

## Designing & Performing Experiments

**Unit:** Laboratory & Measurement

**NGSS Standards/MA Curriculum Frameworks (2016):** SP1, SP3, SP8

**Mastery Objective(s):** (Students will be able to...)

- Create a plan and procedure to answer a question through experimentation.

**Success Criteria:**

- Experimental Design utilizes backward design.
- Experimental Design uses logical steps to connect the desired answer or quantity to quantities that can be observed or measured.
- Procedure gives enough detail to set up experiment.
- Procedure establishes values of control and independent variables.
- Procedure explains how to measure dependent variables.

**Tier 2 Vocabulary:** inquiry, independent, dependent, control

**Language Objectives:**

- Understand and correctly use the terms “dependent variable” and “independent variable.”
- Understand and be able to describe the strategies presented in this section.

**Summary of Concepts:**

Designing experiments involves:

- Decide what you are trying to observe or measure.
- Figure out how to observe or measure it.
- Figure out how to make it happen so you can observe or measure it.
- Set up and perform the experiment to make the thing happen, and observe/measure it.

**Notes:**

Unlike many biology experiments in which the purpose is to observe something, most chemistry experiments involve observing changes to find out *what* happens, *under what conditions* it happens, and measuring *to what extent* it happens. Part of the purpose of chemistry experiments is to get practice making things happen, but another part of the purpose is for you to figure out *how* to get them to happen and how to measure them. This makes chemistry well-suited for teaching you how to design experiments.

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The education “buzzword” for this is *inquiry-based experiments*, which means you (or your lab group) will need to figure out what to do to perform an experiment that answers a question about some aspect of chemistry. In this course, you will often be given only an objective or goal and a general idea of how to go about achieving it. You and your lab group (with help) will decide the specifics of what to do, what to measure (and how to measure it), and how to make sure you are getting good results. This is a form of *guided* inquiry.

## Framing Your Experiment

Experiments are motivated by something you want to find out, observe, or calculate.

### Independent, Dependent, and Control Variables

In an experiment, there is usually something you are doing, and something you are measuring or observing.

independent variable: the conditions you are setting up. These are the predetermined values (the ones you pick). Because you choose the values, they are *independent* of what happens in the experiment. For example, if you are trying to figure out how much sugar you can dissolve in water at different temperatures, you are choosing the temperatures to test, so temperature is the *independent* variable.

dependent variable: the things that happen in the experiment. These are the numbers you measure as a result of the experiment, which means they are *dependent* on what happens in the experiment. For example, if you are trying to figure out how much sugar you can dissolve in water, you don't know how much sugar dissolves until you measure it. This means the amount of sugar that dissolves is the *dependent* variable.

control variable: things that you need to keep constant in the experiment. If there are a lot of factors that could affect your dependent variable, and you want to test the effect of one of them, you need to keep the other ones the same. Otherwise, you don't know what caused the changes that you are seeing.

Control variables are usually parameters that could become independent variables in other experiments. For example, if you are trying to figure out how much sugar you can dissolve in water at different temperatures, you need to use the same volume (amount) of water each time. This means the volume of water that you use is a *control* variable.

If someone asks what your independent, dependent and control variables are, the question simply means:

- “What did you vary on purpose (independent variables)?”
- “What did you measure (dependent variables)?”

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- “What did you keep the same for each trial (control variables)?”

### Qualitative Experiments

If the goal of your experiment is to find out **whether or not** something happens at all, you need to set up a situation in which the phenomenon you want to observe can either happen or not, and then observe whether or not it does. The only hard part is making sure the conditions of your experiment don't bias whether the phenomenon happens or not.

If you want to find out **under what conditions** something happens, what you're really testing is whether or not it happens under different sets of conditions that you can test. In this case, you need to test three situations:

1. A situation in which you are sure the thing will happen, to make sure you can observe it. This is your **positive control**.
2. A situation in which you are sure the thing cannot happen, to make sure your experiment can produce a situation in which it doesn't happen and you can observe its absence. This is your **negative control**.
3. A condition or situation that you want to test to see whether or not the thing happens. The condition is your independent variable, and whether or not the thing happens is your dependent variable.

