ACTIVITY 4

Reducing Error in Experimental Design

LABORATORY

Many factors affect air quality. Which factors do you think have the greatest impact on the air quality in your community?

4 : REDUCING ERROR IN EXPERIMENTAL DESIGN

GUIDING QUESTION

How do you design a study to reduce scientific error?

INTRODUCTION

A 2024 study by Georgia State University (GSU) researchers found that planting trees and bushes near highways can help reduce air pollution from cars and trucks. Professor Roby Greenwald, one of the researchers, said, “Trees and bushes near roadways don’t solve the problem of air pollution, but they can help reduce the severity of the problem.” The study looked at air quality at five places along highways in Atlanta and compared them to similar places without plants. They found that areas with plants had 37% less soot and 7% fewer particles less than 0.1 micrometers in size, which are much smaller than what PM2.5 air sensors measure.

To reduce scientific error, researchers look at other factors that could affect the data. One important factor in the GSU study was the direction of the wind. The plants had the biggest effect on air quality when the wind was blowing from the highway toward the plants. In this activity, you will design an experiment to test air quality in your local area. You will also think about possible sources of scientific error and how to reduce them.

Professor Roby Greenwald (left) and graduate student Nadia Alhadidi (right) demonstrate air quality monitoring equipment. It was used to assess the role that trees and bushes play in reducing air pollution near highways.

CONCEPTUAL TOOLS

MATERIALS LIST

FOR EACH GROUP OF FOUR STUDENTS

- MICROSCOPE (OR STEREOSCOPE)
- 9 PETRI DISHES
- PETROLEUM JELLY
- TAPE
- 9 INDEX CARDS
- PERMANENT MARKER
- GRAPH PAPER

SAFETY NOTE

Label all materials clearly and monitor them over the course of the experiment to ensure that they do not pose a hazard to others.

PROCEDURE

1 You will collect data by placing petri dishes coated with petroleum jelly at a collection site. Particulate matter in the air will fall onto the open petri dish and stick to the petroleum jelly. After collecting your dishes, you will use a microscope to observe the particulate matter in the petri dish. Set up your experiment by:

- **a** washing your hands.
- **b** creating a control by having one person in your group use a clean finger to smear a very thin layer of petroleum jelly on the bottom of one petri dish.
- **c** setting up your own 2 petri dishes by using your finger to smear a very thin layer of petroleum jelly on the bottom of 2 petri dishes.
- **d** using a permanent marker to label the top of each dish, including the control, with the location where it will be placed and your group name.
- **e** taping the dishes closed for transport.
- **f** writing the following on an index card for each dish: *Science Experiment—Please do not move!*

FIGURE 4.1 Spreading petroleum jelly on a petri dish

2 Work with your group to design an experiment to test the levels of particulate matter in your local air. Remember to listen to and consider the ideas of other group members. If you disagree with others in your group, explain why you disagree.

   Begin by discussing the places where you could set your petri dishes and what question you would investigate. For example, you may want to investigate potential differences in air quality near and far from a highway or major road, indoor vs. outdoor, homes with or without pets, distance from a heating/air conditioning vent, street vs. backyard, distance from trees and plants, and so on. Be sure to consider the weather forecast when planning outdoor data collection.

3 When designing your investigation, be sure to address the following questions:

   - What is your hypothesis?
   - How and where will you place your petri dishes?
   - How and where will you establish your control?
   - How will the data you collect help you to make a conclusion?

4 Work with your group to brainstorm aspects of your experimental design and data collection that could result in scientific error. Revise your experimental design to include any ideas you have to reduce these errors.

5 Record your hypothesis and your experimental design in your science notebook.

6 Obtain your teacher's approval for your investigation.

7 Conduct your investigation for three days by:

   a taking your dishes and index cards to the data collection site(s).

   b uncovering petri dishes when placed at the data collection site(s) and securing the index-card labels nearby.

8 After three days, tape the petri dishes closed and bring them back to your classroom.

9 In your science notebook, make a data table to record *quantitative* (number of particulates) and *qualitative* data (particulate color, any identifiable particulates such as dog hair or other particulates) for each petri dish, including your control.

10 Use a microscope to examine your petri dishes by first placing a petri dish on graph paper and tracing a circle around it (as shown in Figure 4.2). Place your petri dish with the graph paper underneath on the microscope to help you track and record the number and type of particulates in the dish. (If you have too many particulates to count them individually, see Figure 4.3 for additional guidance.)

