Mr. Pellino's Handy Tips

For Those Wishing to Excel in Science Fairs

This guide is intended to walk you through some of the more confusing but important things you'll need to do if you want to do well at a science fair. A science fair is a place where you can show others that you know how to be a scientist, just like a recital is a place where you show others that you know how to be a musician or dancer, and a gallery is where you show others you know how to be an artist. It's not designed to tell you what to do for a science project

(Note: We already know how to grow bread mold, and we're pretty clear that swabbing everyday objects can grow some alarming bacteria in a petri dish. Vinegar and baking soda make a very impressive volcano, and we like a good explosion as much as the next person. We know there are differences in toothpastes, but only the people who sell toothpaste really care about that sort of thing. These kinds of projects are valuable to train you how to do science-ish projects, and are great exercises. Every Olympic skater still has to do their figure-eights, and even Lance Armstrong has to practice jumping curbs with his bike. But that's not what wins medals. Remember that science is at its best when it shows new things that are true discoveries, that make you and others say "Aha!" - reach for those, demonstrate your skill to the judges, and you'll be headed for success.)

Null Hypotheses for Fun and Profit

Nothing tells a judge "I know science - and this is science!" like a null hypothesis. It has its roots in detective work, the legal system, scientific method, not to mention magic, illusion, and conjuring. Many people are fond of simply claiming they have a hypothesis, and can tell you that it's really "an educated guess". But a quick, slapdash hypothesis is the very tool you need to do bad science, and in fact is the basis for most of the quackery and hoaxes you see on late night cable television.

A positive hypothesis such as "Baboons who eat marshmallows will have longer tails." is a trap to be avoided at all costs. Why? Suppose you have it in your head that marshmallows should cause longer tails on baboons. As you feed the marshmallows to the baboons, odds are that there will be some change in tail length in the course of your study. It's a quick, easy, and happy way to end your study and go back to video games if you claim the tail growth is from the marshmallows.

But you'd be laughed out of the science fair for doing so. Why? How do you know the tails didn't grow for some other reason? How much growth was there? Was it significant? Was it measurement error? Is it repeatable? Is it an illusion?

To make sure you're not just seeing fairies in the steam from your hot chocolate, or hearing messages in the static on the TV, you should always state your hypothesis as a null - that is, that you assume there is no effect. If you do find evidence, then you can reject that null hypothesis, then you can point to the evidence and everyone can see it, repeat it, measure it. The bottom line for a null hypothesis is:

"There will be no significant difference in Y with respect to X."

In our silly example, Y is tail growth and X is marshmallow feeding. Remember that X and Y are variables, just like in algebra - so you'd better be able to show more than one value for X and observe what happens to Y.

With a null hypothesis, you're doubly-safe, because you can't prove a negative (more on this later), so even if you think you've proven a negative by not finding something, you've really just failed to reject the idea of... nothing, and the universe is intact with no new imaginary inventions from you.

Repeat After Me:

You may as well get this part down soon - it needs to be a constant reminder in everything you try in science: whatever you do has to be repeatable. Others should be able to do what you did and get the same results. If they can't, then it's not science. Science is built on empiricism, which works like this: we do something because it works, we continue to do it because it continues to work. We can depend on the sun rising, because it always has and we can understand the causes that makes it predictable.

If there is a "scientific method" it is the application of empirical thought to the world around us. Just like poetry is the application of rhyming to the world around us, or art is the application of images to the world around us, it's another way of dealing with the world.

If you wanted to be able to put the "scientific method" on a button to wear, it might look like this:

Observe
Measure
Predict
(repeat as needed)

In truth, there are many methods that scientists use to get their observations, measurements, and predictions. They include hunches, intuition, inspiration, dreams, accidents and annoyances.

After you're all done with those three basic steps, no matter how you got there, you need to make sure you - and more importantly others - can confirm and repeat your work. This is why science reports resemble recipes. They really are recipes for getting to the discovery you claim, so the world can confirm that what may have come to you in a dream (like Kekule's dream of a snake that led him to imagine rings of carbon molecules) isn't just a dream, but something useful and reliable.

