Washington State Science and Engineering Fair
P.O. Box 2412
Silverdale, WA 98383
Phone (360) 551-0012
Email wsseffairdirector@wssef.org

Washington State Science and Engineering Fair

Student Handbook

Grades 7-12

Promoting Future Scientists and Engineers

Authors: Debbie Beckett
Mary Omberg
Ron Tognazzini

Editors: Mike Huey
Lois Lugg
Kandis Brighton

Graphics: Ron Tognazzini

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Introduction

In this Student Handbook, you will find information on Science Fair Projects. It is intended as a reference for projects entered in the Washington State Science and Engineering Fair (WSSEF). A committee of Science Fair volunteers developed the information as a guide to develop quality projects that follow the procedures or methods generally accepted for science fair projects. This handbook is not a rulebook, to which all science fair projects must conform. It is best viewed in its Adobe Acrobat ® format with an internet connection to fully utilize the links indicated by underlined blue text. All internet links are cited and referenced in Appendix H.

The student handbook is organized into four chapters and several appendices.

- ☐ **Chapter 1: Science Fair Projects** provides information about science fair projects in general. Topics such as "Why do a Science Fair Project?" inquiry and non-inquiry based projects, and elements of a successful science fair project are discussed.
- ☐ **Chapter 2: Start It!** discusses initial steps of getting started with an inquiry based science fair project prior to experimentation.
- ☐ **Chapter 3: Do It!** discusses experimentation, data collection, analysis, conclusions, and the preparation of an abstract that summarizes the project.
- ☐ **Chapter 4: Present It!** includes information on presenting projects at a science fair competition, like the WSSEF.
- ☐ **Appendices** at the end contain references and materials that were discussed in the four chapters. Some references are included as links to web pages and are shown in blue and underlined if the handbook is printed out in black and white.

Following the procedures and methods indicated in this handbook are not a guarantee that the student's science fair project will be accepted for entry into the science fair. It is the student's responsibility to determine all current rules[1], policies[2], and registration[3] procedures regarding entry into the science fair.

In a similar manner, following the suggestions in this handbook does not guarantee that a student will be selected as a winner of any category or special awards. Awardees are selected at the Science Fair based on evaluations by volunteer judges, trained to select only the best projects, which they consider satisfy the judging guidelines[4] established by the science fair at the time. It is the opinion of the volunteers that have contributed to this handbook that all students that complete a science fair project are winners, but it is up to the professional scientists and engineers that serve as judges to decide which winners are recognized with awards at a science fair competition.

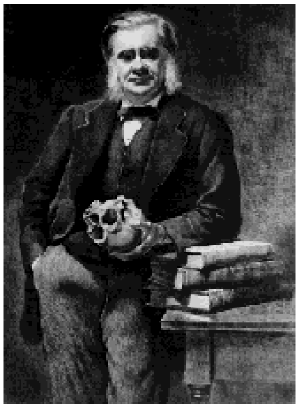
Chapter 1: Science Fair Projects

Why do a Science Fair Project?

What do market analysts, forensic crime technicians, and backyard gardeners have in common? They all apply the inquiry process to the research necessary to solve problems. Most professions have common skills that are required for success, such as critical and creative thinking involving gaining, applying, and communicating knowledge. Working collaboratively and contributing are common themes in education, science, engineering, and technology. These common themes involve habits of mind such as curiosity, open-mindedness balanced with skepticism, a sense of stewardship and care, respect for evidence, and persistence. All these skills and themes are integral parts of doing a science fair project and help to prepare you for a changing world.[5]

Developing Skills

The benefits of doing a science fair project go way beyond learning science. You will become more confident, more mature, more disciplined, and more skilled.[6] Working on a science fair project requires using the skills gained in Social Studies, English, Math, Information Technology, the Arts, and the Sciences, making a science fair project an interdisciplinary activity. Science fair projects provide opportunities to collaborate with many teachers at and beyond your grade level, especially in Math, Science, and English, and implement cross-curriculum, or team leadership and cooperation.[7]



T.H. Huxley, President of the Royal Society & "Darwin's Bulldog"

T. H. Huxley, an accomplished scientist of the 19th century and a self-made man once said, "If a little knowledge is a dangerous thing, where is the man who has so much as to be out of danger?"[8,9] The future, it is said, lies in science, mathematics, and technology. For those with the knowledge, skills, and ability developed through the completion of a quality science fair project, there can be opportunities and exciting careers. It is a future that seeks to improve the lives of people, increase productivity, expand minds, and extend potentials.[10]

