Thinking about doing a project for a science fair? Go for it!

As you think about your project, here are a few things you might keep in mind.

**Stating your Hypothesis**

Perhaps the most central element of any experiment is asking a good question. Science is a process of inquiry. You begin any investigation by asking a question. You may begin with a very general question such as “how does this work?” or “what would happen if I did this to that?” In order to begin to answer such a general question, you need to ask very specific questions to begin to learn about how something works.

For example, you might wonder how does a plant grow? How can I make a plant grow better? These are very general questions. The first thing to do is to find out what is already known about how plants grow and then to investigate particular aspects of plant growth. You might find out that plants need a proper atmosphere with carbon dioxide and oxygen, water, nutrients, light, and warm temperatures. You might then ask a specific question such as what is the effect of temperature on plant growth, or what is the effect of light intensity on plant growth?

This specific question can be stated to form your scientific **hypothesis**. One hypothesis could be: Will additional nutrients result in greater plant growth? That becomes a testable question, which means that it can be investigated scientifically. You can use that to make a prediction.

One of the peculiar aspects of science is that it is far easier to disprove something than to prove something. Some people even go so far as to say science never proves anything, it only disproves things! If you cannot disprove something, then it must be so, at least until someone comes along and finds an exception. In that sort of backwards way of looking at things, scientists form what they call a **null hypothesis**. The null hypothesis says that what you do will have no effect. Then, if you can disprove that, you can have some confidence that it did indeed have an effect. Let’s look at how that works.

**Hypothesis:** The addition of nutrients will make a plant grow taller.

**Null Hypothesis:** The addition of nutrients will have no effect on the growth in height of a plant.

If you can disprove your null hypothesis, it will support your original hypothesis. Why not just say that the original hypothesis was proven? The problem with that is that there might be something else at work that you are not thinking about. What if the additional nutrients fed some fungus in the soil that produced a chemical that in turn made the plant grow taller? Then it was not the effect of the nutrient on the plant, but the effect of a fungal chemical. If the fungus was not there, the plant might not grow better at all, even with the nutrients.
In general, you want to make your hypothesis as specific as possible to try to eliminate as many other things as you can that might be affecting the outcome.

**Where do I get information?**

Once you have your general question, where do you go to get additional information and find out what is already known? You might start with a general reference such as an encyclopedia, but these are usually very general without much detail in the information that they give. A better source of information might be a good general science textbook. If your teacher does not have these available in the classroom, you might check the school library, or a library at a local community college, college or university. The internet may also contain something on the subject. Use a good search engine (web site for internet searches) to see what is out there. You may want to have an adult help you with this because there are a lot of poor sites out there as well as a few useful sites. Don’t forget people resources as well. Ask a teacher, call or e-mail a college professor, ask a professional (doctor, veterinarian, horticulturist, agricultural extension agent, district forester, chemical engineer, or whoever might help), call a local scout troop and ask for their merit badge counselor on a particular subject. Your teacher can probably help you think of other resources as well.

**What is a variable?**

Once you start thinking about what you would like to investigate, you need to think about how you go about it. To begin your investigation, you need to understand the parts of an experiment. If you want to know what effect one thing will have on another, we call the thing that you change or vary the **variable**. In the example we were discussing earlier, the nutrients would be the variable. You might add a little or a lot of nutrients in the form of a fertilizer. Or you might try different fertilizers and compare their effects on plant growth. Either the concentration (amount) of fertilizer you apply or the form (different brands) of fertilizer would be your variable. Select one thing that you want to change (either the concentration or the brands, or whatever) and that becomes your variable. In general, you want to have a single variable to explore as that will make the interpretation of the results much easier.

Actually there are two variables with which you need to be concerned. The variable that you are deliberately changing is called the **independent variable**. In this case, it is the amount of fertilizer that you apply. The other attribute that is variable is the growth of the plant. How much growth occurs is hypothesized to be under the influence of the independent variable. Growth, since it is dependent on the fertilizer, is called the **dependent variable**. The dependent variable is the measurable attribute that varies or changes under the influence of the independent variable.

