2

Research Design

Introduction

In Chapter 1, you worked on focusing your preliminary research ideas. In this chapter, you will learn how experiments are structured. This structure or experimental setup is called the *research design*. The research design of an experiment determines both whether the experiment is likely to succeed and the reliability of its results.

Learning Objectives

The main objective of this chapter is to have you write a first draft of your experimental research design. By the end of the chapter, you should be able to

1. list the main components of an experimental design,
2. describe the purpose of having a hypothesis in a STEM-based research project,
3. explain the importance of doing background research on independent and dependent variables,
4. compare and contrast the individual entities or trials within the experimental groups,
5. describe how constants are different from the control,
6. explain why it is important to consider possible extraneous variables when you are designing a STEM research project,
7. distinguish between quantitative data and qualitative data, and
8. describe how recording only inferences may interfere with data collection.

Key Terms

Constants: The factors within an experiment that are kept the same for all groups or trials in an attempt to reduce the influence of extraneous variables.

Control group: The group in an experiment that receives the exact treatment as the experimental groups *except* it does not receive any change of the independent variable. It is the group to which the experimental groups are compared.

Dependent variable (DV): The variable in an experiment that changes *in response to* the independent variable and, therefore, is also referred to as the *responding variable.*

Experimental groups: The groups or trials in an experiment that receive all the same conditions *except* varying amounts or qualities of the independent variable.

Extraneous variable: An "undesirable" variable in addition to the independent variable that may influence the results of an experiment, introducing error if it is not, as much as possible, controlled or significantly decreased in the research design.

Focal sampling: A behavioral recording technique where a *narrative* (i.e., what is called an *essay* in English class) is written on every behavior of one individual or group for a set length of time.

Hypothesis: A tentative (i.e., not final and definite) and testable proposed explanation for an observable phenomenon.

Independent variable (IV): The variable in an experiment that is purposely changed or manipulated, either in quantity or quality, by the researcher; also referred to as the *manipulated variable.*

Inference: A conclusion, based on facts, that a person perceives to be true.

Population: The complete collection of every item that has the same characteristics of the individuals in the sample group.

Qualitative data: Data that describe characteristics or qualities, such as color, odor, or texture, or data that describe category frequency or ratings, such as stem sturdiness (e.g., "sturdy," "somewhat sturdy," "limp").

Quantitative data: Data that use numbers with a unit of measurement, such as the length of an insect in millimeters (millimeter is the unit of measurement) or the weight of a projectile in kilograms (kilograms is the unit of measurement).

Sample: A subcollection of data that represent a larger population.

Scan sampling: A behavioral recording technique where the activity of the individual or group is recorded only at preselected time intervals.

Sequence sampling: A behavioral recording technique where behaviors that occur within a sequence are recorded in the order in which they occur.

Trial: The replication of experimental and control groups; used to decrease the influence of variations associated with the independent variable, researcher measurement error, and difference between entities studied.

Components of a STEM Experimental Research Design

An experimental research design includes a hypothesis, variables, experimental and control groups, and constants. Each of these elements is briefly discussed below.

Hypothesis

Once you have determined the question you would like to answer, and after you have begun background research, you are ready to modify your question into a testable statement. You do this by writing a *hypothesis*, which is a tentative, yet testable, proposed explanation for an observable phenomenon or event. The purpose of the hypothesis is to formulate what you want to test and defines the limit of your experiment. It is considered tentative because it states a connection that you believe exists and want to test. However, one research experiment will not ultimately "prove" or "disprove" the connection you are suggesting. The purpose of a hypothesis is to *connect the manipulated changes made by the independent variable with the effects on the measurements of the dependent variable.*

Writing hypotheses to be tested through experiments and observations is central to doing research (Gordon 2007). The question you developed in Chapter 1 will help you stay focused as you do your background research. Now, by changing the question into a hypothesis statement, you accomplish several critical research design issues. In writing a hypothesis, you will

1. determine a specific variable to be tested,
2. determine how changes within the experiment will be measured or recorded, and
3. predict an outcome of what you think the results of the experiment will be.