Discovering Something Amazing

A science fair project allows you to pose your own question and answer it. Doing a science fair project involves developing and "owning" the question; researching literature; forming a hypothesis; designing an experiment; gathering and organizing the data; analyzing, graphing, and discussing the data; making a conclusion; writing a research report; and making an oral and visual presentation. Therefore, you develop and apply skills in literature review, laboratory research, statistical analysis, and public speaking while gaining a sense of empowerment and building self-esteem. Because science fair projects are actually cross curriculum projects that provide you with training for solving some of life's problems, the science fair project integrates all aspects of your education and helps to prepare you for career and job assignments. Having completed a science fair project, you will have the skills necessary to design future investigations in a variety of different fields. A science fair project can become the impetus for a future career.[11]

Science fair projects are fun and filled with self-discovery. When beginning the process, you may feel overwhelmed at its enormity, however, you will experience tremendous growth and fulfillment as you progress through the steps and are evaluated by peers, teachers, scientists, engineers, doctors, or others with scientific interests. This experience builds self-confidence and often enables you to present ideas to others in various situations, such as college and job interviews.[12]

A science project is like a mystery in which you are the detective searching for answers. Science projects let you practice and exhibit your detective skills. You not only get to select which mystery to solve, but you can creatively design methods for uncovering clues that will lead to the final revelation of who, what, when, where, how, and why. It is your job to discover the answers![13]

Other Benefits

The science fair project you do for a science class may get you an 'A' and maybe a ribbon.[14] However, if you can take that project to a higher level such as a regional science fair, the WSSEF, or the International Science and Engineering Fair (ISEF), with which it is affiliated, then success could be measured in other ways.

Science research competition is often the ticket to success in college and a career in science. College admissions offices face the dilemma of evaluating thousands of applications from intelligent, motivated students. Colleges look for science research participation. They know that these students have the maturity, self-confidence, and the ability to solve problems that are indicators of success in college.[15]

Scholarships and Prizes

Students often receive scholarships and prizes because of their projects. WSSEF offers awards in an effort to promote future scientists and engineers. You can learn more about awards at the Washington State Science Fair by clicking on the awards[16] section of the WSSEF website. In addition, the top projects from Grades 9 through 12 represent Washington State at ISEF.

Imagine the Olympics, World Series, and Super Bowl all rolled into one and you will get an idea of the scope of ISEF[17]. Society for Science & the Public, a nonprofit organization, began sponsoring science competitions in 1950 with ISEF. Because of their vision and commitment to science research and education, millions of dollars in scholarships, grants, equipment, and trips are given to students every year. [18]

The competition, now cosponsored by the Intel Corporation, involves 3 to 5 million students participating at local levels and over 1,500 students from the United States and 40 other nations proceed to ISEF in the spring of each year. In addition to scholarships, grants, trips, and awards have been presented to students with winning projects. In the recent past, these have totaled nearly $4 million, and the top students have been invited to attend the Nobel Prize ceremony in Stockholm, Sweden.[19]

Science Research and the Process of Science

Research is a process by which people discover or create new knowledge about the world in which they live. WSSEF and ISEF are research driven competitions. Students design research projects that provide quantitative data through experimentation followed by analysis and application of that data. **Projects that are demonstrations, 'library' research or informational projects, 'explanation' models or kit building are not appropriate for research based science fairs.**[20] The following section is divided up into inquiry-based research and non-inquiry based research. Although inquiry based research will be considered in significant depth in other parts of this handbook, this section is the only part of this handbook that discusses non-inquiry based research.

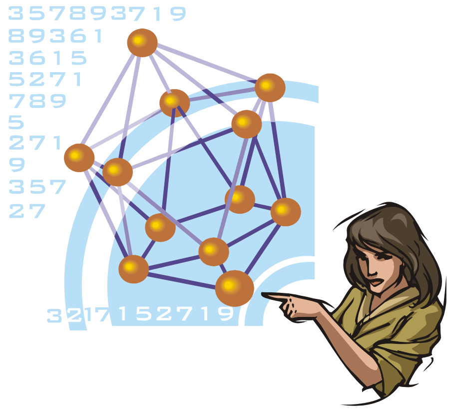
Inquiry Based Research

Inquiry based scientific research is designed to make descriptive or explanatory inferences based on empirical data or information about the world. Scientific researchers observe phenomena, ask questions, infer information about the world from these observations, and make inferences about cause and effect.[21]

Questioning is probably the most important part of a scientific inquiry and is often followed by an "if…then" statement. Students are encouraged to design 'controlled' experiments, ones that allow them to set up a standard and then change only one variable at a time to see how that variable might affect the original condition tested as the standard. Thus, questioning usually leads to experiments or observations.[22]

The Scientific Method

Inquiry based science projects use a process to study what is perceivable in the world. Scientific research uses a process that is explicit, standardized, and public to generate and analyze data whose reliability can be assessed. The result of this process is to minimize the influence of experimenter bias and/or prejudice as he or she tests a theory or hypothesis.[23] This process has been referred as the 'Scientific Method' outlined as an example in Appendix A.

