# Experimental Design Reference Guide

**A. INDEPENDENT VARIABLE:** (I.V.) Also called the **Manipulated Variable**.
The variable you purposely change or manipulate. Will be the CAUSE of the changes you measure.

1. **LEVELS:** The values you choose for your Independent Variable.
2. **TRIALS:** The number of times each level is repeated.

| | | | |
|---|---|---|---|
| Levels | 0 | 12 | 24 |
| Trials | 12 | 12 | 12 |

*(A table for the example on the next page. If you ever see a blank table like this, know how to fill it out.)*

**B. DEPENDENT VARIABLE:** The variable that responds. Also called the **Responding Variable**.
The variable you will measure after the experiment is set up. Will be the EFFECT of the action taken.

**C. CONTROLLED VARIABLES (CONSTANTS):** *All* the other elements that **remain the same** for all the trials. Must be quantified. (Include numbers.) **Do not confuse** with I.V. and D.V.

**D. CONTROL:** A tested group that is of a normal level, does NOT contain the independent variable; the NO TREATMENT GROUP or NORMAL TREATMENT GROUP.
This gives you a way to detect hidden variables or a change.

**E. HYPOTHESIS:** A proposed explanation of an observable phenomenon. You will have an **experimental hypothesis** (**$H_E$**). We will use the "If…, then…" formula. However, in order to apply statistical tests, a **null hypothesis ($H_0$)** is generated. It is a hypothesis stating that there is **no relationship** between two variables. This is the hypothesis that is subjected to statistical analysis. With this, you put the $H_0$ up on a pedestal and attempt to knock it down (*refute*, or reject) using data. Refuting the $H_0$ implies that the $H_E$ can be accepted beyond reasonable doubt. The $H_0$ isn't the opposite of the $H_E$, it simply states that no change will occur.

**Example:**
**$H_E$: If plants are exposed to higher durations of light, then they will grow taller.**
**$H_0$: Various durations of light exposure will not result in any measurable difference in plant height.**

Data that strongly support acceptance of an $H_E$ are said to be **statistically significant**. In other words, the probability that the data arose by chance alone is low enough for you to be confident the results are meaningful and can be accepted. Most tests performed by statistical software generate a single number called the **test statistic**. That number is then compared to probability distributions to arrive at a **p-value**. The p-value is an estimate of the probability that your results are due to chance. In the scientific community, results are only considered significant if the p-value is below some **critical threshold**. For example:

**$p < 0.05$**, results are **significant**. This is known as the 95% confidence level.
(The probability that the results you got could be obtained by chance is less than 5%.)

**$p < 0.01$**, results are **highly significant**. This is known as the 99% confidence level.
(The probability that the results you got could be obtained by chance is less than 1%.)

**$p < 0.001$**, results are **very highly significant**. This is known as the 99.9% confidence level.
(The probability that the results you got could be obtained by chance is less than 0.1%.)

**If the calculated p-value is less than the established critical threshold, we reject $H_0$ (and accept $H_E$).**

**Scenario: A group of students is assigned a plant project in their Ninth Grade science class. They decide to determine the effect of sunlight on radish plants. They grow 12 radish plants in 4" clay pots with 25 mL of water daily and 100 g of potting soil in 24 hours darkness, 12 hours sunlight/12 hours darkness, and 24 hours sunlight. (They use Grow-Lights to simulate sunlight.) After 5 days, they measure the height of all the plants in each pot.**

## 1. TITLE:

Communicates what your experiment is about. It isn't cute, catchy or short, but very descriptive.

**The Effect of** (the independent variable) **on** (the dependent variable.)

Example: **The Effect of** Sunlight **on** the Height of Plants.

## 2. HYPOTHESIS:

Communicates what you think is going to happen in the experiment. A hypothesis is not an "educated guess." After careful research, it is a proposed explanation of an observable phenomenon;
a prediction of how a situation will conclude. It must be testable. It cannot be proven, but upheld or falsified.

**If** (the independent variable) **is** (increased, decreased, changed)**,**
**then** ( the dependent variable) **will** (increase, decrease, change.)

Example: **If** the sunlight **is** increased, **then** the height of the plants **will** increase.

## 5. PROCEDURE:

Write a detailed and precise **procedure** that includes both

1) the materials/equipment needed (include sizes, quantities) and
2) the correct sequence of steps to be taken.

