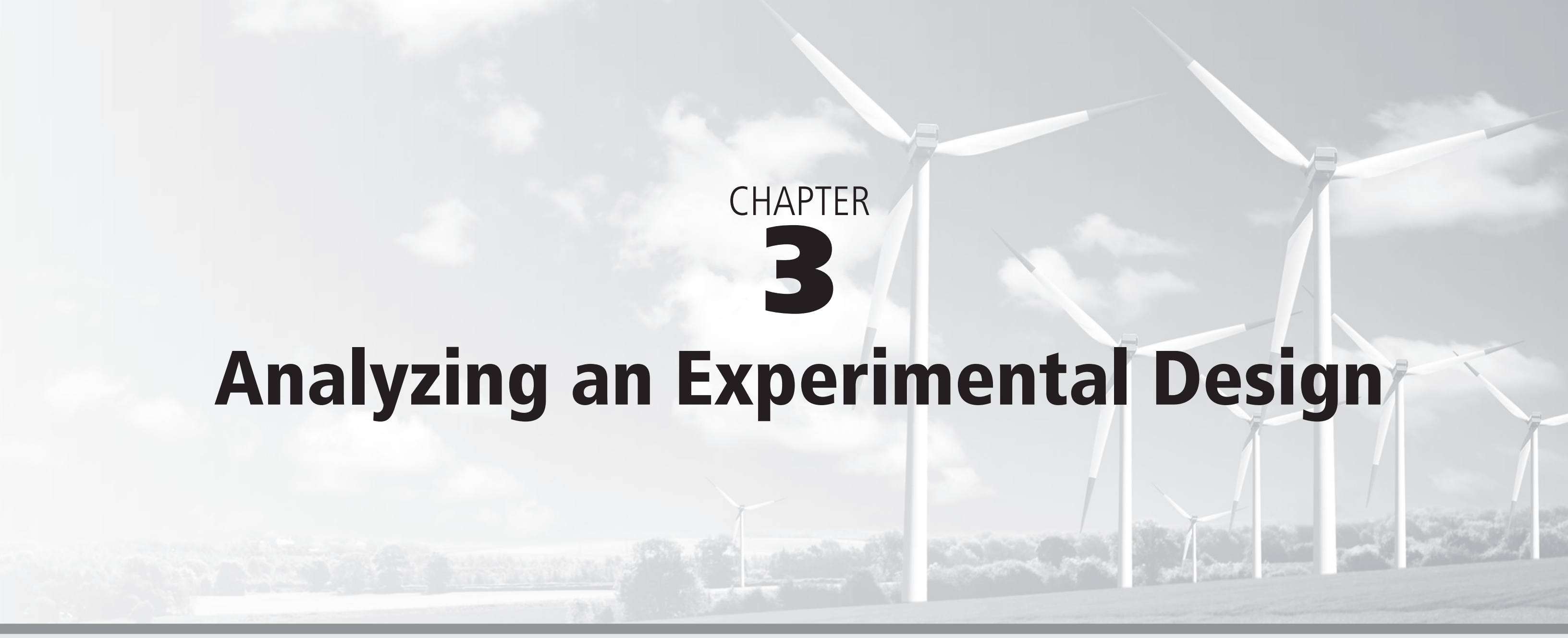


CHAPTER

3

Analyzing an Experimental Design

CONTENTS

INTRODUCTION

At this point you know the components of an experiment and what they mean. Suppose a scientist conducted an experiment which involved "amount of water." Then the scientist asked you: "Was the amount of water the independent variable, the dependent variable, a controlled variable, or the control group in the experiment?" What would you say? It's a tough question. In fact, it is impossible to answer the question given what you were told. The amount of water could be any of the choices depending on its role in the experiment. In Chapter 3, you will use a diagram to communicate the role of various components in an experiment. Also, you will use an expanded checklist to analyze the experimental design diagram and recommend improvements.

Learning Objectives

Specific learning objectives for Chapter 3, *Analyzing an Experimental Design*, include:

- Identify the major experimental components in a structured investigation or scenario: independent and dependent variables, question, hypothesis, control group, controlled variables, and number of repeated trials;
- Develop an experimental design diagram to communicate the major experimental components;
- Respectfully ask questions, provide feedback, and receive critiques; cite relevant evidence;
- Use a checklist to evaluate and revise an experimental design diagram so better qualitative and/or quantitative data are generated to test a hypothesis; and
- Use argumentation skills to compare assessments of an experimental design diagram.

Correlations With Nationwide Standards

In Table 3-1, the core Chapter objectives and STEM concepts are correlated with nationwide learning standards. The correlations for "Exploring STEM connections" are shown in italics. For a synopsis see Appendix A.

