Preparing for the Science Fair

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How this Talk is Organized

- Introduction
- How Do You Prepare for a Career in Science?
- Why Do the Science Fair?
- Science Fair Strategy and Tactics
- Selecting Subject Area and Topic
- Formulating the Hypothesis
- Experimental Design
- Preparing the Research Notebook
- Strategy and Tactics Revisited

How this Talk is Organized

- Preparing the Scientific Report
- Preparing the Display
- Preparing the Presentation
- Strategy and Tactics One More Time
- Is the Reward Worth the Effort? (Yes, so listen to this talk!)

Why Listen to Me?

- I have a B.S. in Chemistry and M.S. in Environmental Health Sciences from the University of Michigan.
- I am a practicing scientist and environmental chemist with more than 30 years experience.
- I have taught chemistry at the high school and college levels.
- I have judged county and state Science Fairs over the last decade.
- I have mentored several State Science Fair finalists and International Science Fair finalists.

How Do you Prepare for a Career in Science?

- Take as many math and science courses as your school offers.
- If school doesn't offer AP credit classes, work with parent groups to upgrade the curriculum.
- Watch Nova and National Geographic shows on PBS and Discover Channel on cable.
- Learn By Doing:

  -- Participate in Explorer Post activities

  -- **Participate in the Science Fair**

  -- Participate in summer internships with research institutes and companies that employ scientists and engineers

Why Do the Science Fair?

- Thinking is fun! Science is fun!
- Excellent experience in:

  -- using imagination and creativity,

  -- developing logical, systematic thinking skills

  -- locating and understanding relevant scientific literature

  -- identifying what's important

  -- organizing and presenting your thoughts, and

  -- scheduling your time
- Sets you apart in college and work applications.

Science Fair Strategy and Tactics

- One-shot deal (Take the credit and run)
- Pick different topic in successive years but in the same scientific field.
- Same topic in successive years with ever more sophisticated hypotheses, experimental designs, methods, data analysis, reports, displays, and presentations. (This is the one I like.)
- Applied science projects seems to have more attraction for judges than fundamental science projects, because they often ask how your results can be applied.
- Don't bite off more than you can chew; keep it simple, especially for your first project.

Selecting a Subject Area and Topic

- Think and pick subject area that interests you
- Pick sponsor who teaches that or related subject
- Get Science Fair release forms from school
- Get parents and sponsor to sign release forms
- Think and pick topic that interests you
- Do basic literature search on topic using Google or equivalent search engine
- Go to the library and read an introductory book on the subject area and/or topic
- Read, think, learn!

Science Fair Subject Areas

- Astronomy
- Biology
- Chemistry/Biochemistry
- Earth Science/Geology
- Engineering
- Environment
- Mathematics and Computer Applications
- Microbiology
- Physics
- Psychology

Science Fair Subject Areas

- See Handout II for detailed breakdown of subject areas and possible project topics

Developing a Hypothesis

- Pose Scientific Question:

  -- When, where, how, why does this natural phenomenon occur?

- Ask Yourself Additional Questions to Clarify:

  -- Under what conditions and circumstances does the natural phenomenon occur?

  -- What are the most important (key) characteristics of the phenomenon?

  -- What are the process and factors (variables) that govern the timing, magnitude, duration, frequency of recurrence of the phenomenon or the manifestation of its key characteristics?

Developing a Hypothesis

- Hypothesis Formulation:

  -- The hypothesis must be a simple declarative statement about the relationship between an observable effect and a process or factor believed to be the cause.

  -- The hypothesis must be formulated so that you can answer true or false or yes or no if restated as a question.

  -- The truth or falsity of a hypothesis must be testable by measuring something.

  -- The hypothesis should focus on one cause-effect relationship at a time.

Developing a Hypothesis

- Hypothesis Formulation: Good Examples

  -- "Sugar dissolves more in hot water than cold water" or better "The solubility of sugar in water increases with increasing temperature."