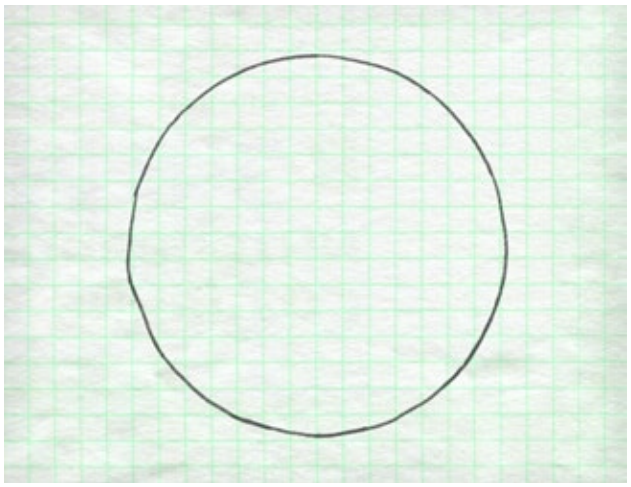


FIGURE 4.2
Tracing a Petri Dish on Graph Paper

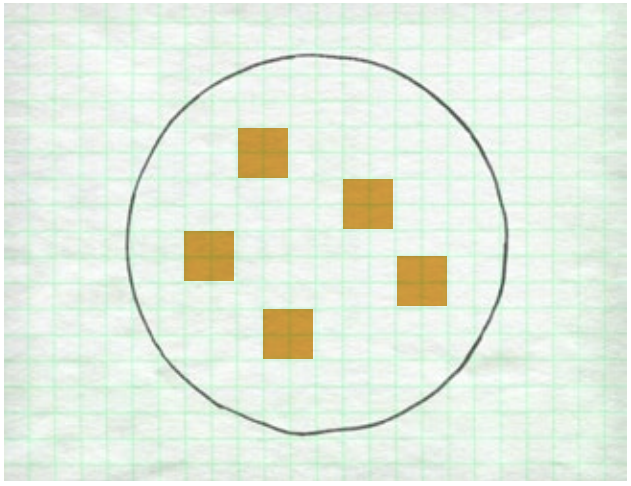


FIGURE 4.3a
Medium Number of Particulates

If you have too many particulates to count individually, count a smaller area of the petri dish to make an estimate of the total number of particulates. Do this by creating a template on the graph paper by marking a few squares on the graph paper (similar to the examples in Figures 4.3a and 4.3b). Then, place your petri dish with your template on the microscope and count only particulates in the squares.

NOTE: Use only one template (either 4.3a or 4.3b) to count the particulates in every petri dish of your group, including the control.

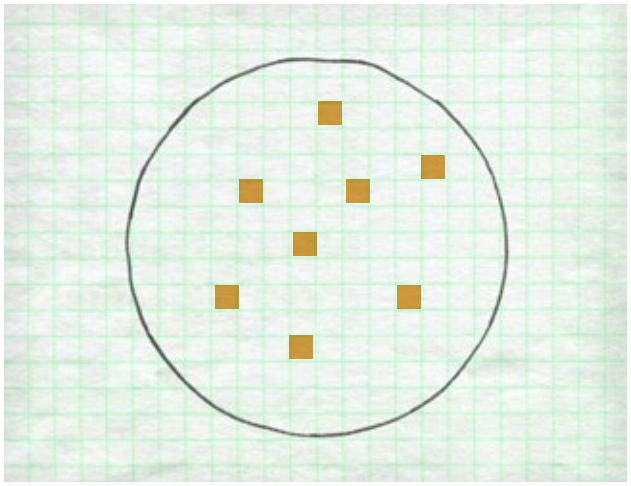


FIGURE 4.3b
High Number of Particulates

11 With your group, share and record data from all the petri dishes, including the control.

12 With your group, discuss your results and the conclusions you can make from your data. In your analysis, consider how your data does or does not support your hypothesis. Record all your findings in your science notebook.

13 Think about the role of scientific error in your experiment.

a Discuss any possible sources of scientific error with your group and how those may have affected your results.

b Brainstorm ways in which your experiment could have been improved by identifying ways to reduce random errors and/or systematic errors in your experimental design.

- Random error is a difference between an observed and true value that has no consistent pattern and is caused by chance and/or unpredictable factors.
- Systematic error is a difference between an observed and true value in a consistent direction, often caused by experimental equipment or design.

14 Share your results with your class.

BUILD UNDERSTANDING

① Review your experimental design and your results.

a What were possible sources of systematic error in your experiment?

