Designing & Performing Experiments

Unit: Laboratory & Measurement

NGSS Standards: N/A

MA Curriculum Frameworks (2006): N/A

AP Physics 2 Learning Objectives: SP 4.1, SP 4.2, SP 4.3

Skills:

- determine what you are testing
- figure out how to get from what you can measure to what you want to determine

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.

Notes:

Most high school physics experiments are relatively simple to understand, set up and execute—much more so than in chemistry or biology. This makes physics well-suited for teaching you how to design experiments.

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 physics. In this course, you will usually 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.

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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 parameters that you specify when you set up the experiment. Because you chose these values, they are *independent* of what happens in the experiment. For example, if you are dropping a ball from different heights to find out how long it takes to hit the ground, you are choosing the heights, so height is the *independent* variable.

dependent variable: the things that happen in the experiment. These are the numbers you measure, which are *dependent* on what happens in the experiment. For example, if you are dropping a ball from different heights to find out how long it takes to hit the ground, you are measuring the time, which depends on the height. This means time is the *dependent* variable.

control variable: other things that could vary but are being kept constant. These are usually parameters that could be independent variables in other experiments, but are kept constant so they do not affect the relationship between the independent variable being tested and the dependent variable being measured. For example, if you are dropping a ball from different heights to find out how long it takes to hit the ground, you want to make sure the wind is the same speed and direction for each trial, so wind does not affect the outcome of the experiment. This means wind speed and direction are *control* variables.

If someone asks what your independent, dependent, and control variables are, the question simply means, “What did you vary (independent variable), what did you measure (dependent variable), and what did you keep constant (control variables)?”

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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 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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Determining What to Measure

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

For a quantitative experiment, if you have a mathematical formula that includes the quantity you want to measure, you simply need to find the values of the other quantities in the equation. For example, suppose you want to calculate the amount of force needed to bring a moving object to a stop. We can calculate force from the equation for Newton's Second Law:

$$F = ma$$

In order to use this equation to calculate force, we need to know:

- **mass**: we can measure this directly, using a balance
- **acceleration**: we could measure this with an accelerometer, but we do not have one in the lab. This means we will need to calculate acceleration from another formula.

Notice that the necessary procedure has expanded. Instead of just measuring force and acceleration, we now need to:

1. Measure the mass.
2. Perform an experiment in which we apply the force and collect enough information to determine the acceleration.
3. Calculate the force on the object from the mass and the acceleration.

In order to determine the acceleration, we need another equation. One candidate is:

$$v = v_o + at$$

This means in order to calculate acceleration, we need to know:

- **final velocity (v)**: the force is being applied until the object is at rest (stopped), so the final velocity $v = 0$.
- **initial velocity (v_o)**: we need to either measure or calculate this.
- **time (t)**: we can measure this directly with a stopwatch.

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Now we need to expand our experiment further, in order to calculate v_o. We can calculate the initial velocity from the equation:

$$\bar{v} = \frac{d}{t} = \frac{v_o + v}{2}$$

We have already figured out how to measure *t*, and we set up the experiment so that *v* = 0 at the end. This means that to calculate v_o, the only other quantity we need to measure is:

- **displacement (*d*)**: the change in the object's position. We can measure this with a meter stick or tape measure.

Now every quantity in the experiment is something we can measure or something we can calculate, so we're all set. Our experiment is therefore:

1. Measure the **mass** of the object.
2. Apply the force and determine the **acceleration** of the object:
    a. Set up an experiment in which the object starts out moving and then it **accelerates** (negatively) until it stops.
    b. Measure the **time** it takes the object to come to a complete stop, and the **displacement** (change in position) from when it first started slowing down to where it stopped.
    c. **Calculate** the **initial velocity**.
    d. Using the **initial velocity**, **final velocity** and **time**, **calculate** the **acceleration**.
3. Using the **mass** and **acceleration**, **calculate** the **force** on the object.
4. Take multiple data points based on the **8 & 10 rule**—take at least **8 data points**, varying the mass over at least a **factor of 10**.

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Generalized Approach

The generalized approach to experimental design is therefore:

1. Find an equation that contains the quantity you want to find.
2. Work your way from that equation through related equations until every quantity in every equation is either something you can calculate or something you can measure.
3. Determine how to measure the quantities that you need (dependent variables). Decide what your starting conditions need to be (independent variables), and figure out what you need to keep constant (control variables).
4. Set up your experiment and take your data.
5. Calculate the results. Whenever possible, apply the **8 & 10 rule** and calculate your answer graphically (explained in the next section).

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