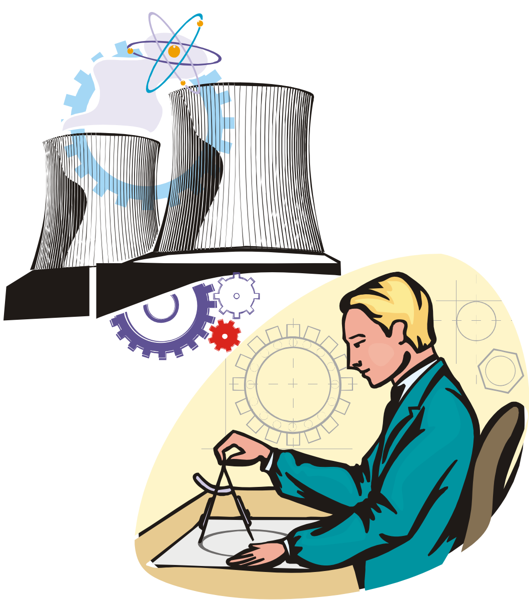


Non Inquiry Based Research

Not all areas of study are best served by scientific method based research. Because engineers, inventors, mathematicians, theoretical physicists, and computer programmers have different objectives than those of other scientists, they follow a different process in their work. The process that they use to answer a question or solve a problem is different depending on their area of study. Each one uses their own criteria to arrive at a solution.

Engineering Projects

Scientists try to understand the universe; engineers apply the work of scientists toward an engineering goal to create things and systems. An engineering project contains an engineering goal, the development process of a product or system and the evaluation of product or system to meet the criteria of the engineering goal. Examples of engineering professions are civil, mechanical, aeronautical, chemical, electrical, photographic, sound, automotive, marine, heating, or refrigerating, transportation, environmental engineering, etc. An example of the steps of an Engineering Project is presented in Appendix B.



Computer and Mathematics Projects

Computer science projects often involve writing new algorithms or developing new data structures to solve a problem in information management. These projects often involve the implementation and application of these new or improved algorithms or data structures in computer systems. Some fields of computer science consider programming language theory, while others apply specific programming languages to solve computational problems in new or different ways. Simulations, computer graphics or 'virtual reality' are other areas on which computer scientists conduct research.[24] The primary difference between a computer science project and an inquiry based science project is that the objective or goal of the computer science project is to enhance the use of computers rather than an inquiry into the nature of a phenomenon in the world or the application of science toward an engineering goal.

Mathematics projects are similar to computer projects except that math projects involve proofs, solving equations, etc. often without the use of computers.[25] Mathematics projects use deduction from mathematical definitions, axioms, and theories to develop solutions in most science and engineering fields, as well as mathematics for its own sake through abstraction and logical reasoning. As in computer science projects, the primary difference between a mathematics project and an inquiry based project is to enhance the use of mathematics rather than to inquire into the nature of a phenomenon in the world or engineering application.

Theoretical Projects

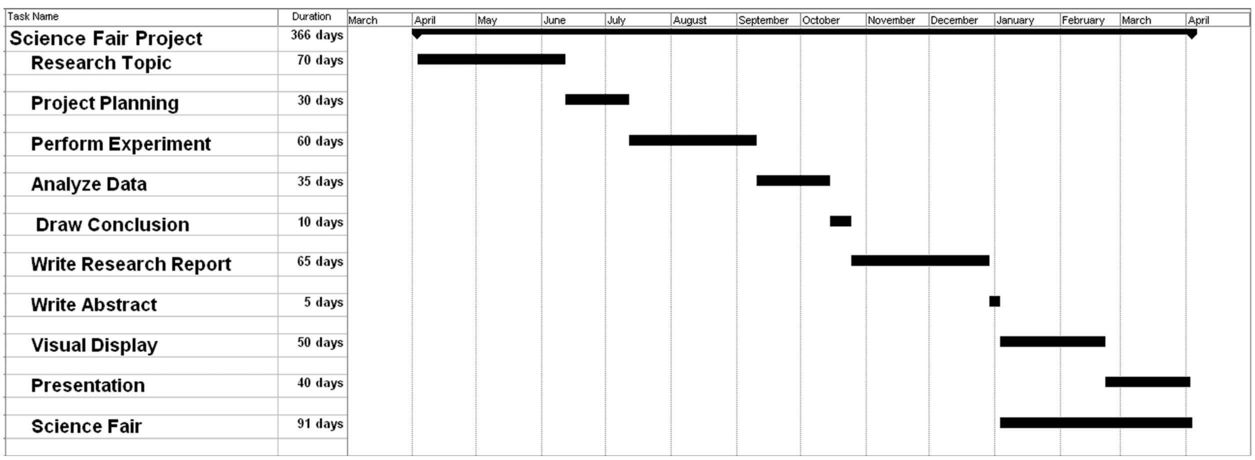
Theoretical projects involve a thought experiment, development of new theories and explanations, concept formation or designing a mathematical model to prove a thought experiment of new theory.[26] Often these projects use mathematics with rigorous deduction, abstraction, and logical reasoning. Theoretical projects are usually involved with the investigation of phenomenon that cannot be readily tested by experiments such as much of cosmology, relativity, or quantum mechanics.