The procedure should be detailed enough so that another experimenter could duplicate the experiment without having to ask you ANY questions! Write for one level of the independent variable and add repetitions for repeated trials. Most steps should include a **number** of some kind: size of pot in mL, amount of soil in grams.

The addition of photos is very helpful here.

## 6. RESULTS:

**6a.** The results simply state what happened. Raw data is revealed here.

**6b. DATA TABLE:** Although there are no universal rules for constructing data tables, generally accepted guidelines and conventions do exist. For example, the independent variable is almost always recorded in the left column and the dependent variable in the right. When repeated trials are conducted, they are recorded in subdivisions of the dependent variable column. If derived quantities, such as the average height are calculated, there are recorded in an additional column to the right. When recording data in a table, the values of the I.V. are ordered from smallest to largest. The title of the data table should communicate the purpose of the experiment and mention both the I.V. and D.V.

Example:

**The Effect of Sunlight on Height of Plants**

| I. V. Sunlight (hrs.) | D.V. Height of Plants (cm) Trials | | | | | | | | | | | | Statistics | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Central Tendency | Spread |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Mean | Range |
| 0 | | | | | | | | | | | | | | |
| 12 | | | | | | | | | | | | | | |
| 24 | | | | | | | | | | | | | | |

**6c. STATISTICS:** There are 3 derived quantities or statistics we will calculate for our data: mean, range, and standard deviation.

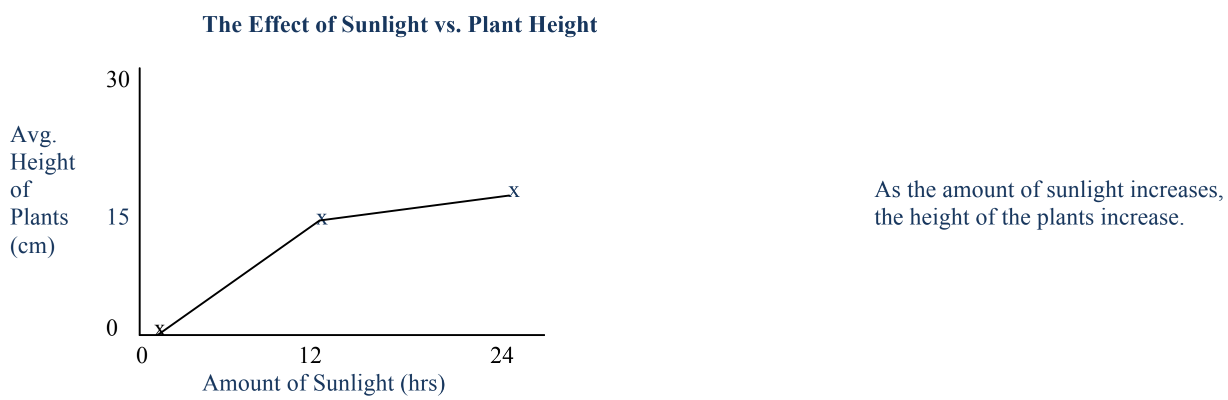
1. **MEAN** - is the average of the data. Mean is calculated by adding all the data for a particular level and dividing by the number of trials; the **Central Tendency** of the data.
2. **RANGE** - is the spread of the numbers within a particular level. Range is calculated by subtracting the lowest value from the highest value; the **Spread** of the data.

# 7. ANALYSIS

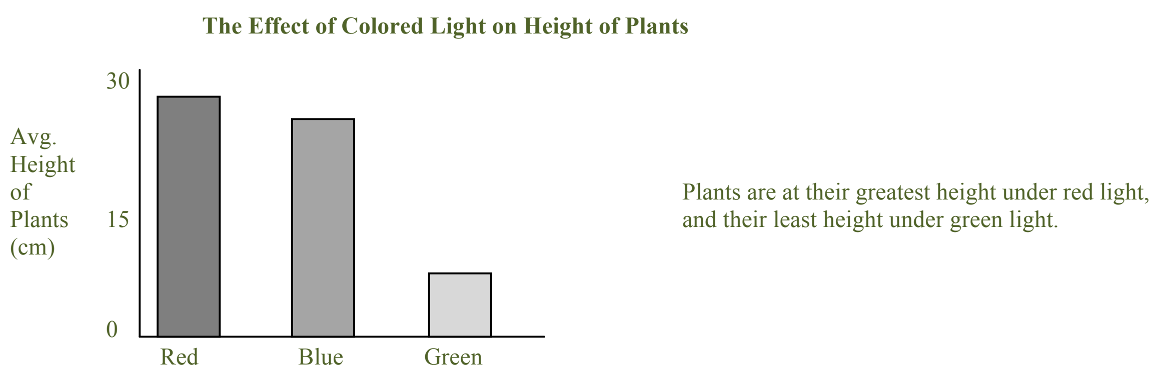
Tear apart the raw data you have gathered. Begin to make sense of it. Apply meaning to the data. Certain elements will help you with this.

