Designing an Experiment

The information in this chapter is a short summary of some topics that are covered in depth in the book *Students and Research* written by Cothron, Giese, and Rezba. See the end of this chapter for full information on obtaining this book. The book is an invaluable resource for any middle or high school science teacher.

The Different Parts of an Experiment

There are different types of practical activities that can be carried out either by working scientists or by science students. Only some of these would strictly be considered experiments. When younger students begin learning how to carry out simple experiments the experiment is often referred to as a “fair test.” The experiment can be a test of the effect of different actions carried out by the experimenter or a test comparing differing conditions as some action is carried out. For example, students might test the effect of different watering schedules on plant growth. Or students might try removing a stain using different stain removers to find out which one is most efficient. Other activities would not be considered experiments. For example, carrying out an exercise to measure the density of a piece of metal. Or carrying out a survey of different types of plants and animals found along a stretch of beach.

Every experiment has specific parts that can be identified by students. These different parts can all be checked off during the design phase of an experiment. If all the parts of the experiment have been accounted for and considered carefully before the experiment is started it is more likely to be a successful and beneficial experience for the student.

An experiment starts and finishes with the factors that change during the experiment. These are the **variables**. The experimenter will purposely change one of the variables; this is the **independent variable** or **manipulated variable**. The second variable changes in response to the purposeful change; this is the **dependent variable** or **responding variable**. For example, if students change the wing shape of a paper airplane and measure the resulting time that the plane stays in flight, the independent variable would be the wing shape and the dependent variable would be the flight time.

A simple experiment should have only one independent variable. That is, the student should only allow the one factor he or she is most interested in to change. There will normally be many other factors that could change and have an effect upon the outcome of the experiment, but these other factors must be controlled or held constant. Any effect on the outcome must then be due to the one factor that was changed, and a definite conclusion can therefore be reached about the effect of this factor. The factors that could be changed but which are deliberately held constant are referred to as **constants** in the experiment. Constants are sometimes referred to as controlled variables, but this term can be confusing for students and is best not used.

The independent variable that is manipulated by the experimenter will have several different values, and these different values are called the **levels of the independent variable**. For example, if temperature were the independent variable in an experiment, then 10°C, 20°C, 30°C, and 40°C might be the different levels. Usually one of the levels of the independent variable is the reference point or "normal" value of the variable, and the other levels will be compared with this one in order to draw conclusions from the experiment. This reference level of the independent variable, which other levels will be compared to, is called the **control** for the experiment. In the example given here, 20°C would likely be the control because this represents normal room temperature.

Another part of the experiment related to the independent variable is a number of **repeated trials** for each level of the independent variable. If the experiment is repeated more than once for each level of the independent variable this will make for a more reliable test. The possibility of obtaining a misleading result due to experimental errors will be less. Every experiment should be carried out several times and then the results of the individual trials averaged together. When it comes to counting the number of repeated trials that are carried out, the important thing is to count the number of measurements that are made. For example, if a flat of 12 plants is grown using a particular kind of fertilizer, and the height of each individual plant is recorded, then the number of repeated trials is 12. The recommended number of repeated trials that should be used will vary depending on the exact nature of the experiment. However, as a general rule, students should repeat the experiment as many times as it is convenient and practical to do so.

Lastly, students should be asked to formulate a **hypothesis** or "educated guess" before they begin carrying out the experiment. This will be a predicted outcome for the experiment, and it will be based on the student's past experiences as well as information they have been able to gather while carrying out background research for their experiment. The hypothesis should be written in the form of an "if-then" statement linking a change in the independent variable to a predicted change in the dependent variable. For example, "If the weight attached to the paper airplane is increased, then the direction of flight will be more of a straight line."

An Experimental Design Diagram

An experimental design diagram is a convenient way of laying out the essential parts of an experiment. Students should always do this before they begin an experiment to make sure that they have remembered each part. The "diagram" is not really a diagram, but more of a visual layout of the parts of the experiment on a page.

There are eight essential parts to be included on the experimental design diagram, reflecting the essential parts of an experiment. Students should be taught to count that they have included all of the eight parts on their diagrams, and each part of the diagram can be included on a grading rubric. The eight parts are listed below and then laid out in the "diagram" format.

1. Title for experiment written as "the effect of the independent variable on the dependent variable"
2. Hypothesis in the form of an "if-then" statement
3. Independent variable
4. Different levels of the independent variable
5. Level of the independent variable that will serve as the control for the experiment
6. Number of repeated trials for each level of the independent variable
7. Dependent variables, including how they will be measured
8. Constants

General Layout for an Experimental Design Diagram

TITLE

The Effect of ______________________ (Independent Variable)

on ______________________ (Dependent Variables)

HYPOTHESIS

If ______________________ (planned change in independent variable),

then ______________________ (predicted change in dependent variables).