Time Commitments and Schedules

Science fair projects, like anything else that is worthwhile doing, take time. Generally speaking, the more time you put into a science fair project, the greater will be your benefits. The next chapter will discuss how to get started with a science fair project, and the chapters after that will tell you how to see it through to completion, but this section breaks the work of doing a science project down into various subprojects. Each subproject consists of a number of tasks with assigned durations of time and predecessor or successor relationships to other tasks and are listed in Appendix C. You can add up the durations of each of these tasks to evaluate the amount of time commitment a science fair project can take. The following two sections consider two different levels of time commitment.

Major Time Commitment

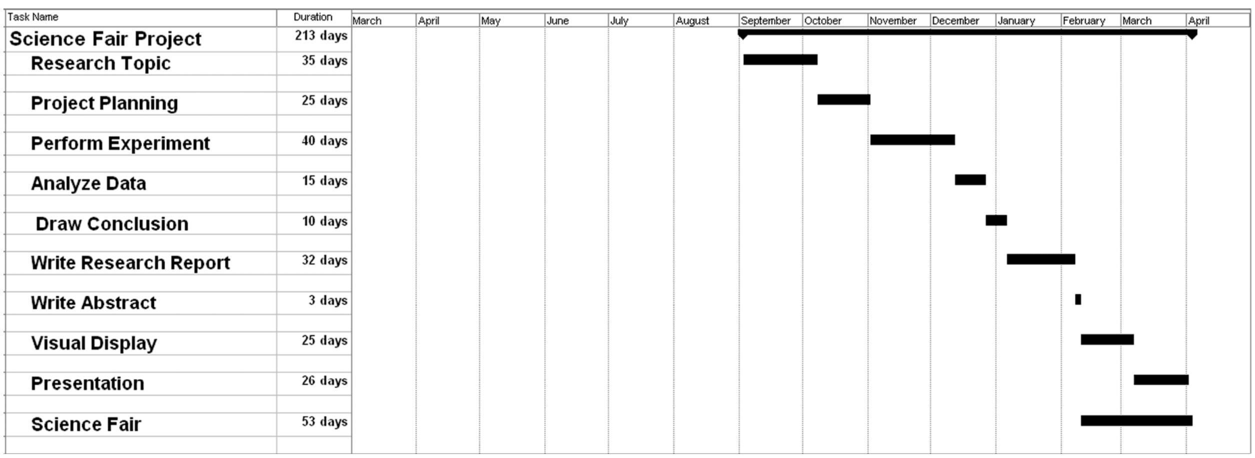
For those that are considering projects that require 200 hours or more effort, and a chance to be selected at the WSSEF to compete at ISEF, should consider a one-year commitment of time. Many High School students make this commitment, because the benefits greatly outweigh the inconveniences. The following Gantt chart graphs the science fair project and its subprojects on the left against a timeline across the top. Durations are indicated in calendar days and the timeline in months.



This major time commitment of 366 calendar days has been scheduled to start at a WSSEF event and ends a year later at the following WSSEF. Most of the subprojects are in scheduled in series until the beginning of January, where the tasks associated with the Science Fair subproject run in parallel with the preparation of Visual Display and Presentation subprojects. Most of the Research Topic subproject takes place before school ends, with experimentation being performed during the summer months. Data is analyzed when school starts up again, and the Research Report and Abstract are completed by the end of the year. The students that make major time commitments may only spend an average of only one half hour per day on their science fair project, but from this schedule, it is clear from past performance that these students that have made a major commitment are generally working on some part of their science fair project all year long.

