such as measurements and qualitative information such as color.

When entering data into a data table, be sure you always use the same units. You would not want to enter plant heights in millimeters one day and in centimeters the next day. Serious errors in interpreting the data can result if the units are not consistent.

When reading a table, be sure you understand what kind of data is being given. Look at the title of the table and all the labeled parts of the table.

Example 1: Go back to Waldo's experiment with different fertilizers on corn plants. He has four groups of corn plants with five plants in each group. He needs to record the height of each plant every two days for three weeks. He should use a data table like the one below to record his data.

PLANT HEIGHT IN MILLIMETERS

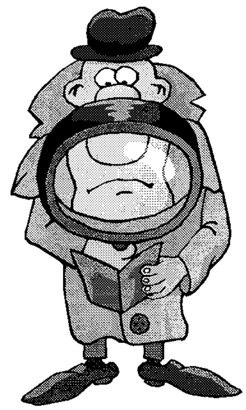
DAY	CONTROL					FERTILIZER X					FERTILIZER Y					FERTILIZER Z				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	65	65	62	66	67	65	66	67	65	67	64	66	65	63	67	65	65	66	67	67
3	66	66	63	67	68	67	68	70	69	71	71	70	71	68	70	66	66	67	68	68
5	68	68	65	69	70	68	69	71	70	72	72	73	73	70	72	67	68	69	71	70
7	70	71	67	71	71	70	71	73	72	74	75	76	76	73	75	69	69	71	73	73
9	72	73	69	73	73	71	72	74	73	75	78	79	79	76	78	71	71	73	75	75
11	72	76	71	76	75	73	75	78	76	78	82	83	84	80	81	73	73	75	77	77
13	74	77	72	79	78	76	77	81	79	82	85	85	87	83	85	76	76	77	81	80
15	75	78	73	80	79	78	80	83	81	83	88	89	90	86	87	77	77	78	82	81
17	77	80	75	81	82	82	83	85	84	86	91	92	93	90	89	79	79	80	84	83
19	80	81	77	83	84	83	84	88	87	88	93	95	95	94	93	82	83	83	86	86
21	81	82	78	84	85	86	87	91	90	91	96	97	96	96	95	84	85	86	87	89

Since nothing has been done to the numbers recorded in this table, the data is called **raw data**.

In this example, notice that the title of the table gives important information about it. It tells you that the numbers given in the table represent plant heights. It also tells you that the heights are in millimeters. Each section of the table is labeled. The rows across are data taken on odd numbered days, so for example, the numbers in the row labeled "1" are the plant heights on day 1. The data in each column represent a plant in each group. You can see from the table that each group has 5 plants labeled one through five. You can see that the control plant #3 on day 1 measured 62 millimeters in height.

What was the height of plant #5 in the Fertilizer Y group on day 15?
Can you see that it was 87 millimeters?

Using Tables to Organize and Interpret Data



As you can see from Example 1, a data table is a good way to record raw data in an organized way. On the other hand, is it a good way to present the data so that others can draw conclusions from it? Not usually. Look at the data table in Example 1. There are a lot of numbers in that table, and it's difficult to tell the significance of them.

It is important to organize the data in a way that makes it easy to interpret. Once raw data is recorded, then it can be organized into another form so that it is easier to interpret. One way to organize raw data is to summarize it into another table. From the summary table, conclusions can be drawn. The goal of many experiments is to find the **optimum** variable, circumstance, or result. (Optimum simply means "the best.") Summary tables can help you identify optimum values.

Example 2: To make the data a little easier to interpret, Waldo averages the plants' growths in each group for each day.

AVERAGE PLANT HEIGHT IN MILLIMETERS

DAY	CONTROL	FERTILIZER X	FERTILIZER Y	FERTILIZER Z
1	65	66	65	66
3	66	69	70	67
5	68	70	72	69
7	70	72	75	71
9	72	73	78	73
11	74	76	82	75
13	76	79	85	78
15	77	81	88	79
17	79	84	91	81
19	81	86	94	84
21	82	89	96	86

What kind of observations and conclusions can you make by looking at this data table? Let's consider a few questions and see if you can interpret the table correctly.

Did all the groups grow?
By looking at the numbers in each column, you can see that all the numbers get bigger as you go down the column. Obviously, each group of plants grew over time. They were taller on day 21 than they were on day 1.

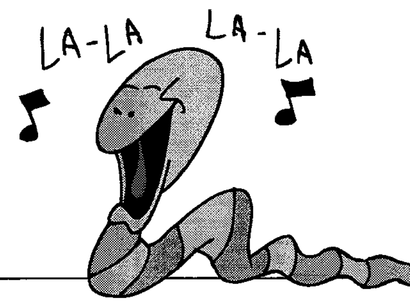
On day 11, which group had an average height of 75 millimeters?
The row across from day 11 shows average plant heights of 74, 76, 82, and 75. The "75" is in the column for Fertilizer Z, so on day 11, the plants in the Fertilizer Z group were an average height of 75 millimeters. The answer is the Fertilizer Z group.