### Quantitative Experiments

If the goal of your experiment is to quantify (find a numerical relationship for) the extent to which something happens (the dependent variable), you need to figure out a set of conditions under which you can measure the thing that happens. Once you know that, you need to figure out how much you can change the parameter you want to test (the independent variable) and still be able to measure the result. This gives you the highest and lowest values of your independent variable. Then perform the experiment using a range of values for the independent value that cover the range from the lowest to the highest (or *vice-versa*).

For quantitative experiments, a good rule of thumb is the **8 & 10 rule**: you should have at least 8 data points, and the range from the highest to the lowest values tested should span at least a factor of 10.

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## Letting the Chemistry Design the Experiment

Determining what to measure usually means determining what you need to know and working backwards to figure out how to get there from *quantities that you can measure*.

Especially in chemistry, most of the complexity of experiments comes from the fact that there are few quantities that we can measure directly. When we have to measure quantities indirectly, we need to be clever, and we need to think about all of the possible ways we could end up with an invalid result, so we can design the appropriate safeguards into the experiment.

For a quantitative experiment, it's often best to start with a mathematical formula that includes the quantity you want to determine. Then, you need to find the values of the other quantities in the equation, either by measuring them directly or by performing an experiment in which you can determine them by measuring other things.

As an illustrative example, suppose you want to calculate the heat released per mole of reactant in a specific chemical reaction. (Don't worry if you don't understand what this means—we will get there later in the course.) You might go through the following thought process:

1. We can't measure heat directly, so we need an equation to calculate it.

We can use the equation:

$$Q = mC\Delta T$$

In order to use this equation to calculate heat ( $Q$ ), we need to find  $m$  (mass),  $C$  (specific heat capacity), and  $\Delta T$  (temperature change), which means we need to use the heat to *change the temperature* of a *mass* of something.

An experimental device that does this is a bomb calorimeter\*, so we will use one of those.

2. Determine our independent variables in the above equation.
  - a. We predetermine  $m$  (the mass of the water in the calorimeter) by putting a known mass of water into the calorimeter. We can measure the mass of the water using a balance.
  - b.  $C$  (the specific heat capacity of the water in the calorimeter) is a constant that we can look up.

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\* A "bomb calorimeter" is a device that uses the heat of a chemical reaction to heat up a known amount of water so you can measure how much heat is produced. Despite the cool-sounding name, a bomb calorimeter doesn't actually involve blowing anything up.

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3. Determine our dependent variables in the equation.

- We need to calculate  $\Delta T$  (the temperature change of the water). This means we need to measure the temperature at the beginning and at the end, and subtract. We can measure the temperatures with a thermometer.

4. Determine our control variables.

- a. We want the heat per mole of reactant. If we're going to calculate the heat, we need to control the number of moles of reactant (*i.e.*, how much of the chemical we use), which means we need to measure the mass of the chemical and convert it to moles.
- b. We need to make sure all of the chemical reacts, so we need use excess amounts of everything else.
- c. We need to make sure no heat is lost to the environment. This means we need to set the experiment up so we can start the reaction after the chemicals are already inside the calorimeter.

Notice that our entire experiment is ultimately determined by starting with what we wanted to know at the end of it, and figuring out what makes it happen, and what problems we need to avoid.

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## The Experimental Design Process

1. **Figure out what you want to know.** Decide on an experiment that you could use to find it. If what you want to know is a term in an equation, your experiment will involve finding out values for the other variables in the equation.
2. **Determine your independent variables.** Based on your experiment and the equation that goes with it if there is one, determine your independent variables. Figure out what they are, how you are going to determine/measure them, and which values you are going to choose for them. (You may want to wait to choose the values until you know what your dependent and control variables are, and use the expected values to backward calculate your choices for your independent variables.)
3. **Determine your dependent variables.** Figure out what they are, and how *and when* you are going to measure them.
4. **Determine your control variables.** Think about the things that you already know that you need to keep constant. Then start thinking about what could go wrong, which will lead you to other things you need to keep constant.
5. **Set up your experiment and do a test run.** Use your test run to make sure you can actually measure what you think you can measure and make sure you are getting results that make sense. *This means you need to perform the calculations for your test run before doing the rest of the experiment*, in case you need to modify your procedure. You will be sad if you finish your experiment and go home, only to find out at 2:00 am the night before the write-up is due that it didn't work.

More complex experiments use this same process, except that each step might have several sub-steps, and/or that each step or sub-step might be its own completely separate experiment.

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