**7a. GRAPHS:** Sometimes, you may not be sure whether to make a bar graph or a line graph of your data. The appropriate type of graph depends on the type of data collected. Use Excel or Create-A-Graph to create your graphs. Excel can also add a line of best fit and other calculating functions.
REMEMBER: ***DRY MIX*****: Dependent (Responding) on the Y axis, Manipulated (Independent) on X axis.**

**LINE GRAPH:** Use when the I.V. is a continuous range of measurements with equal intervals. When the I.V. is numerical and the intervals between the numbers have meaning, such as height of plants, amount of fertilizer, length of time, submersion time. Here, the amount of sunlight (in hrs.) is a continuum: Although measured at 0, 12, and 24 hrs., 3, 16, and 22.47 hrs. exist too and could have a possible *y* value on the graph. This is a good application for a line graph.




**BAR GRAPH:** Use when the I.V. is categorical. There is not standard numerical scale and the intervals have no numerical meaning, such as days of week, color, brand names.




**PIE CHARTS:** Used to indicate portions of a whole, parts that make up 100% of something.

**7b.** Use analytical formulas to determine values useful in assessing validity of study, significance of findings, etc. P-values, Chi Square, and many other formulas may be used here to make sense of the data.

# 8. CONCLUSION PARAGRAPH:

An **Conclusion Paragraph** usually contains

1) a description of the purpose of the experiment,
2) a statement that your hypotheses were supported/refuted, and why,
3) a brief review of your findings (analysis),
4) and recommendations for further study.

Usually the following questions are presented in paragraph form:

1. What was the purpose of the experiment? (Include I.V. and D.V. in this sentence.)

    **Format:** The purpose of the experiment was to investigate (Insert Title.)

    **Example:** The purpose of the experiment was to investigate the effect of stress on the growth of bean plants by comparing the growth of bean plants subjected to stress for 15 days with a control (non-stressed plants.)

2. Was the hypothesis supported by the data?

    **Format:** The hypothesis that (Insert Hypothesis) was (supported, partially supported, or not supported.)

    **Example:** The hypothesis that stressed plants would have a lower mean height was not supported.

    (Optional) How did your findings compare with those of researchers (or other lab groups)?

    **Example:** In contrast, Japanese farmers found that hitting and pulling rice plants were beneficial to plant height.

3. What were the major findings?

    **Format:** The major findings were (insert your results here, in one sentence.)

    **Example:** The major findings were that there was no significant difference existed between the mean height of stressed plants and non-stressed plants 30 days after transplanting.

    What's the meaning of your results? What is the reason(s) your results were what they were? What happened that you did not expect?

    **Format:** (Insert anomaly if there was one) was not expected. This may be explained (insert explanation).

    **Example:** The stressed bean plants were expected to have a lower height. The fact that they didn't and that Japanese rice farmers stress their points on purpose to achieve better growth means that something about stressing out plants makes them grow better. Perhaps some plants that are stressed release a chemical in response to the stress that promotes better growth and others don't release that chemical, such as rice vs. beans. Or perhaps there is a difference in reaction to stress between monocots and dicots.

4. What recommendations do you have for improving this experiment?

    **Example** Improved experimental design techniques including a larger sample and a longer growing period would benefit a similar study.

    What recommendations do you have for further study? (This is above and beyond this experiment.)

    **Example:** Additional investigations using various sources of stress at more frequent intervals would be a good additional experiment. Another idea would be to use different types, such as a monocot and a dicot. If further research were done, perhaps scientists have isolated a chemical released by plants during stress. It would be interesting to investigate the amounts of this chemical released during stress.