Common Time Commitment

It is common that a science fair time commitment be constrained to start with the school year. This constraint is based on the availability of schoolteachers, which perform the role of adult sponsors for the student. This constraint limits the total amount of time for a project. The schedule below was developed for those students that spend less than 100 hours on their science fair project. It contains the same number of tasks and subprojects, but reduces the duration of each to fit within the available time constraints. In this schedule, research and project planning are completed by Halloween, and the experiment is performed prior to Winter Break. Analysis of the data and draft conclusions are completed when school resumes in January, and the Research Report is written while school is in session. The final preparations for the science fair are performed in less than two months, starting with an opportunity to register in the middle of February.



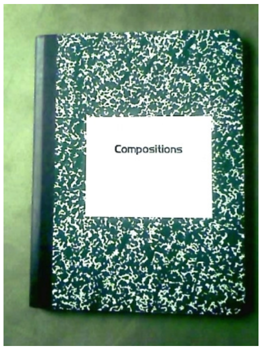
One of the significant disadvantages of the normal time commitment, is that the experiment is conducted in the late fall when the availability of sun light is limited for those organisms that thrive in a warm sunny environment. Experiments that involve the growth of plants or populations of marine organisms are generally required to include artificial environments that replace the sun and the heat that it provides. Some students have conducted their research and project planning, before the end of the previous school year and performed their experiment(s) during the summer when school is normally out of session. These students start the school year with a rich set of data to be analyzed just like those that have made a major time commitment and can obtain the help of a schoolteacher. In doing this type of schedule, a student may spend between 100 and 200 hours on a science fair project.

Chapter 2: Start It!

The following steps and statements are suggested because more often than not they have been included in projects that are considered successful by peers and professionals. The authors have found that student researchers that have demonstrated most of the following steps are generally at an advantage during science fair competitions, compared to those that have not.

Keep a Notebook, Daily Log, Journal, or Data Book

One of the most important aspects of doing a science fair project is its documentation. This documentation is so important that it is included in item 1 of the Scientific Method in Appendix A. A project notebook, daily log, journal, or data book is (are) your most treasured piece(s) of work. Accurate and detailed notes make a logical and winning project. Good notes show consistency and thoroughness to the judges and will help you when writing your research paper. A notebook or separate data book that contains raw data tables recorded during experimentation or testing is essential. They may be a little 'messy' but be sure the quantitative data recorded is accurate and that units are included in the data tables.[27] Every experiment should be reproducible and the entries in your notes should be sufficient for someone else to reproduce the experiment.[28]



The first thing to do when beginning a science fair project is to get the notebook. You will work out your thinking and the development of your problem in the notebook. The scientific notebook is a bound or spiral book with pages that are not removable.[29] The validity of your documentation partly depends upon insuring the work has not been tampered with or pages removed.[30]

When preparing the notebook several things need to be done:[31]

1. Write your name inside the front cover. This is necessary to reduce the chances that you will lose your notebook or that others will use your notebook for their science projects. Remember, the Exhibit Requirements[32] for displaying your project at WSSEF require that names of entrant and school be hidden from view by covering them up with tape or a post-it for the duration of the fair.

2. Every page in the notebook should be numbered from the start. If the book pages are not already numbered, number every page in order at the upper corner along the outside edge of the pages.

3. Divide the book into sections and start a table of contents. Successful students typically divide their logbook into at least four sections.
   a. **Choosing a Project** - In the first section, begin your quest for ideas by listing topics or problems that you might investigate, and your thoughts about each.
   b. **Background search or literature review** - Make a section of the notebook for literature review. For each literature review session, write the name of the library, the date, and the time visited at the top of a new page. List the resources you examine. If you take notes from a text, head the notes with all the information you will need to make a citation. Use the margins to enter the page of the reference from which the notes were taken. This will give you easy access to the "who," "what," "where," and "when" that you will need when writing your research paper.
   c. **Experiment or Design** - The next section contains experimental research or engineering design including the drafts of the research plan, raw data collection records, and all records of the data analysis.
   d. **Daily Log** - The last section is the daily log where daily activities related to the research project are recorded. After the experiment is recorded, head a new page with "Discussion" or "Interpretation" before writing your inferences. Start a new page to write the "Conclusion." Remember, the better the records you keep, the easier it is to validate your work.