Which group of plants had the optimum growth?
By looking at the row that contains data for day 21, you can see that the group fertilized with Fertilizer Y had the greatest, or optimum, growth. The average plant height for this group was 96 millimeters. The control group averaged 82 millimeters, the Fertilizer X group averaged 89 millimeters, and the Fertilizer Z group averaged 86 millimeters.

What might you conclude in general about using any of the fertilizers versus not using fertilizer?
Can you see that all the groups that received a fertilizer grew taller than the control group that received no fertilizer? From this data, you might conclude that using any of these fertilizers will increase corn plant growth over using no fertilizer.

Performing Scientific Experiments

Section 2.4
Determining Validity of Experiments



Pre-View 2.4

- **Scientifically valid** – a description of a scientific experiment, data, or conclusion that is relevant or meaningful

In order for an experiment to be **scientifically valid**, it must give meaningful results. To get meaningful results, the experiment must be carefully designed, controlled, and performed. Many things can affect the validity of an experiment and can make any conclusions drawn less valid. Look at some examples below.

Examples of Factors that Make an Experiment Less Scientifically Valid

- Using equipment that isn't calibrated; it gives inaccurate readings
- Using only one member in a test group instead of using multiple members per group
- Failing to have a control group
- Not controlling factors in an experiment that can affect the results and conclusions
- Making assumptions without sufficient data or failing to recognize alternative explanations
- Being unable to repeat an experiment to obtain the same results

Example 1: In a science fair experiment, Patrick tests the effects of music on earthworms. The table below shows his experiment with his results.

Group	Number of Earthworms	Initial Length	Initial Mass	Music Type	Final Length	Final Mass
A	1	3.25 cm	7.5 g	Heavy Metal	3.50 cm	7.2 g
B	1	5.72 cm	10.2 g	Classical	n/a, worm died	
C	1	2.36 cm	5.4 g	Country Western	3.21 cm	7.5 g
D	1	5.45 cm	10.0 g	Hip Hop	5.60 cm	12.1 g

After his experiment, Patrick concluded that classical music is deadly to earthworms but hip hop music causes them to grow.

Did Patrick perform a valid experiment? Is his data valid? Are his conclusions valid? The answer to all these questions is no. Can you identify the problems in this experiment that makes it less valid? List some of the problems below:

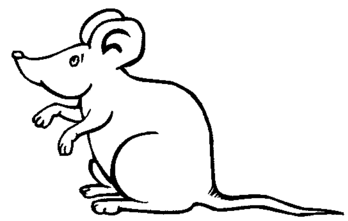
____

____

____

Did you come up with the following?

- Patrick has no control group. He should have had a group that did not receive any music.
- Patrick had only one earthworm per group. He should have had multiple worms per group.
- The earthworms had different initial lengths and masses. He should have used worms that were more consistent in size.
- If Patrick had done some research, he would have found that earthworm mass can vary greatly from day to day depending on how much they eat and how much water they absorb. With this fact in mind, he has no way to determine if the increase or decrease in length or mass could be attributed to the music.
- Patrick's conclusions are not valid because his results have more logical explanations than the music. Did classical music really kill one of the worms? Probably not. Did hip hop cause one worm to grow faster? It is unlikely.
- Do you think that if Patrick or someone else repeated this experiment that he would get the same results? Repeatability is very important in validating a conclusion.



Example 2: Students in a biology class are conducting an experiment on mice and recording their data in the table below. All mice are the same age and similar in mass.

Group	Number of Mice	Avg. Beginning Mass	Fat Kcal/day	Carbohydrate Kcal/day	Protein Kcal/day	Total Calories (Kcal/day)	Avg. Mass After 30 Days
A	5	20.5 g	80	80	80	240	
B	5	20.7 g	120	60	60	240	
C	5	20.2 g	60	120	60	240	
D	5	20.4 g	60	60	120	240	

Which hypothesis is being tested?

A. Mice prefer a high fat diet over a diet high in either carbohydrates or protein.
B. Mice that eat a high protein diet have a lower percentage of body fat.
C. Mice in a larger group will gain more mass than if they are in a smaller group.
D. Mice that eat a diet higher in carbohydrates than fat or protein will gain more mass.

To answer this question, analyze what is given in the table. Notice that each group of mice receives an equal number of calories per day. The calories come from the macronutients of fat, carbohydrates, and protein. The number of calories from each macronutrient varies for each group. The data that is to be collected is mass after 30 days.

Given these "clues" from the table, the answer must have something to do with the amount of macronutrients, and mass. The only valid hypothesis that fits the data is answer choice D. The other answer choices are not valid because they do not match what is being tested and measured in the experiment.