(Note: yes, we all know what David Hume said, that if you're using empiricism because it's always worked, then science is just a big circular argument. Since there is a similar fatal flaw you could find in every branch of philosophy, Hume can go sit in the corner while we use empiricism to keep from getting bit by buses and dying of horrible diseases.)

A Field Guide to Variables

The definition of something is often contained in what it is not. If this sounds a bit Alice-In-Wonderland-ish, it is. Lewis Carroll was a math teacher after all, and knew the value of logic. Many of his scenes reflect problems of logic and arithmetic. There are two main variables you have to identify if you want to have a project at all: Independent and Dependent. The names are confusing, mostly because you're sure you're in charge of what's going to happen and you're sure those marshmallows are dependent on you. But it's not about you, it's about the science at hand, and right now it's about the variables.

Dependent variables depend on independent variables. In our example, tail growth is the dependent variable, because it depends on the other variable, marshmallows. So by not being the dependent variable, we have to call the marshmallows "independent". Yes, I know, the amount of marshmallows seems to depend on what you decide, but that's not as important as the thing you're observing. Here's a handy table to remind you how to think about these:

	Known as this in terms of...			
	Math	Computers	Everyday	Notes
Independent	X	Input	Cause	Can be anything reasonable
Dependent	Y	Output	Effect	Depends on the independent.

Let Me Intervene

(Or) How to deal with things you didn't plan to deal with. In other words, there's always more than the one independent variable that you can imagine having some effect on your dependent variable. How old are the baboons? Are they different genders? Different strains? Is there a diabetic baboon in your group? Are all the marshmallows from the same batch? Did you use the white ones or the colored or flavored marshmallows?

These are known as intervening variables. You need to do one of two things - either eliminate them by using all one gender or age cohorts or all white marshmallows, or else you can study them, too. This means you set up strata, or layers of things to measure, and end up with a big matrix, where you can then pinpoint the effects of marshmallows on tail growth in left-handed 3-year-old female baboons, or right-handed six-year-olds, etc. The one thing you can't do is ignore these intervening variables - they stick out like sore thumbs to a judge's eye.

Operationalize!

(Or) How can you put your obscure science into real terms that can be done in a few weeks' time? Clearly you can't do everything science can imagine in the amount of time you have for a typical science fair. While this is an argument for sticking with one area year after year (judges like the depth of knowledge you can gain by exploring a topic further each time, on the other hand novelty often catches the eye of a judge who's "seen it all"), the truth is if you have a new project, you'll need to provide a working definition of the things you want to study. What do you mean when you say you'll measure the sound levels in a classroom? At all frequencies? At one frequency? Seven certain ones? Constantly? At one-minute intervals? These are all things that allow you to focus on the task at hand, and can be a big help in eliminating or dealing with intervening variables. When you turn a variable from a concept to an operating definition, you are operationalizing them.

Control? This is Chaos!

Besides the intervening variables we mentioned earlier, there are some things you can't anticipate. There may be things that happen to the baboons every day that you didn't know were part of a baboon's life. The outside world changes, and can change your subjects. Just the act of doing an experiment might change the subject's behavior.

To make things more complicated, there is such a thing as the "placebo" effect - where giving a fake medication has been known to make people feel better. The "Hawthorne" effect is when simply paying attention to a subject can cause changes in them.

To make sure you can detect these things you can't otherwise control, you create just that - a "control" group, that either has nothing done to them, or everything except the important part of the independent variable. In our marshmallow example, you would visit and treat a "control" group of baboons just as if you were giving them the marshmallows, but just not actually hand them a marshmallow. If you're giving a questionnaire, make sure you ask the questions in the same manner, tone of voice, etc. Tiny changes in the initial conditions can result in big changes in results - that's the gist of chaos theory, and you want to be able to identify and account for all the little things that could pile on to your independent variable. A control group can help you identify these.

A-B Control: It's Not Just for GameBoy Anymore

A-B Control refers to the idea that if you can change something in your independent variable to get some dependent result, you should be able to reverse it and see the original values again. You can make "A" happen and then make "B" happen, and you can do this until you run out of time, energy or patience. It's as if you flip a light switch and the lights go out. You need to flip the switch again and check both results to make sure it was the switch that did it, and not a fuse, circuit breaker, blackout, or eclipse.