TABLE 3-1 Correlations With Nationwide Standards

NEXT GENERATION SCIENCE STANDARDS

- **Scientific & Engineering Practices:** Asking questions and defining problems; Planning and carrying out investigations; Constructing explanations and designing solutions; Using mathematics and computational thinking; Engaging in argument from evidence; *Obtaining, evaluating, and communicating information*
- **Cross-Cutting Concepts:** Patterns; Cause and effect; *Systems and system models*
- **Disciplinary Core Ideas:** Motion and stability; Energy; *Heredity; Earth's systems; Engineering Design; Links among engineering, technology, science, and society*

COMMON CORE STANDARDS—MATHEMATICS

- **Mathematical Practices:** Construct viable arguments and critique the reasoning of others; *Model with mathematics*
- **Mathematical Domains:** Interpreting categorical and quantitative data; *Expression and equations; Functions; Interpreting functions*

COMMON CORE STANDARDS—LITERACY IN SCIENCE AND TECHNICAL SUBJECTS

- **Reading:** Cite textual evidence; Determine key ideas or conclusion; Follow multi-step procedure; Determine meaning of symbols, key terms, etc.; Integrate words and visual representations; Read and comprehend text
- **Writing:** Write arguments; *Conduct short research projects; Gather relevant information; Draw information from informational texts*

ISTE STANDARDS—STUDENTS

- **Creativity and innovation:** Identify trends and forecast possibilities
- **Research and information fluency:** Process data and report results; *Locate . . . and use information from a variety of sources/media; Evaluate and select information sources and digital tools based on the appropriateness to specific tasks*
- **Critical thinking, problem solving, and decision making:** Collect and analyze data to identify solutions and/or make informed decisions
- **Digital citizenship:** Demonstrate personal responsibility for lifelong learning; *Advocate and practice safe, legal, and responsible use of information and technology; Exhibit a positive attitude toward using technology that supports collaboration, learning, and productivity*
- **Technology operations and concepts:** *Understand and use technology systems*

Source: Confrey & Krupa, 2012, p. 9; Morphew, V. N., 2011, pp. 299–300; National Governors Association Center for Best Practices, 2010, English language & literacy, pp. 64–66; National Governors Association Center for Best Practices, 2010, Mathematics, pp. 6–8; NGSS Lead States, 2013, Volume 1, p.1; NGSS Lead States, 2013, Volume 2, pp. 67–79.

CONSTRUCTING AN EXPERIMENTAL DESIGN DIAGRAM

Although lists can be useful tools of analysis, diagrams are frequently more powerful tools. For example, you can analyze an experiment by listing its components. However, constructing an **experimental design diagram** of the same experiment is a more effective way to quickly visualize the design of the experiment.

To construct an experimental design diagram for an experiment with one independent variable follow these steps.

1. **Write a testable question:** Communicate what you want to learn about the effect of the independent variable on the dependent variable.
2. **State a hypothesis**: **If** the (*independent variable)* is (*describe how you changed it*), **then** the (*dependent variable*) will (*describe the effect*) **because** (*state the reason*).
3. Draw a rectangle and subdivide it into three rows. In the first row write the **independent variable (IV).**
4. In the second row, communicate the **levels of the independent variable**. To do this, subdivide the row into a column for each level of the independent variable. Write the specific levels of the independent variable (IV) above each of the columns. If one of the levels is used as the **control group** for the experiment, write the words *control group* under that level.
5. In the third row, communicate the **number of repeated trials**. Subdivide this third row into the same number of columns as the second row. In each column, write the number of repeated trials conducted for each level of the independent variable.
6. Put the **dependent variable (DV)** below the rectangle.
7. Write a list of **controlled variables (CV)**.

In Figure 3-1, the general format of an experimental design diagram is illustrated. Use Figure 3-1 to construct an experimental design diagram for the scenarios given in Box 3-1, *Practice—Experimental Design Diagram*.

FIGURE 3-1 General Format for an Experimental Design Diagram

WRITE A TESTABLE QUESTION Communicate what you want to learn about the effect of the independent variable on the dependent variable.

STATE A HYPOTHESIS If the independent variable is (*describe change*), then the dependent variable will (*describe effect*) because (*state the reason*).

IV: Write the **independent variable.**
Divide this row, and the one below it into columns, one for each **level of the independent variable**. Place the words **control group** below the standard of comparison.
In each column, write the number of **repeated trials** conducted for each level of the independent variable.

DV Write the **dependent variable**.

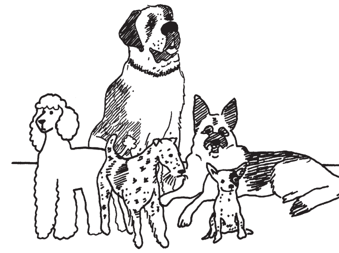
CV Write a list of **controlled variables**.

Name ______________________________ Date ____________

PRACTICE
Experimental Design Diagram

DIRECTIONS Read several of the scenarios and construct an experimental design diagram. Use the available information within the scenario.

1. Zelda's friends were always talking about how smart their dogs were. Of course Zelda thought her Chihuahua, even though small, was the smartest. For a project, Zelda decided to see if some breeds of dogs learn behaviors faster than others. She used her Chihuahua, and asked her neighbors if she could borrow a poodle, a German shepherd, a Saint Bernard, and a Fox Terrier. In the basement of her home, Zelda tried to teach each dog to sit and shake hands using "Dawg Treats" as a reward. She gave each dog a 30-minute lesson. She repeated the lessons over five days. If the dog learned she recorded the number of lessons required to teach the trick. If the dog never learned the trick she recorded that.


©Kendall Hunt

2. Dion moved his trophies from his bedroom to the basement den of his house. He noticed the trophies needed more dusting. Because people often came into the basement from the yard and tracked dirt on the carpet, he thought if he put the trophies on higher shelves there would be less dust. He cut fourteen identical pieces of wax paper, covered them all lightly with petroleum jelly, and attached the paper to metal coat hangers. He hung two hangers so the bottom of the paper was at 0, 0.3, 0.6, 0.9, 1.2, 1.5, and 1.8 m off the floor in the hallway. A week later he took the hangers down. Holding the greased wax paper in front of a bright light, he compared the amounts of dust collected at each height, e.g., small, medium, and large.