  -- "The steeper the incline, the faster a ball will roll down the incline." or better "The speed with which a ball rolls down an incline after release increases with the angle of inclination to a maximum at 90 degrees (perpendicular)."

  -- "Listerine is the most effective at killing mouth germs among the most popular, over-the-counter mouth washes tested."

  -- "The sky is blue because the blue light component of sunlight is the most strongly scattered by nitrogen molecules in the air."

Developing a Hypothesis

- Hypothesis Formulation: Bad Examples

  -- Sugar dissolves in water differently.

  -- Sugar dissolving depends on water temperature.

  -- Steepness affects ball rolling.

  -- The greater the incline, the greater the speed of the ball.

  -- Listerine is the best mouthwash.

  -- Listerine's popularity is justified.

  -- The sky is blue to the naked eye.

  -- The sky is blue because blue light is scattered by gas molecules, or particles, or pollution.

Experimental Design

- What are the key characteristics of the phenomenon of interest?
- Which are critical for testing my hypothesis?
- What are the properties, factors, and conditions I want to hold constant?
- Which do I want to vary?
- Which are the key experimental variables?
- How do I measure each key variable?
- What are the units of each key variable?

Possible Experimental Variables

- Light (color, intensity, angle of incidence, duration of exposure)
- Sound or Radio Waves (amplitude, frequency, intensity, duration of exposure)
- Electric or Magnetic Fields (intensity, direction, constant or varying, duration of exposure
- Gravitation Field (simulate increase with centrifugal force. Can you simulate a decrease?)
- Type of solvent (oils, water, alcohols)
- Concentration of solute (sugar, salt, ammonia) in solvent
- Heat (Temperature) or acidity (pH)

Experimental Design

- Units of Variables

  Density is in units of mass (e.g., grams) per unit volume (e.g., liters)

  Temperature is in units of Fahrenheit, Celsius, or Kelvin

  Pressure is in units of atmospheres or millimeters of mercury or Pascals

  Concentration is in units of mass of solute or contaminant per unit mass or volume of solvent or matrix or

  … number of atoms or molecules per unit mass or volume of solvent or matrix, where the unit of atoms or molecules is the mole (6.023×10^{23} or Avogadro's number)

Experimental Design

- Minimizing Artifacts

-- What is the best way to isolate a portion of the natural system into a test system so as to be able to obtain representative, accurate, precise, and reliable measurements of the changes in critical characteristics of the phenomenon of interest in response to systematic changes to the key variables one at a time?

-- … without introducing artificial responses or nonresponses (artifacts) that would not occur if the system was not isolated in that way?

Experimental Design

- Minimizing Artifacts

-- There is no perfect experimental design.

-- There are always trade-offs.

-- Any time you isolate a portion of the natural system for testing under controlled conditions, you change the system in some way.

-- The goal is to minimize those changes and/or figure out ways to check for and correct for or compensate for those changes.

-- This is the single biggest challenge in science, and the challenge is greater for work in the natural environment than in the laboratory.

Experimental Design

- Detecting and Correcting For Artifacts

-- Some artifacts are easy to check for, such as rinsing your experimental apparatus with distilled water after the experiment and running a test on the rinsate to see if whatever you were monitoring (solute) accumulated on the walls of the isolating vessel or container so much that your results are meaningless.

-- Once detected, some artifacts are relatively easy to correct, such as changing the container material to one with much less affinity for the solute.

Experimental Design

- Detecting and Correcting For Artifacts

-- However, if there is no such material or it costs too much, one way to compensate for such an artifact is to increase the volume of the container until the amount of the solute accumulated on the container walls is small compared to the amount that remains in solution.

-- This is because the surface area of the vessel increases as the square of its dimensions but the volume increases as the cube of its dimensions.

-- But large containers require more storage space and more solvent to fill them and more solute to achieve the same concentration.