Which reminds me of a good example of why A-B control is useful.

Eclipses happen. You may think you know why they happen, but the ancient Chinese didn't, and in their world, it was perfectly reasonable that a giant dragon was devouring the sun. So to stop this disaster, they would haul out all their pots and pans and make as much noise as possible to scare the dragon away. As the sun was consumed more and more, they got louder and louder, and just at the height of the evil, suddenly the noise began to work - the sun was disgorged and the dragon gave back the day. Perfect! Works every time we try it! The problem is, their whole theory would become useless the day someone checked what would happen if they didn't make the noise, and the eclipse ended on its own. They could not control the eclipse, they could just react to it. They could not make thing "A" happen, then make thing "B" happen, and back and forth.

Proving Negatives: Don't Try This At Home. Actually Don't Try This Anywhere.

You can't prove a negative. So don't try. I can't prove that there are no purple polka-dotted elephants in the state of Connecticut. That goes for mountain lions as well. Why not? Suppose I start looking. Is it possible that the elephant is very smart and staying one step ahead of me? (remember, to reject the null you would only have to find one...)

You can imagine a lot of explanations for why I can't find one. Maybe he's following behind me craftily, just out of sight? Isn't it possible that there are hundreds of them, and with sophisticated GPS tracking and two-way radios and advanced planning that they can all stay out of reach? You realize this is getting a bit ridiculous. And this is where you can start talking about being reasonable. When you've exhausted the reasonable explanations, you still can't prove there are no such elephants, but you've reached a point where a "reasonable mind" can't imagine the opposite to be true.

Way to go, Sherlock!

"When you eliminate the impossible, whatever remains - no matter how odd - must contain the truth." These are the words of Sir Arthur Conan Doyle, as voiced by his famous character, Sherlock Holmes. In detective work, it's a means of eliminating the silly possibilities that the human mind can invent. There's nothing wrong with silly possibilities, as long as they're part of silliness, imagination, inspiration, humor, etc.

Descarte's Whiskers, Occam's Razor

Rene Descartes was a polymath. He allegedly thought up the X-Y grid while trying to make sense of the flight patterns of flies on his bedroom ceiling. He also found a way of cutting through an annoying problem of his time: How do I know I exist? It was his era's version of repeating everything your brother or sister says. Annoying, Useless, For anything you can say that makes you sure you exist, someone can once again ask "How do you KNOW that?"

If you think you know that you exist because others can see you, then your annoying brother or sister can also argue that maybe you're just dreaming it, or maybe we're all dreaming you, or... you get the picture.

Annoying on a cosmic level. And you could argue this way forever, never getting anything else done, never being able to get through the day, or moving on to other important philosophical questions, because you still can't prove you exist.

Descartes however, was pretty sharp. There's only one good portrait of him, and he's got a smirk on his face, and a stylish mustache, which means he probably had better things to do than listen to people moaning about how they may not actually exist. So he came up with a neat trick: If I didn't exist, then I couldn't be thinking about whether I exist or not. (Note: for those of you keeping score at home, that's built with a null hypothesis - it supposes an negative then produces a positive to reject it) Stated positively, "I think - therefore I am!"

A similar cut-through-the-mess approach is known as "Occam's Razor". William of Occam had a similar problem with all the alternative theories about nature and existence. So he proposed a simple rule to help weed out the unreasonable stuff that can keep people from finding the truth: "All else being equal, the simplest solution is often the best." This is the basis for evidence in court, and something you use all the time. So do your parents. If you're twenty minutes late getting home, it's possible you were abducted by aliens, traveled several light years through hyperspace to their home planet, and helped them design a life-saving device based on bubble gum and shoelaces, and whisked back here to earth all in twenty minutes earth-time.

Possible, but not probable. You probably stopped at the corner store to buy bubble gum and shoelaces, and odds are that's what made you late. Occam's Razor is to blame for your parents' not believing you. It's also how people can dismiss most UFO claims, psychic surgery, and spoon-bending.