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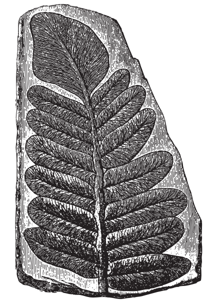
3. When studying fossils in her Earth Science class, Casandra learned different fossils are deposited over time. She knew fossils were present in the cliff behind her house, and thought the fossils might change as she went from the top to the bottom of the bank because of changing life over time. She marked the bank at five positions: 5, 10, 15, 20, and 25 m from the surface. She removed three buckets of soil from each of the positions and determined the kind and number of fossils in each sample. Casandra was an experienced rock climber and worked with her Dad to follow safety precautions when collecting the soil.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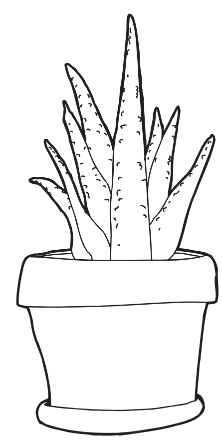
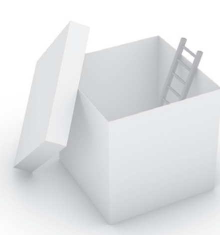
4. Carlos read that seedlings compete for light, water, and nutrients. This is why gardeners thin seedlings to have good flowers. Carlos decided to test how close together the seeds could be planted before the plants were harmed. He bought some marigold seeds and potting soil and got 12 paper salad bowls of the same size from his mom. Carlos punched four holes in the bottom of each bowl. Then, he filled each bowl two-thirds full, which took 350 ml of soil. In the first set of three bowls, he planted one seed in each of the bowls; this would be the comparison. For each set of three bowls, he planted different numbers of seeds, e.g., 2, 4, and 8 seeds per bowl. Carlos placed the bowls in a tray in the window so the plants received the same light. Every three days he gave the plants the same amount of water. After 25 days Carlos counted how many plants were in each container. He also measured the plants' heights (cm) and described the plants as healthy or unhealthy.

5. Amanda wanted to determine if the color of food affected what kindergarten students would select. She put food coloring into four identical bowls of mashed potatoes. The colors were red, green, yellow, and blue. She also had a fifth bowl of natural mashed potatoes. Because an earlier survey had shown red to be the students' favorite color she thought the students would select this color most often. Each student indicated their choice. Amanda did the experiment using a total of 100 students. She recorded the number of students choosing each color. (Notice, the students did not eat the potatoes.)

6. Lou read the juice of the *Aloe vera* plant promoted the healing of burned tissue. He decided to investigate the effect of varying the concentration of *A. vera* on the regeneration of planarian. Lou bisected planarian to obtain 10 parts (5 heads and 5 tails). For each experimental group, he applied concentrations of 0%, 10%, 20%, and 30% *A. vera* to the planarian parts. Fifteen milliliters of *A.vera* solutions were applied. All planarian were maintained in a growth chamber with identical food, temperature, and humidity. Lou thought the higher concentration solutions would promote healing. On Day 15 Lou observed the regeneration of the planarian heads and tails; he categorized regeneration as full, partial, or none.





DIAGRAMMING AN EXPERIMENT

Knowing how to construct an experimental design diagram is of little use unless you can apply these skills to an experiment you are conducting, whether in class or of your own design. To test your application skills conduct the investigation in Box 3-2, *Experiment—Huff, Puff, and Slide.*

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MY WORKSPACE

Name ______________________ Date ____________

EXPERIMENT
Huff, Puff, and Slide

QUESTION *How far can I blow a cup?*

HYPOTHESIS *Construct your own.*

MATERIALS
- Safety goggles
- Long, flat, smooth surface (about 2 m)
- Meter stick
- Plastic container, about 250 ml (8 oz)
- Pennies, 10

SAFETY
- Wear safety goggles and appropriate protective equipment.
- If you have respiratory problems do not conduct this experiment.
- Wash hands after investigating.
- Follow your teacher's directions for safety, cleaning the laboratory area, and disposing of materials.
- See Appendix B, *Using Safe Procedures*

PROCEDURE
1. Place two pennies in the container.
2. Place your chin on one end of the smooth surface. Place the container 15 cm from your chin.
3. Blow as hard as you can on the side of the container. Measure how far the container slides in centimeters. Record your data.
4. Repeat steps 1–3 with 4, 6, and 10 pennies in the container.

DATA TABLE

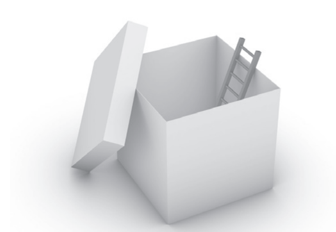
Number of Pennies	Distance Moved (cm)
2	
4	
6	
10	

ANALYZING THE EXPERIMENT

1. Construct an experimental design diagram for *Huff, Puff, and Slide*.

2. Describe ways you can improve the experiment.

3. What is your confidence in the experimental data? How could you modify the experimental design to improve confidence in the data?



ASSESSING AN EXPERIMENTAL DESIGN DIAGRAM

In your analysis of the *Huff, Puff, and Slide* investigation, you constructed an experimental design diagram. How does your experimental design diagram compare with ours, which is shown in Figure 3-2?