4. When making a new entry, begin on a new page. Date each page as you use it.
5. The notebook must include all the steps of the scientific method, from the inception of the project to its completion. Scientific notebooks include literature and experimental research, the development of your idea or product and its evaluation, and all calculations.
6. You can keep a log or daily journal in a section of your scientific notebook, or in a separate book. If you plan to use a separate book for your log or daily journal, use the same type of bound book. **The logbook is the chronological record of events during the experimentation.**

When making entries in your notebook, follow these guidelines:[33]

- ☐ Write the entry immediately after the work was performed.
- ☐ Write the date of the entry at the top of the outside margin of every page.

- ☐ Mark and title each section clearly.
- ☐ Write legibly and in clear, understandable language.
- ☐ Use the active voice in the first person when making an entry so it clearly indicates who did the work. Your experimental entries should read like a story. Illustrate as necessary - a picture can be worth a thousand words!
- ☐ Record everything - no detail is insignificant.
- ☐ Title, label, and date all graphs and tables.
- ☐ Tape, staple, or paste computer printouts, photographs, etc. into logbook
- ☐ Never remove or obliterate an entry from your notebook. What you think is "a goof" may later turn out to be to be a great asset!

Pick a Topic

Research Your Topic

This most important step in getting started with a science fair project is often the most difficult part. It involves a process that starts with very general and often vague ideas. Then by reading or listening to others discuss their ideas, you find a topic that not only interests you, but contains a problem or question that can be investigated through scientific inquiry.

In choosing which topic to research, you should consider those topics that interest you:[34]

- ☐ A hobby such as music, gardening, or model rocketry, might give you something to investigate.
- ☐ Sometimes your interest in a sport can provide ideas for a science fair project.
- ☐ Magazine or newspaper articles on science-related events can spark your interest.
- ☐ Find out if there is a sizable amount of information and equipment available pertaining to a topic of interest.
- ☐ Science-based websites may inspire ideas.

Finding Ideas for Projects
You may find ideas for a science fair project from many varied sources, such as those listed here:

- ☐ Science books
- ☐ Science lab manuals
- ☐ Science fair books
- ☐ Encyclopedias
- ☐ Science periodicals
- ☐ Science teachers
- ☐ Newspaper
- ☐ Educational TV
- ☐ Science museums
- ☐ Professional Journals
- ☐ Consumer Reports

Science Fair Categories

Two science-based websites that can help to start thinking about a research topic are the category definitions of science fair projects. For WSSEF, a link off the registration page[35] defines the categories that all high school science fair projects entering that fair must be placed in for judging. In addition, the ISEF also provide definitions for the categories[36] for all students that are eligible to enter their science fair. These definitions usually contain a listing of one or more words that describe an entire field of science, but these listings can be helpful to you as keywords for narrowing down your topic of interest within a category and performing the next step.

Perform a Background Search or Literature Review

The next step in selecting your research topic is to do a literature review. Just as in the previous steps, this step involves investigating general information first and then investigating specific information when you find a general topic that seems of interest to you. The goal of this step is to choose a topic for a project that is feasible. While doing your literature review you should consider some of the following feasibility questions:[37]

- ☐ Can the project be completed within the amount of time allowed? Have you considered the time needed for retrials or repeats of the experiment? For example, in plant projects, do you need a large number of plants ready to sample in two or three week intervals?
- ☐ Are there environmental concerns? For example, is it the right time of year to make your observations or collect samples?
- ☐ Do you have adequate laboratory resources (available time, materials, and equipment) or natural resources, or both, to carry out your investigation?
- ☐ What is the cost of completing the project? Is it within your budget? Do you need special equipment beyond what is available? How will you get it? Have you budgeted for retrials?
- ☐ Is the design of the experiment adequate? Are the effects measurable in an objective way?
- ☐ Does the project conform to **ALL** state or federal laws pertaining to scientific research? Perhaps the best way to approach this question is to ask, is this project a WSSEF Special Project[38] and does it require any additional ISEF forms?

The following is a list of some of sources of information that you might be able to use for a background search or literature review.

- ☐ Libraries (school, public, and college)
- ☐ Previous projects you or others have done
- ☐ Students who have already completed science fair projects
- ☐ Local college or scientific institution support (for information, equipment, and facilities)
- ☐ Local research firms
- ☐ Verifiable Internet Sources

Write a Draft Introduction

Prepare a draft introduction on the research project that you plan to perform. This draft introduction will document what you found out in the background search or literature review about a question that your science fair project will investigate. It should include a purpose or justification of why it is important to do an investigation of your question and a hypothetical answer based on your literature investigation. Alternatively, if you are doing a non-inquiry based project, you should justify why it is important to solve a specific problem and the goals or criteria needed to accept your solution.

This draft introduction will be finalized later and become the beginning of your Research Plan when you complete a plan for your project.