For instance, in the following planaria example, the question only asks "how" reproduction is affected by temperature and is not written in such a way that it could be answered in a single experiment. How the reproduction "effect" would be measured is not clear. Planaria reproduction could be measured many different ways, such as the number of offspring that come from one individual or the mortality rate of offspring. (The independent variable is underlined once and the dependent variable is underlined twice.)

Question: *What effect does temperature have on planaria reproduction?*

Hypothesis: *If the speed of planaria reproduction is related to temperature, then planaria in lower temperatures will reproduce more slowly than planaria in higher temperatures.*

The hypothesis, on the other hand, identifies not only the specific variable to be tested (temperature) but also what will be measured (speed of planaria reproduction). The inclusion of a prediction—that lower temperatures will lower reproduction rates—makes it clear that the experiment is designed to either support or reject that prediction. Hypotheses like this one are testable because (a) one variable is tested, (b) it is clear how the changes will be measured, and (c) it includes a prediction that will be either supported or rejected by conducting the experiment.

You should write your hypothesis after you do your preliminary research but before you begin your experiment. More details about how to write a hypothesis are provided in Chapter 4, "Writing Hypotheses."

Variables

The *independent variable* (IV) is the variable that is purposely changed or manipulated. Information about the independent variable is known before the experiment begins. Independent variables are also known as *manipulated variables* because you change either the quantity or quality of this variable in the experimental groups. Therefore, the independent variable will determine the organization of levels for the experimental groups. Although more complex experiments can have more than one independent variable, research projects that are to be completed over a series of weeks or months should only have one variable that can easily be tested and measured.

The *dependent variable* (DV) is the variable that changes in response to the independent variable and, therefore, is also referred to as the *responding variable*. Essentially, this is the "effect" and the data that you record during the experiment. It is best to quantify measurements as much as possible, but accurate descriptive data throughout the experiment are helpful as well.

Every research question has several ways in which changes could be measured. Background research should help you determine which dependent variables are most likely to show change in the time you have to conduct the experiment. Therefore, it is important to base the choice of your dependent variable on what you have learned in your background research. Plan your experiment so it focuses on a few related dependent variables. For example, for the research question "How effective are plant-based insect repellents?" there are several different options of dependent variables that a researcher could choose.

Research Question: "How effective are plant-based insect repellents?"	
Independent Variable	**Possible Dependent Variables**
Different brands of plant-based repellents (ideally with differing levels of the active ingredient)	• Total number of insect bites • Size of insect bites • Color and/or itchiness of insect bites • Length of time

Experimental Groups

Experimental groups are the treatment groups or trials that receive all of the same conditions, *except* varying amounts or qualities of the independent variable. Experimental groups are sometimes called *treatment groups* because they receive the change of the independent variable. An important component of designing strong experiments is replication (i.e., performing an experiment more than once). In some STEM experiments, experimental groups containing several entities can be running at the same time, while other experiments will have multiple trials, or runs, that are conducted periodically over time.

The word *trials* refers to the number of treatment replications that you perform on experimental and control groups. Having multiple entities in each experimental group or running multiple trials is important because it decreases the influence of variations associated with the independent variable, researcher measurement error, and difference between the entities studied. For example, in a biology experiment with seeds and pH, four experimental groups, each with multiple seeds, can be set up at the same time, each with different pH levels, and data can be collected from each of the groups at regular intervals throughout the experiment. But an engineering research project testing the mechanical advantage of differing arm lengths of a catapult would use multiple trials of each arm length, which would require making adjustments to the catapult in between experimental groups.

By doing thorough background research, you should be able to determine both how many experimental groups to have and the appropriate levels of the independent variable for each of the groups. The organization of the experimental groups is critically important for a strong research design. Having experimental groups that are not varied enough in quantity or quality may not show any change in the dependent variable and, therefore, will not help you determine any connection between your independent variable and dependent variable. Let's look at an example. The following hypothesis is testing to determine a relationship between levels of vitamin C and when a fruit is picked.