**What is a control group?**

In order to tell if the thing you changed (variable) had an effect, you need to compare the group that you altered with a group that you did not alter. The group that is identical to your
experimental group, but is not treated with the variable is called the control group. This group becomes the group for comparison to see if changing the variable did have an effect. Why is this important?

Just ask yourself, do plants grow as they get older? Of course they do! So how do you know if your fertilizer had any effect or if the plant grew simply because it was getting older and plants naturally grow taller as they age? You wouldn't know unless you had a control group for comparison. By seeing how much the control group grows in comparison to how much you experimental group grew, you can tell what effect, if any, the fertilizer had.

**How many groups and specimens do I need?**

Let’s think about people for just a moment. Do you have classmates that are tall and some that are short even though they are the same age? Are some people heavier than others even though they are the same age? Just as people are variable, all organisms have variation among the members of their species. This natural variation makes it important for you to look at the effects of changing the variable on more than a single individual.

In our fertilizer example, what if the control group consisted of a single individual that just happened to be a fast growing plant and what if the experimental group was a single individual that was a runt plant? This experiment will probably not show the true effects of the fertilizer on plant growth in general. When we say in general, we are talking about average results when we look at the effects of changing the variable on lots of individuals.

Therefore, in the control group, you need more than one individual. In each experimental group, you need more than one individual. If you are looking at the effect of fertilizer on plant growth, and decide to test the effects of one, two, and three teaspoons of fertilizer per gallon of water that is used to water the plants, then each fertilizer concentration will become a treatment, and each treatment group should have more than one individual. In this case, you would have four groups: a control group (no fertilizer, just water), a one teaspoon per gallon group, a two teaspoon per gallon group, and a three teaspoon per gallon group.

How many plants should be in each group? That will depend on how much variation naturally occurs in the type of plant that you are using. A good general rule is to have at least ten plants in each group. If there is a lot of variation in the type of plant, you might want to have more – maybe up to thirty or more. If you have only one or two plants in each group, it will be very hard to be sure that your variable has any effect.

In summary, you need a group of subjects to measure for each difference in your variable that you wish to test. For statistical analysis, if you are advanced enough to worry about that, you may want to have several groups of subjects for each treatment. These are called replicates and are needed for some types of statistical analysis. Most beginners won't need to worry about this. But you do need to be sure that you have as many samples or subjects in each group as you can manage well.
**How do I measure my results?**

In general, comparisons are easier to make in science if they are based on numbers. If you can measure the dependent variable, then you can make decisions more easily about whether or not the independent variable had an effect when compared to the control group. To help us be completely objective in making the comparison, scientists use statistics to determine if the measured differences are significant, or meaningful.

Measurements are best done by a scalable, quantifiable means. What that means, is measure length or height with a ruler, or weight with a balance or scale, or temperature with a thermometer, etc. Scientists tend to prefer to see the use of the metric scale in reporting results. If you cannot use a continuous scale like millimeters or grams, but have to use categories for your results, then you need to have a clearly established basis for your measurement.

For example, what if you are looking at the effect of nutrient deficiency on leaf color. Then you need to have a color scale that you can use to make the same comparison each time you observe the leaves. You might want to prepare a color table or pick up some paint charts from a local paint store and use certain colors as your standards for comparison.

Basically, any means you use to measure the results is acceptable as long as it is repeatable and can be communicated clearly to others. Your results may in the form of a measurement, a category of response, or frequency (how often it happens). Be creative and imaginative when thinking about how you might measure your results. Just be sure that the method is defined and repeatable.

**How do I report my results?**

Your results should be written into a report and should also be presented in graphs or tables if possible. Tables can summarize lots of results for easy reading and understanding. Just be sure that the table is well organized and has clear labels and entries. A good table or graph will also have a clear title.

Graphs can be prepared in a variety of ways including line graphs, bar graphs, box and whisker plots. Your teacher can help you decide which method of graphical presentation is best suited to your results. Be sure to label your graph properly. It is customary to plot the independent variable along the X-axis (across the bottom) and the dependent variable is plotted along the Y-axis (up the side). Make sure that the axes are properly labeled as the variable and the units used to measure the variable.