FIGURE 3-2 Experimental Design Diagram for *Huff, Puff, and Slide*

QUESTION *How far can I blow a cup?*

HYPOTHESIS *If the number of pennies is increased, then the distance the cup will slide will decrease because it has a greater mass.*

IV: Number of Pennies			
2 Pennies	**4 Pennies**	**6 Pennies**	**10 Pennies**
1 Trial	1 Trial	1 Trial	1 Trial

DV Distance container slides (cm)

CV Size of container
Shape of container
Slide surface

Using a Checklist

From the experimental design diagram you can spot the missing parts quickly and easily. For example, there is no control group designated in the experiment. Other components may be present, but of poor quality. To assess the quality of experimental components it is helpful to use a checklist.

In Box 3-3, the checklist from Chapter 2 was expanded to include questions about the experimental design diagram, creativity, and complexity of the proposed experiment. Use the checklist in Box 3-3 to review the *Huff, Puff, and Slide* experiment. Then, compare your analysis with ours.

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CHECKLIST
Experimental Design Diagram

EXPERIMENTAL COMPONENT	SELF CHECK	PEER CHECK	POINT VALUE	GRADE
QUESTION				
1. Is there a question?			3	
2. Does the question communicate what you want to learn about the interaction of the IV and DV?			6	
HYPOTHESIS				
3. Is there a hypothesis?			3	
4. Does the hypothesis clearly state how changing the IV will affect the DV?			6	
5. Does the hypothesis state the reason for the prediction?			3	
6. Is a directional hypothesis written? If not, is a reason provided for the non-directional hypothesis?			6	
INDEPENDENT VARIABLE				
7. Is there just one IV? Operationally defined?			9	
8. Are the levels of the IV clearly stated? Operationally defined?			9	
DEPENDENT VARIABLE				
9. Is there one or more DV? Operationally defined?			9	
CONTROLLED VARIABLES				
10. Does the list of CV include the major factors that might impact the experimental outcome?			6	
11. Is each of the identified CV operationally defined?			3	
CONTROL GROUP				
12. Is there a control group? Operationally defined?			9	
REPEATED TRAILS				
13. Are there repeated trials?			6	
14. Are there a sufficient number of repeated trials?			3	
EXPERIMENTAL DESIGN DIAGRAM				
15. Are the components placed in the proper place?			6	
16. Are any components missing?			3	
CREATIVITY AND COMPLEXITY				
17. Is the experimental design creative?			5	
18. Is the experimental design at an appropriate level of complexity?			5	
TOTAL			100	

COMMENTS

Comparing Assessments

With the checklist you identified strengths and weaknesses of the experiment, which may be different from ours. By comparing assessments you can develop a stronger set of recommendations for improving the *Huff, Puff, and Slide* experiment.

Question. The question—"How far can I blow a cup?"—is too general. The question needs to focus on the variables being investigated, e.g., "How does the number of pennies impact the distance a cup will slide?"

Hypothesis. The hypothesis is already stated in an "if . . ., then . . . because . . ." format and requires no change.

Independent Variable. The independent variable, number of pennies, is correct. The unit of mass in this experiment is the mass of a U.S. penny which is approximately the same for all pennies. To be more precise you could measure the mass of the pennies using units such as grams. The levels are clearly stated, but the sequence of 2-4-6-10 pennies is missing the level of 8 pennies. The levels of the independent variable are usually set at equal intervals or multiples, such as 2-4-6-8-10 pennies.

Dependent Variable. This variable is the distance traveled (cm). Using the metric unit (cm) to operationally define distance is appropriate. One improvement would be to state which path you measured: a straight line or the actual path the container took.

Controlled Variables. The controlled variables could be stated more clearly. You could describe the type of smooth surface, perhaps a polished wooden table, stone countertop, or a linoleum floor. Likewise, describe the type of container, such as a clear plastic cup (250 ml) or a specific brand and size of margarine container (Golden Glow, 250 ml). Tell where to aim the air stream, at the base or the middle of the container. Indicate if the container was covered or uncovered.

Control Group. A zero (0) pennies level of the independent variable should be added and labeled as the control group. This would be a no treatment control group.

Repeated Trials. There is a problem here! Only one trial was done. When you conduct repeated trials you test each level of the independent variable several times. A major way to improve this experiment would be to add around five trials. Remember, repeated trials are used to reduce the effects of chance errors and to increase confidence in the findings. Because the data are quantitative calculate the mean.

Experimental Design Diagram. The control group is missing. The other components are shown in the appropriate place (see Figure 3-1).

Creativity and Complexity. Deciding upon creativity and appropriateness are "judgment calls" on your part. **Creativity** means novel and appropriate outcomes are presented. These could be a novel topic for the experiment, an unusual hypothesis, or unique ways the independent, dependent, and controlled variables are defined. In the following chapters, we will discuss how creativity can be demonstrated in various experimental components.

For an experiment to be **appropriate,** it should address a question whose answer is unknown to the investigator. Determining the effect of different colors of ground covers on plant growth is an appropriate experiment, whereas determining the effect of light versus no light on plant growth is not. Almost everyone knows plants will die without light. In determining appropriateness consider the experimenter's background knowledge. An appropriate experiment for a sixth grader is not an appropriate experiment for a high school senior. *Huff, Puff, and Slide* may be an appropriate experiment for a middle school student who needs to better understand the relationships among force, mass, and distance traveled. However, an older student would need to explore more complex relationships, including derived dependent variables such as velocity, acceleration, and kinetic energy. For the independent variable, older students could investigate factors such as the position of the mass in the cup or the direction of the force on the cup.