Project Planning

Organize Your Time, References and Written Materials

Now that you have selected a topic, performed a literature review, found a question to investigate or problem to solve, and written a hypothesis or criteria for a solution, you need to plan how you are going to complete your project in time to submit it to the science fair. The amount of time that you have is dependent upon the dates[39] for the WSSEF. Gather all your reference and written materials and design your experiment based on the data you will need to collect.

Plan an Experiment

When planning your experiment it is important to know what extra safety assessments, precautions, forms, and reviews you may need to do if your project involves:

- ☐ Potentially Hazardous Biological Agents
- ☐ Vertebrate Animals
- ☐ Human Subjects
- ☐ Hazardous Chemicals, Activities or Devices

Experiments involving any of these issues are identified by WSSEF as Special Projects[40] and are specifically constrained by the rules and regulations[41] of the ISEF. These constraints can greatly affect not only the way in which you conduct your experiment, but the amount of time and resources that may be needed to comply.

Variables

Experiments are all about collecting data, which can be attributed to variables in your investigation. The goal of your experiment is to discover, through data collection and analysis, the relationship(s) between the variables in your investigation.

Controlled Variables

Controlled variables are those variables which might affect your experiment, but which you control and not allow to vary during the data collection process. An example might be to vary the temperature of a gas, while measuring its pressure in a container whose volume does not change. In this case, the volume is the controlled variable. A second experiment of the same investigation might vary the temperature of a gas, while measuring its volume at a constant pressure. In this case, the pressure is the controlled variable.

Independent or Manipulated Variables

The variable that you change has traditionally been called the independent variable. Another name that has been adopted by the Washington Office of Superintendent of Public Instruction is the manipulated variable. The independent or manipulated variable is a variable that the researcher selects, either at random to avoid bias in sampling a set of variables, or from a uniform increment in a range of particular interest for the question being investigated. It is much easier to analyze the effects of an experiment if you allow only one variable to change while measuring its affect on another variable during data collection. In the gas examples above the temperature was the independent or manipulated variable.

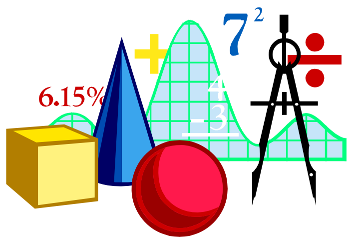
Dependent or Responding Variables

The dependent or responding variable is obtained because of the manipulated variable during the experiment. In the gas example above, the pressure was the dependent or responding variable in the first example, and the volume was the dependent or responding variable in the second example. More than one dependent or responding variable might result from a single independent or manipulated variable. In an experiment involving the growth of plants as a function of a chosen amount of a particular fertilizer, the researcher may select the height of the plant and the number of leaves as the dependent or responding variables.

Types of Data

Data can be collected in various types and forms. Data, which has units of measure, are often considered to be quantitative, and can be analyzed using numerical methods such as statistics. Data, which comes in the form of descriptions such as words, pictures including videos, or objects, can be rich with information, but inferences of that meaning need to be analyzed with logic rather than mathematics. Most scientific inquiries include both types of data. Experienced researchers recognize that most quantitative data is based on qualitative judgments, and they often find a way to describe and manipulate qualitative data using numerical procedures.

Quantitative Data

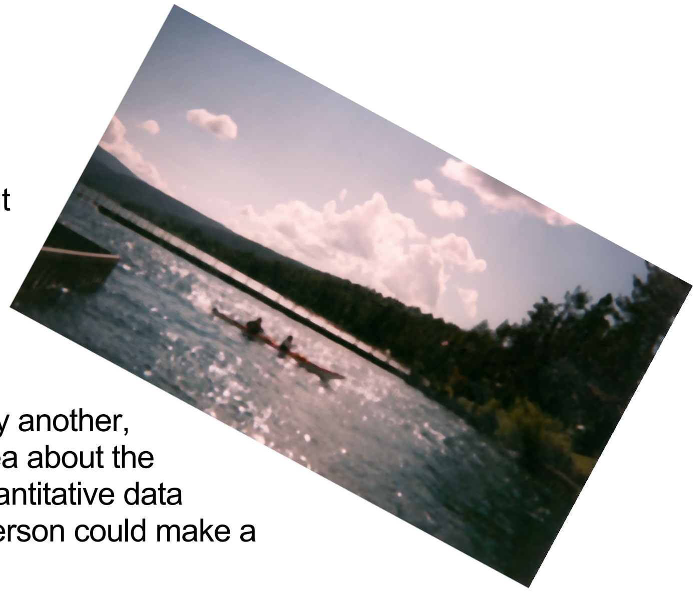


Examples of quantitative data are scores on tests, time, weight, mass, length, volume, etc. Often things, which can be measured, are considered quantitative data. However, things, which can be counted, are also quantitative in that the units are the things being counted, such as 5 apples. In this example, the units are apples, and the numerical value is 5.