It is important that the information in your tables or graphs be the averages or means of the measurements in the different treatment groups. If you have a control group of ten plants, and two different treatment groups with ten plants in each group, you should not plot 30 points on your graph. You should have three points on your graph and each point should be the average of the ten measurements in a particular group. There may be occasions where you would want to
plot each data point, for example if you are making a scatter diagram to show clustering of results, but that is pretty rare. In general, plot the averages, and if possible, add the standard deviation or standard error of the mean. That will make obvious whether the differences between the plotted points are meaningful. Your teacher can help you calculate the standard deviation. You also can find lots of web sites that can help you find standard deviations or other statistics to report.

**How do I make sense of it all?**

In your final report, you not only want to report the results, but you want to make sense of those results. You need to say what the results mean, that is, what did you learn from doing the experiment? What do we know now that we did not know before you did your experiment? How did your experiment add to what is known about the subject? Also, most science experiments cause us to ask new questions based on what we did and what we learned. In your report, you might want to talk about what you would do differently if you had to do the experiment over again. You also might want to say what you would do next to find out more if you had the opportunity. These are questions that science fair judges often ask anyway and it would help you out to think about these things in advance.

**What about Statistics?**

Do I need statistics to help me interpret my measurements (data)? The answer depends on how much confidence you want to have in your conclusions and in how you had your experiment designed.

Remember, some variation or differences in the groups is to be expected just because individuals are naturally different. Statistics help us decide if the difference is really due to the effects of the variable, or are occurring simply by chance. Statistics tell us how likely or how probable those differences are because of natural variation instead of our independent variable effects.

The use of standard deviations or standard error bars in the presentation of graphical information can be one of the easiest ways to help judges see if there are significant effects from changing your variable.

Sometimes a simple t-test might be very informative. For more elaborate designs, an analysis of variance (ANOVA) might be appropriate. To decide what is appropriate for you, you should talk with a math teacher, or a statistics teacher if your school has one. If you have a business teacher or economics teacher at your school, chances are good that they have studied statistics also.

If you use statistics in analyzing your results, the judge will want to know that you understand what you did. If you are not prepared to explain the statistical analysis, then you either need to state that your relied on someone else’s expertise to do that part of the experiment and give them appropriate credit, or go to a simpler method of analysis and presentation that is comfortable for you. Most judges will not criticize you if you rely on someone else and state that up front, but
they will still expect you to know and explain why the statistical analysis was necessary and what it was for, at least in general terms.

Most middle school science fair projects do not include statistical analysis.

**Just a Few More Things**

In writing your report, please watch your grammar. Many students make simple mistakes that take away from the quality of their presentation. For example, please watch out for the following common mistakes.

**Affect and Effect**

Do not confuse these two words. **Affect** is a verb and means to influence or to have an effect on. For example, one might say “the addition of fertilizer will affect how tall a plant grows.” **Effect** is usually used as a noun and means a result or outcome or influence. The effect (outcome, consequence) of adding the fertilizer is taller plants. Effect also can be used as a verb, but in this case, it means to cause, accomplish, or produce. For example, one might say “the new law will effect changes in public behavior,” meaning that the law will cause people to behave differently. As another example, one might say “I will effect repairs to the broken machine,” meaning that I will cause the machine to be fixed. Mistaken use of affect and effect is all too common among science fair presenters.

**Varying and Various**

**Various** means different, unlike, separate, or individual, and is usually used when discussing the concentrations or applications of the independent variable. For example, “I applied various concentrations of fertilizer to the plants.” **Varying** is progressive and means changing or continuing to change. If you say that you applied varying amounts of fertilizer, you are saying that you applied changing amounts, which is most unlikely, and if true, would seriously complicate the interpretation of the experiment. Please do not use varying (changing) when you really mean to use various (different).

**Just Do It**

Now that you have read all this, don’t feel like it is too much to do. Start looking around and asking questions, then set up your science experiment and go for it! When you finish, think about writing it up and showing off what you did at a local science fair. You might just have the next important discovery in your hands!