If the concentration of vitamin C in oranges is related to the length of time it has been removed from the tree, then oranges freshly picked will have higher levels of the vitamin.

The *experimental groups* for this experiment should be *varying times after the fruit is picked*. It is important that these groups be selected carefully to show an adequate spread of results. If the vitamin C levels are measured in oranges at intervals of 6 hours, 12 hours, and 24 hours, the levels of vitamin might not differ enough to notice. Similarly, experimental groups divided into extreme high and low quantities will not show the detail needed to analyze the effects. If experimental groups in the orange/vitamin C experiment are measured at 1 day, 4 weeks, 8 weeks, and 16 weeks, the levels of vitamin C might be drastically different, but, without multiple gradients of the independent variable, there is no subtle data to determine critical levels or provide insight as to why those changes might have occurred. Therefore, it is important that you use background research to study the variables so that your groups can be set up appropriately.

It is also possible that experimental groups cannot be predetermined. Sometimes, it is only after the data are collected that data can be grouped for analysis. For the river otter experiment shown in Figure 2.1, the data could be categorized into groups based on the range of temperatures that were actually observed on data collection days. The independent variable of this experiment is the change in water temperature and the dependent variable is the frequency of river-otter behaviors that the researcher categorizes as active or nonactive when making observations.

Figure 2.1

Sample Behavioral Ecological Design Table

<table>
<tr><td colspan="5">Hypothesis Draft
Behavior of a river otter in different water temperatures</td></tr>
<tr><td>Independent Variable
Water and air temperature</td><td colspan="4">Background Questions
What is the normal river otter behavior?
How should I record and quantify behavior in my lab notebook?
How quickly does water temperature change in the fall? (Will it be significant enough to study?)
How do otters prepare for the winter months? Behaviorally and physically?</td></tr>
<tr><td>Dependent Variable
Quantitative
None

Qualitative
Descriptions of behaviors
Tallies of specific behaviors (categorical data)</td><td colspan="4">Constants
Make observations at the same time of day
Same otter observed in the same location throughout the experiment

Note: Experimental and control groups can't be predetermined! I will categorize after data are collected, choosing temperature category ranges that match the observation data.</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Control Group
Average expected temperature for the season</td><td>Exp. Group #1</td><td>Exp. Group #2</td><td>Exp. Group #3
Coolest water temperature</td></tr>
</table>

Control Group

The *control group* is the *one* group to which all other groups will be compared. The control group receives the exact treatment as the experimental groups *except* it does not receive the change of the independent variable. In the orange/vitamin C experiment, the control group would be the level of vitamin C while still attached to the tree (or shortly thereafter), but in all other ways, it is treated and cared for in the same manner as the experimental groups. This way you can determine whether or not there are hidden variables that may be changing without you knowing it.

A control can also be a known measurement or level of the independent variable. In the river otter experiment, the average expected temperature could be designated as the control group.

Sometimes a control can only be designated after data are collected. Also, for some experiments, there is no control group and the comparison among the experimental groups is enough.

Notice there is no control group for the geology research design shown in Figure 2.2. This is acceptable because the data collected at each depth will be compared to one another because the researcher is looking for a pattern in an event that occurred many years ago. This geology research design also highlights how, because the data are located in the environment, there are fewer constants than there would be if completed in a controlled setting.

In the chemistry design shown in Figure 2.3, it is important to note that several trials of this experiment should be performed, and additional experimental group rows could be added in the table to indicate this. Comparing this data to another brand of cosmetics would be a way to expand this experiment.

Both the experimental and control groups are considered a smaller sample of the larger population. Statistically, a *sample* is a subcollection that represents the entire population. The sample is the group from which you actually collect data. The *population* represents a complete collection of every item that has the same characteristics as the individuals in the sample group. For example, in an experiment that has three experimental groups and a control group, these four groups make up a representative sample of the entire population. Understanding that these groups are samples that represent a population is important when you begin to statistically analyze your data after your experiment.