As you can see, using a combination of an experimental design diagram and checklist is an effective way to analyze and improve an experiment. Use the checklist to assess the experiments in Box 3-4, *Practice—Assessing Experimental Design Diagram.*

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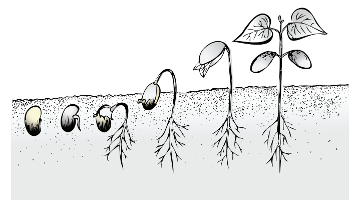
Name ______________________ Date __________

PRACTICE
Assessing Experimental Design Diagram

DIRECTIONS Use the checklist from Box 3-3 to assess several of the experimental design diagrams below, or ones assigned by your teacher. For your convenience, a checklist follows the designs. For each scenario summarize ways to improve the experimental design.

Scenario 1: Compost and Bean Plants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QUESTION *Does age impact the nutrient content of compost?*

HYPOTHESIS *If older compost is applied, then the bean plants will grow taller because more nutrients are available.*

IV: Age of Compost		
3-Month-old Compost	**6-Month-old Compost**	**No Compost (control group)**
25 plants	25 plants	25 plants

DV Height of plants (cm)

CV Type of compost—grass
Bean plants
Amount of compost—450 g
Same sunlight conditions
Same water every 2 days
Time to grow—30 days

WAYS TO IMPROVE

Scenario 2: Depth and Water Pressure

©courtesy of author

QUESTION *How does depth impact water pressure?*

HYPOTHESIS *If the depth of the hole is increased, then the distance squirted will increase.*

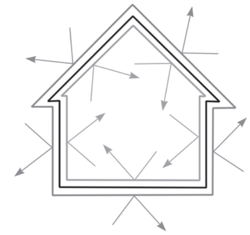
IV: Depth of hole below surface (cm)			
5 cm	**10 cm**	**15 cm**	**20 cm**
3 cartons	3 cartons	3 cartons	3 cartons

DV Distance liquid squirted (cm)

CV Identical paper milk cartons
Height of liquid in container—30 cm
Liquid—water

WAYS TO IMPROVE

Scenario 3: Effectiveness of Insulation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QUESTION *Does brand impact the effectiveness of insulation?*

HYPOTHESIS *If jars of water are wrapped with different brands of insulation, then the temperature of the water in the jars will change by different amounts.*

IV: Brand of Insulation				
Lowes ™	**Home Depot ™**	**Smith Builders**	**Discount Building Supplies**	**Green Contracting Company**
1 jar	1 jar	1 jar	1 jar	1 jar

DV Temperature of water in jar

CV Jars all ½ full
Jars placed in direct sunlight for 4 hr
Jars fitted with plastic lids

WAYS TO IMPROVE

Scenario 4: Metals and Rusting Iron


©Anton Mykhailovskyi/Shutterstock.com

QUESTION *How do active metals impact the rusting of iron?*

HYPOTHESIS *If the chemical activity of the metallic wrapper is increased, then less rusting will occur because the acid will react with the wrapper.*

IV: Type of Metallic Wrapping Strip			
Iron Nail with No Metal (control group)	**Iron Nail with Magnesium**	**Iron Nail with Aluminum**	**Iron Nail with Lead**
6 nails	6 nails	6 nails	6 nails

DV Amount of rusting (small, moderate, large)
Color of water

CV Plastic cup—250 ml
Amount of water—200 ml
Type of nail—galvanized iron nail, 15.2 cm
Dimensions of metallic wrapper—5 cm x 22 cm
Length of experiment—2 weeks

WAYS TO IMPROVE

Scenario 5: Dropping Magnets

QUESTION *Does dropping harm a magnet?*

HYPOTHESIS *The more times a magnet is dropped the fewer iron filings it will pick up because my teacher said dropping harms magnets.*

IV: Number of Times Magnet Dropped		
5 drops	**10 drops**	**15 drops**
10 magnets	10 magnets	10 magnets

DV Mass of iron filings picked up (g)

CV Craft bar magnets, 30 of same brand
Height dropped—1.5 m
Type of floor—cement

WAYS TO IMPROVE

Scenario 6: Perfumed Bees

QUESTION *Do perfumes worry bees?*

HYPOTHESIS *If the perfume contains an ester, then the bees will fly more around the hive because they are agitated by the chemical.*

IV: Type of Perfume		
Perfume 1 (Wooden Glade)	**Perfume 2 (Meadow)**	**Perfume 3 (Eastern Spice)**
4 trials	4 trials	4 trials

DV Time to emerge from hive (min)
Flight pattern observed over 15 min

CV Amount of perfume—10 ml
Distance from the hive—3 m
Container for perfume—clear plastic plate
Placement of container—grass
Same weather conditions—air temperature and wind
Recovery time between trials—30 min