Experimental Design

- Accuracy, Precision, and Reliability

  -- What is the best accuracy, precision, and reliability one can achieve with the method?

  where:

  accuracy is how close the measurement comes to the true value (unbiased); inaccurate data are biased so high or low they can't be used.

  precision is the degree to which the measurement can be reproduced; imprecise data are so variable they can't be used.

  reliability is the degree to which I am confident that the measurement is not due to chance; unreliable data are so likely due to chance they can't be used.

Experimental Design

- Data Quality Objectives

  -- How accurately, precisely, and reliably do I need to measure the response to detect a change relative to background or null control conditions?

This is another tough question for scientists.

Experimental Design

- Data Quality Objectives

  -- How many replicate samples or measurements do I need to collect or make to ensure that I did not wrongly conclude that there was a response when there was not (Type I error) or wrongly conclude that there was no response when there was (Type II error)?

  Confidence in results increases with increasing no. of samples (N)

  Use minimum of N = 3 replicates for each trial, but N = 5 is better

Experimental Design

- Addressing Sources of Unrepresentativeness

  -- How do I control the experimental environment to eliminate the effects of extraneous factors and conditions?

  -- How do I detect/correct for blank readings or interferences?

  -- How do I eliminate or compensate for artifact responses?

  -- Should I include a positive control that I know will respond in a well-defined way to a well-defined change in the variable of interest?

Methods and Procedures

- What are standard or preferred methods for carrying out the measurements?
- What is the lower limit below which there is no longer a reliable, one-to-one relationship between a change in the variable and the change in the reading of the apparatus or instrument? (method detection limit)
- What is the limit of each method to detect an incremental change in each variable? (sensitivity)
- How do I test the apparatus or instrument to verify that is performing within design specifications? (calibrate with certified standards; run blanks, replicates spiked matrices to test)
- Do I need to modify the standard method to better fit my circumstances?

Methods and Procedures

- Data Collection

  -- Clean sampling equipment and calibrate measurement instruments before each trial.

  -- Run blanks to ensure that sample bottles contain no contaminants of concern and instruments read zero response when there is nothing there.

  -- Make replicate collections or measurements under controlled conditions to account for natural variability in the system.

  -- Record other relevant info. about sampling or measurement conditions (e.g., time of day, temp., humidity, elevation, atm. pressure, etc.).

Results

- Data Screening

  -- What do I do with contaminated samples or faulty lab results?

  Report as bad data and don't use in calculations or graphs or conclusions

  -- What do I do with unexpected, extreme, or bizarre results?

  Where the line is between extreme but plausible and extreme and implausible is a judgment call.

  Generally, +/- 2 S.D.'s or

  +/- 95^{th} % confidence intervals

  Don't use "outliers" if enough valid data.

Results

- Data Screening

  -- What statistical models and assumptions are usually made to screen out questionable data?

  Calculate average and standard deviation of replicate results

  Calculate upper and lower confidence intervals for results (+u.c.i; - l.c.i)

  If datum falls outside of two standard deviations or outside 95th percentile c.i.'s, report result but flag as questionable.

  -- Test sensitivity of conclusion that hypothesis is valid or invalid to screening assumptions by comparing conclusions when flagged data are omitted vs. included.

Preparing the Research Notebook

- Use a standard, bound, hard-cover laboratory notebook with sewn, ruled pages
- Title notebook with project name and time period of entries, then number the pages
- For each event or trial, start on new page, record date, time, other potentially pertinent information (e.g., ambient temperature, humidity, cloud cover) and results (i.e., observed change or no change)
- Include unexpected results and problems.
- Don’t transcribe from other sheets.
- Fix errors by strike-through and initial changes. No erasures, white-out, or torn pages.

Strategy and Tactics Revisited

- What do I do if the Experiment is a Failure:

  -- You learn from failures, as well as successes.

  -- Try modifying the experimental design and testing it using one trial (pilot study) before committing to multiple trials and replicates.

  -- If you're stuck, but there's enough time to start from scratch, go to web and find a list of last-minute science fair projects.