Samples are commonly used in research studies to make claims regarding the entire population. The assumption is that as long as the sample represents the population—that is, that the characteristics of those entities within the sample match those in the population—these types of inferences (claims) can be made. The larger the sample, the more likely this assumption is correct. In the STEM studies we are conducting, rarely if ever, can data be collected from an entire population; therefore data from samples must be studied instead.

Figure 2.2

Sample Geology Research Design Table

<table>
<tr><td colspan="5">Hypothesis Draft
The number and type of fossils will differ at varying depths.</td></tr>
<tr><td>Independent Variable
Soil sample from different depths (meters)</td><td colspan="4">Background Questions
What methods for collecting soil from a cliff will do the least amount of damage? And be safest for me?
How will I identify fossils?
What categories for "type" will I use?
How do I best organize my lab notebook for this type of research?
How will I count partial fossils?</td></tr>
<tr><td>Dependent Variable
Quantitative
Number of fossils (# per kg)
Qualitative
Type of fossils</td><td colspan="4">Constants
Soil samples removed from clliff on the same day
Soil samples spread out and allowed to dry before weighing
1 kilogram from each depth</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Exp. Group #1
Soil sample from top surface of a cliff</td><td>Exp. Group #2
Soil sample at 5 meters</td><td>Exp. Group #3
Soil sample at 10 meters</td><td>Exp. Group #4
Soil sample at 15 meters</td></tr>
</table>

Figure 2.3

Sample Chemistry Research Design Table

<table>
<tr><td colspan="4">Hypothesis Draft
Comparing color dyes found in cosmetics</td></tr>
<tr><td>Independent Variable
Cosmetics that contain straight dyes</td><td colspan="3">Background Questions
In what cosmetics are dyes found? which will be easiest to test?
What are the different types of dyes?
What testing has been done on dyes? Are some dangerous?
How are cosmetics tested?
What makes cosmetic dyes stay where they are applied?
Can I use chromatography to distinguish the different dyes?
How do I do that? what supplies will I need?
Are dyes required to be listed in the ingredients?
What makes a cosmetic product darker? Different darker dyes or many dyes used together?</td></tr>
<tr><td>Dependent Variable
Quantitative
# of dyes per product

Qualitative
Description (and photographs) of chromatograms</td><td colspan="3">Constants
Chromatograms are all made from filter paper used from the same package.
Same method of obtaining samples is used for all groups.

Same product and brand is used, but different shades and multiple trials.

Note: Experimental groups will be various shades from lightest to darkest.</td></tr>
<tr><td>Experimental Groups and Control Group</td><td>Exp. Group #1
Lightest color product</td><td>Exp. Group #2
Darker than control. Lighter than group 2</td><td>Exp. Group #3
Darkest color product</td></tr>
</table>

Constants

Constants are the factors within an experiment that are kept the same for all groups or trials in an attempt to reduce the influence of additional variables. Once you have chosen the independent variable, you must design an experiment to take all of the other potential independent variables into account and make them constant. Otherwise, you will not be able to support a clear relationship between the two variables for which you have data.

How you decide to perform the experiment, meaning the step-by-step procedure, is crucial and can greatly influence the integrity of your experiment. Your treatment of each of the groups must be the same in every way. When analyzing the data after the experiment, you will have to critique your methods to see if something you may have done, or failed to do, influenced the results. This is another reason why background research before starting the experiment is so important.

You need to consider what it means to provide a constant environment for all the groups. For example, in a plant experiment where different intensities of light are used, it is likely that the soils will dry out at different rates. Does keeping the water a constant mean that each plant gets watered the exact amount, on the same days of the week? Or does keeping the water a constant mean that each plant gets enough water so that its soil is moist 1 cm below the surface? Although there is not always a "right" answer to these types of questions, you need to do background research to determine which methods would introduce the least amount of error.