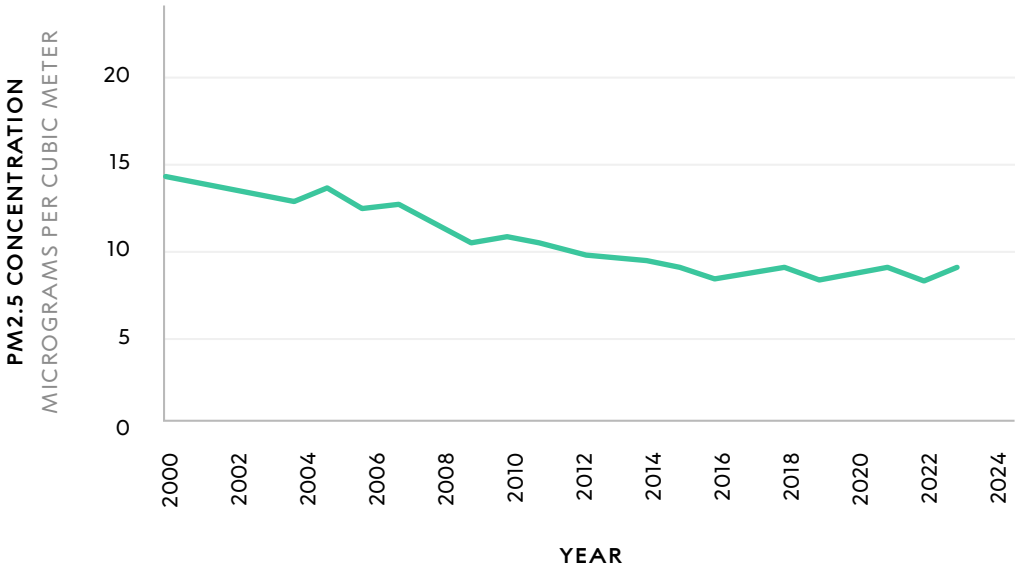
b How did you address these possible sources of systematic error in your experimental design?

c What possible sources of systematic error did you **not** address in your experimental design? Given more time and resources, how could you address them?

You can work with your partner to reduce potential sources of error when examining your samples.

② The graph in Figure 4.4 shows annual average PM2.5 air quality in the United States over a 24-year period. PM2.5 levels have decreased by 37% during that time. A person living near an area of frequent wildfires complains that their PM2.5 levels have increased during the same period.

FIGURE 4.4
PM2.5 Air Quality in the United States, 2000–2023



a Explain how this could be true.

b Figure 4.4 is from the U.S. Environmental Protection Agency (EPA), which addresses systematic and random error in its data. Explain one possible systematic error that could affect such data and how it could be addressed to reduce scientific uncertainty.

CONNECTIONS TO EVERYDAY LIFE

3. Like a scientific procedure, a recipe provides a list of steps to follow in order to produce an intended outcome, such as a batch of cookies. Imagine you are in a cooking class where eight groups each baked a batch of chocolate chip cookies using the same recipe. Some of the cookies came out chewy and thin, while others were thick and dry. What are some possible sources of (a) random error and (b) systematic error?

4. Janeen wants to improve her running speed, so she decides to experiment by running the same 1–mile route every day for a week to see if she gets faster. By the end of the week, her mile time had improved by 30 seconds. The following things happened during her experiment. Explain whether they are related to random error or systematic error and how each might have affected her results.

   a Janeen starts her stopwatch a little bit early because she needs to secure her phone in her pocket before she starts running.

   b Midway through the week, Janeen starts drinking an electrolyte drink 20 minutes before her run.

   c Each time she runs, her speed varies slightly due to factors such as how much energy she has, random distractions (like a car honking), or even slight changes in the weather. Some days, she feels tired and runs a little slower.

5. How might you redesign Janeen's experiment from item 4 to reduce sources of scientific uncertainty in her data?

EXTENSION

One way to reduce scientific error is to gather data by using different experimental techniques. Look online for different experimental approaches for measuring air quality. For example, you could evaluate the visibility of a local city, as shown in the following images. Design and conduct a different experiment to measure your local air quality. Compare the results with the results from this activity. Explain which approach is less likely to have random errors and/or systematic errors and why.

The view of Lahore, Pakistan, on a good visibility day (left) and a poor visibility day (right) is affected by the local air quality.

KEY SCIENTIFIC TERMS

random error
systematic error