  -- If you're stuck, and it's too late to do another experiment, write it up as is and focus on explaining what went wrong, what you learned, and why and how to redesign the experiment to fix the problem.

Preparing the Scientific Report

- Outline
  - -- Acknowledgements
  - -- Introduction
  - -- Background
  - -- Study Site
  - -- Methods and Procedures
  - -- Results
  - -- Discussion
  - -- Conclusions
  - -- Recommendations
  - -- References

Preparing the Scientific Report

- Acknowledgements
- Introduction:

  -- Purpose of Project/Study/Experiment

  -- Why this project is important

  -- Organization of Report
- Background:

  -- Brief history of the work of others relevant to your topic

  -- Where you got the idea

  -- Your approach to experimental design

  -- Description of field site or lab where work was performed (Maps and photos are good here.)

Preparing the Report

- Methods and Procedures:

  -- What did I measure? .. calculate?

  -- What standard methods and procedures did I use?

  -- What modifications to standard methods and procedures did I make to fit my circumstances?

  -- What pre-studies do I need to perform to validate the modified method or procedure?

  -- What instruments, equipment and reagents did I use in my experiment? Who made them? Where did I obtain them?

  -- What are the ranges and limits of detection of the instruments?

Preparing the Report

- Methods and Procedures:

  -- What containers, apparatus (e.g., balance), reagents (chemicals), instruments (e.g., spectro-photometer), etc., did you use to perform the exp.

  -- Who supplies them?

Preparing the Report

- Results:

  -- Put results in table that clarifies what was varied and measured.

  Check work. Percents add to 100%.

  -- What are the relationships or patterns among the data taken at the same or different times? … conditions?

  Go to literature and look up applicable pattern recognition tests, and do the math.

  Fractal analysis is still a hot topic in pattern recognition.

Preparing the Report

- Results:

  -- How do you distinguish real from chance results?

  Calculate mean (average) and standard deviation (square root of variance) of results of replicate trials

  Use Student's "t" test to determine statistical significance of differences between null or reference mean results and your replicate results for each trial and for all trials combined (pooled) together.

  Go to references and do math for more sophisticated statistical tests.

Preparing the Report

- Results:

  -- How sensitive are the results of the data analysis to the data screened out by the screening assumptions?

  Put back in to test.

  -- Do the data appear to violate any fundamental scientific laws (e.g., conservation of mass, energy, or charge; filtered > unfiltered)?

  Do calculations to test.

Preparing the Report

- Results:

  -- Graph the results (y vs. x), where y is the effect/response you are looking for and x is a variable hypothesized to influence that effect

  -- Is relationship linear (i.e., $y = m * x + b$, where m is the slope and b is a constant or nonlinear, i.e., $y = m * x + n * x^2 + o * x^3 + \ldots + b$?)

  -- How does the relationship change if you subtract off from your data or divide your data by the no effect (null) or control response?

  -- How does the relationship change if you take the logarithm of the data and re-plot the results?

Preparing the Report

- Discussion:

  -- What happened as expected? … not?

  -- What is the best explanation for the results, consistent with prevailing scientific hypotheses and established theories and laws?

  -- What are strengths and weaknesses of the best explanation?

  -- Are there equally plausible alternative explanations for results?

  -- What are strengths and weaknesses of the alternative explanations?

Preparing the Report

- Discussion:

  -- What are the sources, magnitudes, and consequences of error or uncertainty in the measurements? … propagated error in calcs?

  -- Is the hypothesis accepted or rejected at some degree of statistical confidence?

  -- How sensitive is conclusion to accept/reject hypothesis to uncertainty in the data? … screening assumptions? … statistical model and assumptions?

  -- As Feynman said, you have to be your own toughest critic and skeptic when you do science, because you can fool almost everybody else by what you withhold, at least for a little while.

Preparing the Report

- Conclusions:

  -- The hypothesis is or is not rejected based on the design and results of the experiment to some degree of statistical confidence, taking into account the sources and magnitudes of and sensitivities to the uncertainty in the results.