In the reproduction/temperature experiment on planaria (pp. 17–18), the constants might include the methods used to observe and handle the planaria, the length of time each group receives light, and how often planaria are fed and environments cleaned. The list of conditions to keep constant within your experiment can be extensive. It is important to learn as much as possible about the entity being studied AND about the independent variable. You want to be as informed as possible about any additional factors that may influence the results.

Be careful that by controlling for one extraneous variable you are not introducing another one. An *extraneous variable* is a variable in addition to the independent variable that may influence the results of an experiment. Extraneous variables can introduce errors if they are not controlled or significantly decreased. For example, if planaria specimens are placed in different rooms to keep the varying temperatures from interfering with the experimental and control groups, additional variables have now been introduced. The different rooms might have varying amounts of light or might be used more or less frequently by people. You will not be able to control everything, but you will have to make decisions on what is least likely to influence the results. Be ready to address any limitations of the experiment. Explaining the efforts that went into reducing the effects of extraneous variables is important. Figure 2.4 shows a sample of what a biological experimental design might look like when put into an experimental design table.

Difference Between Quantitative Data and Qualitative Data

Quantitative data are data that use numbers with a unit of measurement—for example, the length of an insect in millimeters or the weight of a projectile in kilograms. *Qualitative data* are data that describe characteristics or qualities, such as color, odor, or texture, or data that describe category frequency or ratings, such as stem sturdiness (e.g., "sturdy," "somewhat sturdy," "limp"). Therefore, both describe the same situation but in different ways. While quantitative measurements are of upmost importance in all STEM-based research, qualitative descriptions of data are appropriate to supplement and give a different view of the same data.

Quantitative = data that can be expressed in numbers (quantified)

Qualitative = descriptive data or data that has been put into categories (i.e., categorized data)

Quantitative Data Uses

Quantitative data are the primary data collected for most STEM research. The purpose in collecting quantitative data is to enable you to categorize, organize, and classify your observations in such a way that the experimental groups can be compared mathematically to one another and to the control group. In other words, the quantitative data collected throughout the experiment (hourly/daily/weekly) can later be calculated into changes over the course of the experiment to determine if the difference is statistically significant. End of the experiment mathematical calculations may include means, modes, medians, total change, rate of change, or speed of change. These numbers are used to determine whether the differences are statistically significant. See Chapters 7–9 for a lot more information about mathematical analyses.

As the researcher, you will first consider quantitative measurements by measuring the effects of the dependent variable. You must consider using

Figure 2.4

Sample Biology Research Design Table

Hypothesis Draft If the amount of solid surface on top of the soil is related to the strength of the seedling, then seedlings will break through thinner surfaces more consistently and with less damage to the seedling.				
Independent Variable Varying depth of solid surfaces for seedlings to grow through	**Background Questions** What species of seeds would best be used? What type of seed has a fast germination rate and is easy to grow in controlled conditions? What are the best solid surfaces to use? (Plaster of paris, concrete mix, spackling paste?) What other variables might be introduced by using these materials? How can I reduce those? What are the best ways to measure "strength" of seedlings? (Crack of surfaces, speed at which they get through the surface?)			
Dependent Variable *Quantitative* # of days it takes to break through surface width/length of the crack Thickness of seedling stem *Qualitative* Condition of the seedling during and after breaking through surfaces Conditions of roots and seedling	**Constants** Seedlings all have the same lighting, watering, and feeding schedule (plants are rotated weekly). Data collection is done at the same time every day. Temperature of the room remains the same for all seedlings. Seeds of the same kind came from the same package. Seeds are all planted in the same type and size container (clear plastic cup). All seeds have the same quality and amount of soil underneath the solid surface.			
Experimental Groups and Control Group	**Control Group** No solid surface (just soil)	**Exp. Group #1** .5 cm depth solid surface	**Exp. Group #2** 1 cm depth solid surface	**Exp. Group #3** 1.5 cm depth solid surface

mathematical measurements such as area, angle, conductivity, density, electrical current, force, heat, humidity, length, light intensity, mass, pH, pressure, salinity, temperature, time, velocity, volume, or others. Your teacher will most likely require you to use only metric units or the International System of Units (SI), so you will use *centimeters* instead of *inches* and *liters* instead of *gallons.* The quantitative data you choose to record should be based on your background research.