WAYS TO IMPROVE

ASSESSMENT
Scenarios of Experimental Designs

EXPERIMENTAL COMPONENT	SELF CHECK	PEER CHECK	POINT VALUE	GRADE
QUESTION				
1. Is there a question?			3	
2. Does the question communicate what you want to learn about the interaction of the IV and DV?			6	
HYPOTHESIS				
3. Is there a hypothesis?			3	
4. Does the hypothesis clearly state how changing the IV will affect the DV?			6	
5. Does the hypothesis state the reason for the prediction?			3	
6. Is a directional hypothesis written? If not, is a reason provided for the non-directional hypothesis?			6	
INDEPENDENT VARIABLE				
7. Is there just one IV? Operationally defined?			9	
8. Are the levels of the IV clearly stated? Operationally defined?			9	
DEPENDENT VARIABLE				
9. Is there one or more DV? Operationally defined?			9	
CONTROLLED VARIABLES				
10. Does the list of CV include the major factors that might impact the experimental outcome?			6	
11. Is each of the identified CV operationally defined?			3	
CONTROL GROUP				
12. Is there a control group? Operationally defined?			9	
REPEATED TRAILS				
13. Are there repeated trials?			6	
14. Are there a sufficient number of repeated trials?			3	
EXPERIMENTAL DESIGN DIAGRAM				
15. Are the components placed in the proper place?			6	
16. Are any components missing?			3	
CREATIVITY AND COMPLEXITY				
17. Is the experimental design creative?			5	
18. Is the experimental design at an appropriate level of complexity?			5	
TOTAL			100	

COMMENTS

DESIGNING EXPERIMENTS WITH MULTIPLE INDEPENDENT VARIABLES

The first part of this chapter focused on experiments involving one independent variable. However, scientists do not always confine themselves to one independent variable. Experiments may include repeated measurements and two or more variables. Once you have experimented with one independent variable, you may find you need to design a more complex experiment to test a hypothesis. This chapter component will provide a basis for designing and diagramming more complex experiments.

Repeated Measures Over Time

A typical change to experiments with one independent variable is to obtain multiple measures of the dependent variable over time. An experiment to determine the influence of earthworms on soil quality would be enhanced by reporting results weekly, rather than at the end of a two-month period. Similarly, the influence of aerobic exercise on resting pulse rate can be more accurately assessed with monthly measurements, rather than one measurement at the end of the year. This design is particularly effective when different effects over time are hypothesized. One fertilizer may act more quickly than another to promote plant growth, yet they may produce equivalent growth at six weeks. To understand how an experimental design diagram would be produced for an experiment involving **repeated measures over time**, look at a scenario involving crickets.

> **Scenario.** Juan read bees were attracted to certain colors and wondered whether crickets also had a color preference. He hypothesized crickets would be attracted to the brightest color, red. He divided an aquarium into four sections; the sections contained a red, blue, green, and no plate. Juan put 2 g of mustard seeds in each dish. Then, he put 30 crickets into the aquarium. He observed the number of crickets in each section at the end of 30, 60, 90, and 120 min. Also, Juan recorded the mass of mustard seeds (g) consumed at the end of 120 min. He repeated the experiment on five different days and was careful to keep the amount of light the same.

In this experiment there are two independent variables—color of dish and time. Also, there are two dependent variables: the number of crickets, which is recorded at specific times, and the mass of mustard seeds consumed, which is measured only at the end of the experiment. In this experimental design, one independent variable is shown on the side and the second independent variable across the top (see Figure 3-3). Although these variables can be switched, we prefer to put time across the top. This preference is related to how graphs are constructed, which will be discussed in Chapter 6. In this experiment, a graph would typically have time on the x-axis, the number of crickets on the y-axis, and multiple trends to represent the number of crickets in each section of the container.

FIGURE 3-3 Attraction of Crickets to Color

QUESTION *Are crickets attracted to different colors?*

HYPOTHESIS *If crickets are fed from different colored plates, then they will be more attracted to a red plate, which is brighter.*

IV: Color of dish	IV: Time (min)			
	30 min	**60 min**	**90 min**	**120 min**
None (control group)	5 trials	5 trials	5 trials	5 trials
Red	5 trials	5 trials	5 trials	5 trials
Blue	5 trials	5 trials	5 trials	5 trials
Green	5 trials	5 trials	5 trials	5 trials

DV Number of crickets in each section at 30, 60, 90, 120 min
Total mass of mustard seeds (g) eaten from each plate at 120 min

CV Kind of seeds—mustard
Amount of seeds—2 g
Number of crickets put in aquarium—30
Same aquarium
Same amount of light

Repeated Treatments of Subjects

As discussed earlier, substantial variation exists among living organisms, especially humans. By exposing the same subjects to different treatments you can minimize experimental errors resulting from variations within subjects. Repeated treatment designs are particularly effective in psychological and biological studies involving higher organisms. For example, the most effective time for learning could be investigated by determining sixty subjects' rate of learning of nonsense syllables at three different times during the day. With a repeated treatments design each subject serves as his or her own control. Thus, genetic and environmental factors are minimized. Because nonliving matter exhibits less variation, repeated treatment designs are less common in the physical and earth sciences. Any time humans or other vertebrates are used in an experiment the researcher must follow specific guidelines, which are generally described in Chapter 9, *Analyzing and Addressing Safety Risks*. To understand how an experimental design diagram would be constructed for **repeated treatments over subjects**, analyze a scenario involving performance on mathematics tests.

Scenario. Although Sienna's classmates learned the advantages of studying in a quiet place and focusing on the task, the majority of students continued to complete homework while listening to music or watching television. Sienna hypothesized that the ability to solve mathematical problems would decrease with increased stimuli in the environment. Sienna taped a 30-min segment of a television program which included a mix of conversation, music, and screen action. She developed four equivalent mathematics tests (20 items) on decimals and percentages. Fifteen students were randomly selected from her class and appropriate permissions were secured for each student. Students completed a mathematics tests while exposed to no stimuli, to a sound tape of the program, to a video with no sound, and to a complete tape of the program. The form of the mathematics test, type of stimuli, and order of presentation of the stimuli were randomized. The time for completion (min) and the number of correct items were recorded. The tests were administered over four days, at the same time of day, and in identical test sites. The sound level of the auditory stimuli and the screen size of the visual stimuli remained constant.