  -- Do other hypotheses or more general scientific theories or laws need to be modified or withdrawn if results are reproducible by others?

  (If you draw such a conclusion, your hypothesis formulation, experimental design, and data collection, analysis, and discussion must be flawless. Be prepared for vigorous debate.)

Preparing the Report

- Recommendations:

  -- If the results are reproducibly inconclusive, is the experiment worth repeating, and if not, what did I learn from the experience?

  -- If the results are reproducibly inconclusive, and the experiment is worth repeating, what changes to the experimental design will fix the problem?

  -- If the results are reproducibly conclusive, what experiments do I need to do next to extend my results? (e.g., bigger range of change of variables individually; multiple variables changed simultaneously: factorial exp. design)

Preparing the Report

- References*

  -- Basic texts on subject area and topic

  -- Methods and procedures

  -- Related studies

  Ask sponsor or mentor for standard reference format for Palm Beach Co. science fair, if available; otherwise, use his or hers or one from a key paper you read. See also Handouts.

* Note: Judges like me are old-fashioned, so include some evidence that you used a library and actually picked up a book on the subject area or topic.

Preparing the Display

- Project Title on top
- State hypothesis
- Describe experimental design and environment in which it was performed
- Describe experimental set-up

  -- include photo
- Show results in tables and graphs
- If work was done outdoors in the field:

  -- show map with site location in Florida with a blow-up with site details

  -- include photos of site

Preparing the Display

- Organize the display so that the information in logical order follows the natural flow of the eye from top to bottom and right to left
- Even smallest graph must be legible at 3-4 ft
- Frame each page with contrasting background color
- Neatness counts; pleasing to eye; neither over- nor underwhelming choice of fonts, patterns, colors
- Ask for critique of display by parents, sponsor

Preparing the Presentation

- Key Points to Hit

-- Where you got the idea

-- Your hypothesis

-- How you designed the experiment

-- How you carried it out (identify and thank assistants, sponsor, mentor, and parents)

-- What you recorded (show lab book)

-- What happened, pointing out key tables and graphs

-- Your conclusion: H = false or true at some level of confidence; inconclusive; failure

-- Next steps to expand on successful work

Preparing the Presentation

- End by noting that everything in display and presentation is in report.
- Open report to table of contents and hand to judge if he or she has not already picked it up and at least thumbed through it.
- Open report and show judge Table of Contents, then flip to key tables and graphs, then flip to Reference section if judge does not take it.
- Offer to answer any question judge may have about report or display.

Preparing the Presentation

- Practice, practice, practice with display as backdrop

  -- First without an audience

  -- Don't practice in front of mirror

  -- OK to tape record and/or videorecord to smooth out wrinkles in length, organization, choice of words, nervous gestures

  -- Then practice with friendly audience (e.g., parent, older sibling); accept critique

  -- Then dry run with mentor/sponsor

  -- It's OK to be nervous; it's a natural reaction, but practice gives you confidence to overcome.

Strategy and Tactics One More Time

- Getting Ready for the Big Day

-- Get a good night's sleep.

-- Eat a good breakfast.

-- Enjoy the ride to the judging venue.

-- Introduce yourself to your neighbors and ask them about their projects.

-- When a judge comes to review your project, stand up, look judge in the eye and introduce yourself by shaking hands, step aside to give judge a clear view, and offer to answer queries.

-- Listen carefully to questions, constructive criticism. Answer slowly and clearly. Say thanks.

Is the Reward Worth the Effort?

- You only get out of it what you put into it.
- No pain, no gain.
- You are building your scientific muscles.
- Even world-class weightlifters start out by working out with light weights.
- But what a sense of accomplishment when a fellow participant, your science teacher, or a judge compliments you on your work, or, better yet, you win or take second place.
- Then on to the big leagues: State and then International competition and scholarship $'s.
- Others I guided have made it. You can, too.