Be sure to have reasons that support the relationship between the independent and dependent variables. For example, in an experiment that seeks to determine whether powdered drinks contain different food dye concentrations, it would not make sense to measure pH because pH is not the factor being studied in the relationship between the variables.

Quantitative data are used primarily to measure your "effects." There are other ways, however, in which quantitative measurements are a part of your experiment. First, you need to record measureable differences between your experimental groups. For example, if your independent variable is pH, you must record accurate measurements to ensure that the pH levels for each experimental group are appropriately different from one another. Second, you need to record quantitative measurements to ensure that extraneous variables remain constant. For example, temperature is often an added influence in an experiment and so must remain constant. Therefore, you must find ways within the experimental design to keep temperature the same and then plan to monitor and record this measurement periodically throughout the experiment.

The type of data and how you collect it will depend on what type of STEM research project you plan to do. In mathematics, physics, and population and human genetics research, the data may already exist. You may even be able to find reliable resources of data online. Then, it is a matter of obtaining the data and organizing it so that an analysis correlating it to the dependent variable can be made.

Qualitative Data Uses

Qualitative descriptions help you record changes within your experiment that may not necessarily be measureable. When collecting these observations, you describe how something looks, smells, feels, sounds, or tastes (when appropriate) or categorize it into a specific category. However, just because you may not be using numbers, don't lose your objectivity. Your observations should be scientific in nature and not make judgments or inferences. An *inference* is a conclusion, based on facts, that is perceived to be true by the researcher. Be careful, however, when you make an inference. The statement

"The solution looks normal" is an inference, but this conclusion obviously is based on observations that are not recorded. Although you may know what you mean, inferences written without factual descriptions will not help you compare results at the end of the experiment. Statements that include inferences are best saved for after data are collected. Instead, the actual observations, which lead to the inferences, should be recorded. Remain scientific and use detailed and descriptive language.

If you have trouble determining how to describe qualitative data, ask yourself, "What is 'normal' about this?" Make a long list of adjectives to describe the qualitative aspects of your dependent variable. For example, if you are studying viscosity of a fluid, list words that will help you describe varying thicknesses of the solutions—for example, *stringy, thready, dense, clumps,* or *runny*. If you photograph the entities throughout the experiment, you'll be able to compare qualitative differences. You may notice something in photographs that you didn't notice on a day-to-day basis. These observations will help supplement the quantitative data that you collect.

In addition to narrative descriptions, qualitative data can also be in the form of category frequency or ratings, both of which use numbers. Counting frequencies allows you to keep track of changes that are not normally quantified. For example, to record color change, you could use paint swatches, with each gradient of color assigned consecutive numbers—perhaps low numbers for lighter shades and higher numbers for darker shades. In a catapult-testing experiment, after research and/or pretrials, you might determine that there are three basic arch shapes in which the projectile might fall. After each trial, you could measure distance (quantitative) but also determine which of the three arch categories a catapult belongs to (qualitative).

If you choose to do behavioral research, you might collect data on location, like at a zoo, for animal behavior or at a coffee shop for human behavior. Recording behavior is a good time to use qualitative data. Behavioral research can be recorded several ways; the most common are focal sampling, scan sampling, and sequence sampling (Morgan 2009).

- In *focal sampling,* you choose one individual or group of individuals and record your observations for a set length of time. You watch and record everything you observe, writing in a narrative form.
- In *scan sampling,* you record the activity of an individual or group at preselected time intervals. Scan sampling should give you a sample representation of the behaviors taking place, and if you predetermine categories, it will also allow you to tally behaviors that can be used in data analysis. For example, if using scan sampling in the river otter experiment (Figure 2.1), you might observe the river

otter in two-minute segments for several hours. At the moment each two minutes has passed, you would record what the otter is doing. Otter behavioral categories to be tallied might include walking, swimming underwater, floating on back, diving, grooming, foraging, or playing. Scan sampling helps keep an accurate record of observed behaviors as well as a record of changes over time if multiple observations are made.