This design looks similar to the ones constructed previously for one independent variable. The independent variable, type of stimuli, is placed across the top. However, on the side you communicate the number of subjects, which is the number of repeated trials. Because each subject is tested four times with different stimuli there are four repeated measures. This diagram is shown in Figure 3-4, *External Stimuli and Problem Solving.*

FIGURE 3-4 External Stimuli and Problem Solving

QUESTION *How do different stimuli affect mathematical problem solving?*

HYPOTHESIS *If the number of stimuli increases, then performance on a mathematics test will decrease because of reduced focus on the task.*

IV: Type of Stimuli				
Subjects	**None (control group)**	**Sound**	**Video Without Sound**	**Video With Sound**
1				
2				
3				
.				
.				
15				

DV Time to complete test (min)
Number of test items correct

CV Length and difficulty of test
Length of stimuli
Presentation of stimuli—same sound level and screen size
Time and place of test administration

Two Independent Variables

When physicians prescribe medication they give specific directions for taking the medicine. These directions reflect numerous experiments over the years which have shown certain medicines are more effective at specific times of day, taking a medicine with food will minimize side effects, and certain foods will interfere with medical effects. For example, people who take cholesterol-lowering drugs are generally directed not to eat grapefruit. When two variables influence an outcome, scientists say the variables are interacting. If you take a drug at the recommended time, then a lower dosage may be used. However, if you take the drug at another time, a higher dosage may be required to achieve the same effect. Both the time of day and the dosage interact to impact the drug's effectiveness.

If you were interested in the impact of thermal and acid rain pollution on the respiratory rate of fish, you could conduct two different experiments. For the first experiment, you could investigate the impact of acid rain pollution by using simulated acid rain with different pH values such as 4.5, 5.5, and 6.5. Then, you could conduct a second experiment to investigate the impact of different temperatures of water (10°, 20°, 30°, 40° C) on respiratory rate. These multiple or serial experiments would enable you to learn the impact of acid rain and thermal pollution separately. However, they would not enable you to investigate the potential interaction of these variables. That is, does one variable interact with a second variable to reduce or increase the impact? To see how interaction works, analyze an experiment involving the impact of two independent variables—UV light and acid rain—on the durability of paint.

> **Scenario.** Larry read that acid rain and sunlight cause paint to fade faster. Larry wanted to learn how these variables impacted the fading of Chromo-Sure yellow paint (color 216). In the experiment, he exposed five samples of painted wood to a combination of different amounts of ultraviolet light (5, 10, 15 units) and different strengths of simulated acid rain (pH = 3, 5, 7). For each combination he used five samples (3 cm x 3 cm) of wood, which he had painted with one coat of the yellow paint. For the different UV exposures he used three lamps of the same brand. He used 20 ml of the acid rain solution. After two weeks of exposure, he estimated the amount of fading by comparing the paint samples with an original sample. He described the fading as none, small, medium, or large.

When there are two independent variables, one independent variable is shown across the top and the second independent variable along the side. Because time is not involved, as with the cricket experiment, there is no convention regarding the placement of the variables. The number of repeated trials is shown within each of the resulting boxes. Larry's experimental design diagram is shown in Figure 3-5, *Fading of Paint*.

FIGURE 3-5 Fading of Paint

QUESTION *Do acid rain and ultraviolet radiation interact to impact the fading of house paint?*

HYPOTHESIS *If paint is exposed to higher acidic rain and ultraviolet radiation, then the variables will interact to produce a great amount of fading.*

UV Light Strength (units)	pH of Simulated Acid Rain		
	3	5	7
5	5 trials	5 trials	5 trials
10	5 trials	5 trials	5 trials
15	5 trials	5 trials	5 trials

DV Amount of fading (rating scale of none, small, medium, large)

CV Brand and color of paint—Chromo-Sure yellow, #216
Size of samples—3 cm x 3 cm
Same brand of UV lamp
Amount of acid rain—20 ml
2 weeks of exposure

EXPLORING STEM CONNECTIONS

You know how important we think it is for you to make connections among various scientific disciplines, mathematics, technology, and engineering. In Box 3-5, *STEM Perspective—Huff, Puff, and Slide*, some options are described. As before, select among the options, complete a teacher assigned investigation, or identify a topic you want to explore.

MY WORKSPACE

STEM PERSPECTIVE
Huff, Puff, and Slide

Science
Explaining how the natural world works

1. **Forces, interactions, and energy.** Explore the following connections. Then, use key scientific concepts to explain the experimental findings.
   a. Make a diagram to communicate the energy changes occurring in the *Huff, Puff, and Slide* experiment.
   b. What is Newton's Second Law of Motion? How does the law relate to the experiment?
   c. For Newton's Second Law of Motion, there are online simulations where you can explore the effect of changing the variables of force, mass, and acceleration. To conduct a simulated experiment, search for sites such as:

   Explorlments—*Newton's Second Law;*
   Math & Science Gizmos—*Fan Physics* (free trial); and
   PhET Interactive Simulations—*Forces and Motion* and *Forces and Motion: Basic.*
2. **Planning investigations.** Was the air flow well controlled in the experiment? Explain. What tools might you use to provide the air flow? What instruments might you use to measure the air flow? (Hint: think how meteorologists measure wind speed)
3. **Systems and system models.** What are the major components of the respiratory system? How were these components involved when you blew on the cup?
4. **Heredity: Inheritance and variation of traits.** What genetic and environmental factors impact a person's lung capacity? How do these factors interact?
5. **Earth's systems.** Meteorologists report wind measurements. Explain why knowledge of the wind is important.