INDEPENDENT VARIABLE

____

LEVELS OF INDEPENDENT VARIABLE AND NUMBERS OF REPEATED TRIALS

Level 1 (**Control**)	Level 2	Level 3	Level 4
Number of trials	Number of trials	Number of trials	Number of trials

DEPENDENT VARIABLE AND HOW MEASURED

____

CONSTANTS

1.

2.

3.

4.

The Four-Question Strategy

It is always extremely difficult for a student to think of a specific topic for an experiment. The student may be able to think of a general topic of interest, but it is still not easy to translate this general area of interest into a focused topic for study. The four-question strategy is a clever activity to help students explore the possible variations of a general topic before attempting to state a specific problem, hypothesis, variables, constants, and control. When we teach students the process of experimental design, we should model and practice this four-question strategy with our students before asking them to design an original experiment on their own. The teacher can lead the students in a class through one example of the four-question strategy, all together, using the chalkboard. The students can then practice the four-question strategy, alone or in small groups, using a prompt provided by the teacher, before attempting to work through the four questions for an experiment that they areinterested in carrying out.

Example of an Experimental Design Diagram

Title

The Effect of Type of Insulation Wrap on Temperature of Water in a Jar

Hypothesis

If jars of water in the sun are wrapped with different types of insulation, then the temperature of the water in the jars will increase by different amounts.

Independent Variable

Type of insulation

Levels of Independent Variable and Numbers of Repeated Trials

No insulation **(Control)**	Cotton	Wool	Nylon
3 jars	3 jars	3 jars	3 jars

Dependent Variable and How Measured

Change in temperature of water in jar, measured in degrees Celsius

Constants

1. All jars are identical
2. All jars are fitted with the same plastic lids
3. All jars half-filled with water
4. All jars placed in direct sunlight

The four-question strategy involves the following four questions.

- Question 1 – What materials are readily available for conducting experiments on general topic of interest)?
- Question 2 – What action is observed when studying (general topic of interest)?

- Question 3 – What are all the ways that I can change the set of materials that would change the action?
- Question 4 — In what ways can I measure or describe the response to the change?

A specific experiment follows from the answers to the four-question strategy. One of the answers to Question 3, "How can I change the set of materials?" will be the independent variable in the experiment. All the other answers to Question 3, other things that could be changed to make an effect, will need to be controlled when the experiment is carried out. They will be the constants in the experiment. The answer for Question 4 will become the dependent variable of the experiment.

The following example of the four-question strategy shows how the four questions might be answered using the general topic of plants.

- What materials are readily available for conducting experiments on plants?

  Soil, Plants, Fertilizer, Water, Light/Heat, Containers

- How do plants act?

  Plants grow

- How can I change the set of plant materials to affect the action?

  Plants: Spacing, Kind, Age, Size

  Water: Amount, Scheduling, Method of application, Source, Composition, pH

  Containers: Location of holes, Number of holes, Shape, Material, Size, Color

  (Possible changes in Soil, Fertilizer, and Light/Heat would also be listed.)

- How can I measure or describe the response of plants to the change?

  Count the number of leaves

  Measure the length of the longest stem

  Count the number of flowers

  Determine the rate of growth

  Weigh the fruit produced

  Measure the diameter of the stem

Once students have carried out the four-question strategy, they should be asked to create an experimental design diagram for an experiment that they could carry out based on their answers. Once they have constructed an experimental design diagram, the students will be ready to proceed with writing an experimental procedure to follow for their experiment.

It will often be helpful for the teacher to help students further in beginning the experimental design process by providing a prompt to help the students begin the four-question strategy activity. You can provide the students any of the following as a starting point for them to begin the four-question strategy.

- Lists of simple and available materials
- Questions to be investigated
- News briefs or articles that lend themselves to further experimentation by students

- Science demonstrations in a book
- Textbook or laboratory activities
- Library book

Whatever type of prompt is used, it should be chosen so as to stimulate student interest and curiosity.

RESOURCE

- *Students and research: Practical strategies for science classrooms and competitions.* Cothron, J. H., Giese, R. N., & Rezba, R. J. (3rd Ed.). (2000). Dubuque, IA: Kendall/Hunt Publishing Company.

This book provides all the information you will need to know about teaching K – 12 students to design experiments.