- In *sequence sampling*, you record behaviors that occur within a sequence, in the order in which they occur. The rubric in Table 2.1 is an example of sequence sampling. The rubric was designed for a horse-training experiment in which the researcher wanted to keep track of a horse's progress as it learned a new skill. The behavior (taking a first step) was broken down into smaller pieces and then used during each training session to record the progress of the horse as it learned the new behavior.

Table 2.1

Sample Rubric for Observation of Horse Behavior (From Lifting the Hoof to Taking First Step)

1	2	3	4	5
Slightly bends knee for less than a second and puts back on ground	Bends knee but leaves toe of hoof on ground for about a second and then puts weight back on ground	Lifts hoof off ground but puts it back down less than a second	Lifts hoof off ground for a second and then puts weight back on ground	Lifts hoof off ground for more than a second

Table 2.2 shows sample quantitative and descriptive data for various types of research projects. The table may help you tell the difference between quantitative data and descriptive data that you collect during your experiment.

Table 2.2

Sample Quantitative and Qualitative (Descriptive) Data for STEM Research Projects

STEM Field	Entity Studied	Quantitative Data	Qualitative (or Descriptive) Data
Anatomy and physiology	Elbow joint range of motion (ROM)	110°	Patient winced at 95° but was able to go to 110°.
Biology	Earthworm growth	62 segments above the clitellum, 170 below	Worm pink at the posterior end and brown everywhere else.
Chemistry	Precipitation reaction	2.1 g	Bright yellow precipitate = 4 (scale 1–5)
Geology	Soil porosity	360 ml	Color of the soil did not change with the addition of water, but a bitter odor was noticeable.
Mathematics	Travel time	40 min.	The roads were wet because it was drizzling at the time of data collection.
Physics/ engineering	Tensile stress and strain	87 g 6.4 cm	Cord made loud cracking sounds before it snapped.

Chapter Questions

1. What are the main components of an experimental design?
2. What is the purpose of having a hypothesis in a STEM-based research project?
3. When doing background research on independent and dependent variables, what sort of information will help you write a good research design?
4. How do the individual entities or trials within the experimental groups differ? How are they the same?
5. How are the constants different from the control?
6. How should the consideration of extraneous variables affect the design of a STEM research project?
7. How do quantitative data differ from qualitative data?
8. Why might recording inferences (instead of facts) interfere with data collection?

Chapter Applications

Now it's your turn. Look back at your Student Handout #1, Focusing Preliminary Research Ideas, on page 14. Use it to complete the Student Handout #2, the Research Design Table, on the following page. Refer to the example design tables provided in this chapter. Carefully consider the elements of your experiment. Think about the variables that can best be observed and measured, taking into consideration the equipment, resources, and lab skills you have at your disposal. Consider advice and suggestions from your teacher and your classmates. Completing this table in writing will help you determine the strengths and weaknesses of your research design. It will tell you what you still need to learn more about. Don't be surprised if you complete several drafts of the table, maybe on completely different topics.

If you are working with a group or with a partner on this project, your teacher may prefer that you brainstorm together regarding the research ideas and variables and then complete the remaining parts of Student Handout #2 individually. In that case, group members can discuss the differences between the different proposed research designs and then combine the best of each version to make a single group draft. At that point, consider typing up the group draft and posting it to a Google Doc that you can share with all members of your group and with your teacher (for more information on Google Docs, see p. xxviii). In that way, each group member can make edits to the document, and the teacher can check on the group's progress.

The next chapter will help you develop research questions to help focus your background research. Continue doing background research on your topic. Though it may seem contradictory, the more background information you have, the better you will be able to modify your research design.

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