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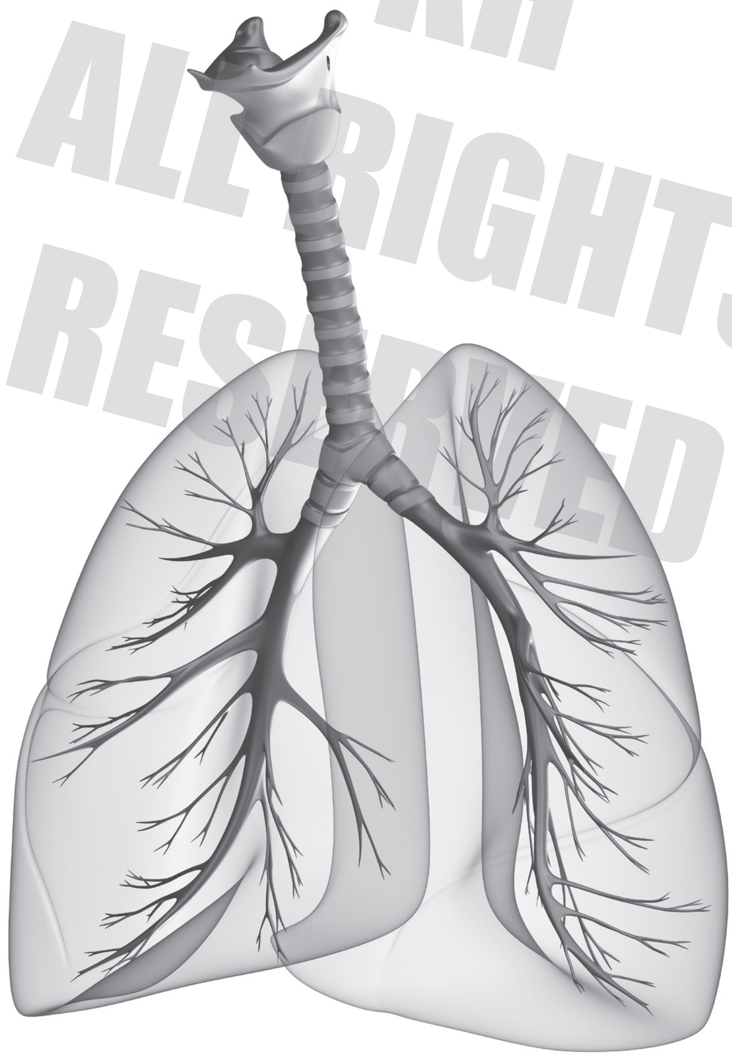
Technology and Engineering

Modifying the world to meet human needs and wants

6. **Engineering design.** In Chapter 8, apply your knowledge of force and motion to designing a wind operated device. See Box 8-4, *Wind Power.*
7. **Links among engineering, technology, science, and society.** Explore the following connections.
   a. Wind farms are a form of renewable energy. How does the use of wind energy in the United States compare with its usage in other parts of the world? What geographical and societal factors underlie these differences?
   b. For disabled people devices exist they can operate with their breath. What are some recent innovations?



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Mathematics

Describing, analyzing, and interpreting patterns and relationships

8. Collecting additional data. In *Huff, Puff, and Slide,* you experimented with blowing a container with various numbers of pennies to see how far the container would slide.

a. *Finding the control group value.* When analyzing this experiment you found you did not collect information for the control group. Using the same container collect this data. To maintain the controlled variables, be sure to use the same surface and blowing technique.

b. *Finding the missing level of the independent variable.* It is better to use set intervals for incrementing the levels of the independent variable. When analyzing the experiment you found the level of eight pennies was missing. Using the same controlled variables collect this data.

9. Detecting mathematical patterns. In the table below, record your new data from question 8, as well as the original data from the *Huff, Puff, and Slide* experiment.

Number of Pennies	Distance Moved (cm)
0	
2	
4	
6	
8	
10	

a. *Relationship of pennies and distance traveled.* Use words to describe the relationship between these variables. Sketch a graph to illustrate the features. Do the data support or refute the hypothesis you made?

b. *Use a graph to make a prediction.* What do you think will happen if you continue to increase the number of pennies in the container? What value will the distance (cm) approach as you add more and more pennies to the container?

c. *One more level of the independent variable.* Use your graph to predict how many pennies you will need to place in the container for the container to no longer move when you blow on it. Collect data to test your prediction. Remember to keep the controlled variables the same. How do the prediction and data compare?

10. **Constructing scatter plots.** In Chapter 6 learn about scatter plots, trends, and mathematical models. Construct and interpret scatter plots for your experimental data or the data in question 9.

11. **Using algebra to represent patterns.** In Volume 2 (Chapter 15) learn about linear and non-linear mathematical models. Use what you learn to explore the relationship between the number of pennies (or mass) and the distance moved.

12. **Adding time as a dependent variable.** In the experiment you measured the distance traveled. By collecting another variable—time—you can explore other aspects of motion such as the velocity and acceleration of the cup when it contained different numbers of pennies. How could you use the capabilities of digital technology to measure time? Once you have this data how can you calculate the cup's average velocity? Acceleration?.

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