(Note: for the record, it's entirely possible all those things are actual, but if the UFO abductions are all real, then simple math predicts there's more flying saucers than airliners. Similarly, you can perform very convincing psychic surgery with some food coloring, gummi worms and 20 minutes practice, and spoon-bending used to be taught as a magic trick on cereal boxes.)

Reporting - The Big Top

Follow a report format: A pretty typical one includes:

Title
Abstract
Background
Materials & Methods
Data
Results
Conclusions
Discussion
References

See. Hear.

How to use charts and graphs to your advantage.

Charts are usually just a table-ized summary of the data you collected, usually organized by variables, and with as few cells as needed to show all the possibilities you covered. if you did two different things to two groups of subjects, you need a 2-by-2 chart - with headers along the top and left to let people know that the northern baboons who got mini marshmallows had an average tail growth of 2.3 centimeters (in our silly example). Charts are the basis for graphs, and graphs are a way of illustrating charts.

Graphs seem to be the big payoff when you have to show someone what happened in your project. The right ones can show judges and readers exactly what happened and why you rejected your null hypothesis. The wrong ones will just make your head spin.

Nowadays, any decent spreadsheet or presentation software has a tool for making graphs. The key with a graph is to use the right one for the data you have.

Bar: this is used to compare either data or statistics that represent different groups. The average reaction time of group A should be one bar, the average reaction time of group B should be another.

Line: this is used to show the change in something over time. Line graphs assume the thing you measured is actually capable of going through all the values the line covers. For instance, if you measure the growth of a seedling, it's OK to use a line graph, because you can be reasonably sure that the seedling was actually 3 cm tall between the times it was 2 cm tall and 4 cm tall. You need to have a numerical scale for a line graph: if what you're measuring changed from "blue" to "red" - don't draw lines between them - there's no assurance that it was ever "purple" in between. Even with numbers, be careful: your daily rhythm of temperature could be hidden if you take your temperature at 8 Am and 8 PM and get the same number - it doesn't mean that your temperature was flat all day long.

Scatter: this is used for two things: to show a distribution of values (actual measurements of many seedlings or baboon tails) or to show that you measured something but aren't necessarily sure that it actually went from 25.7° to 87.3° in a smooth continuous line.

Pie: This is probably the most misused graph type of all time. Pie charts look really cool. You can explode them, shadow them, and people will look at them first, right or wrong. Pie charts are for one thing and one thing only: to show the parts of a whole. For instance you have 100 tomatoes, some green, some red, and you want to show the proportion of each. Several pie charts can show how the distribution is different for different groups. A pie chart made of the tail length growth numbers in all your baboons will be nearly meaningless. Also, make sure pie charts start at the 12 o'clock position with the biggest slice / number and go clockwise with each smaller slice. The smallest slice / number is last and should bring you back to the 12 o'clock position.

Make sure your bar graphs either start at zero, or clearly indicate that they don't . graphs that don't start at zero tend to exaggerate differences and can be misleading.

What's It All About?

In science, every experiment, every investigation means you learn more, and dig deeper into some topic. It is often said that "you know more and more about less and less until you know everything there is to know about nothing at all." That sounds weird, but a stereotype of a scientist is the one-trick pony, the specialist who can tell you the daily growth rate of the terminal edge of the shell of the little pond snail, but can't tie his own shoes.

Poets understand the importance of what they do, so do musicians, teachers, and cab drivers. Scientists can and should, too. Understand your project from all angles. Take a step back from your project before you present it. Consider the real-world implications and be prepared to discuss your project in everyday terms. You should be able to explain it to the leading expert in that field, your grandparents, your congressman, a musician, poet, cab driver, and a first-grader.

Summary

So what can we take from all this? Here's a quick recap:

1. Use a null hypothesis.
2. Know your variables, independent, dependent, and intervening.
3. Operationalize your variables.
4. Use controls where possible.
5. Record everything - no matter how insignificant you think it might be at the time.
6. Choose charts and graphs carefully to untangle things.
7. Follow a report format.
8. Understand your project from all angles.

This does not guarantee success, but it does point you in the right direction on many of these points. You could find another hundred references on this subject, this draws from m any of them and from 30 years' experience by TMSC and TMA staff. Your mileage may vary.

Good Luck!