Most, but not all, quantitative data has some form of precision associated with it. If data is collected that involves length, then the precision of the device used to measure it establishes the precision of the quantitative data. For instance if measuring length with a meter stick that is graduated in millimeters, the precision of the data collected can be considered to be half of a millimeter. However, if counting the number students in a science class, then the precision is considered absolute, because science classes do not have half-students.

Some quantitative data have units, which have been defined by a qualitative value. The temperature scale, which is used to measure heat in units of °C or Celsius has been qualitatively defined with zero at the freezing point of water. The temperature scale that uses °K or Kelvin is defined with zero at a temperature with no heat. Both of these scales have identical increments, but it is only correct to say that 100°K is twice as hot as 50°K. Something with a temperature of 100°C is not twice as hot as 50°C because of its qualitative definition.

Qualitative Data



Qualitative data may not be considered as predictable or reliable as quantitative data, but it often provides more information because of its intuitive nature. A landscape photograph[42] of a place might be considered beautiful by one person and not worth visiting by another, but does give the viewer an idea about the place that would take many quantitative data measurements before either person could make a judgment about the place.

The most common qualitative data is divided up into categories. Sometimes the categories can have order like small, medium, large, or extra large for clothing sizes. Another example of qualitative data in ordered categories are letter grades for class work. Letter grades from F, D, C, B, and A, are ordered, and contain meaning about a student's performance. That meaning might be different between various teachers assigning those grades, but taken together, grades describe a level of performance, in this case from lowest to highest. Ordered data may have an arbitrary number scale assigned to it to allow for numerical manipulation, or statistical calculations to be performed on it. Grades for students are an example of a numerical scale being assigned to letters to be able to calculate a statistic referred to as the grade point average. The grade point average has no meaning by itself, until it is compared back to the letter grades for performance evaluations. For instance if a grade of C is considered an average level of performance with an assigned value of 2.0, then a grade point average above 2 is considered above average and visa versa.

This grade point average example can be used in evaluating the ordered qualitative data derived from surveys. Often responses to a survey are divided up into five ordered responses such as strongly disagree, disagree, no opinion, agree, and strongly agree. Each of these responses to a survey question can then be assigned a number from 1 to 5, and the results of the survey can be averaged over a large number of responses. The average can then once again be restated in the words of the ordered response to the survey question or statement being investigated.

Other qualitative data may have no order, such as gender, race, religious affiliation, or sports preferences. That still does not prevent a researcher from being able to count the number of males in a sport, and make an inference about the influence of gender for that sport.

Experiments with Control Groups

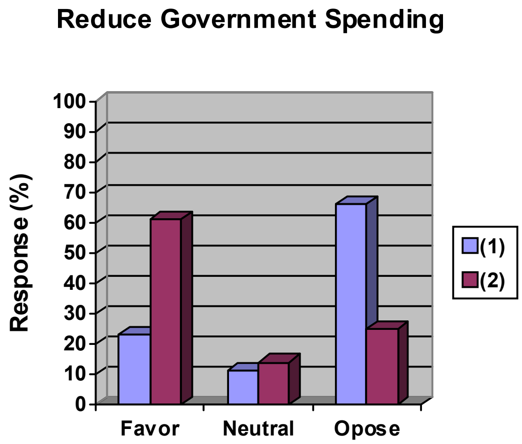
Sometimes experiments require a control group from which data is collected for analysis and comparison with other groups that have data collected for independent (or manipulated) variables, and dependent (or responding) variables. An example of an experiment with a control group is one involving the growing of plants with various soil amendments. Often a control group of plants in the same growing conditions is measured for height or number of leaves as a standard by which the other test groups with amendments will be compared.

Other experiments do not require control groups, because the data collected will be used to compare to theoretical or empirical data calculated from relationships that were established by others. These kinds of experiments often use a set of the same values for independent (or manipulated) data to derive a theoretical or empirical dependent (or responding) data set. Then the experimental dependent data is compared to the corresponding theoretical or empirical data to make inferences regarding the experiment.

Data Planned to be collected from Surveys

Surveys are attractive to student researchers because of the limited amount of time and effort required to collect data about a problem that is not easily analyzed using experimental results. The student should be warned however, that surveys are subject to questions regarding population selection, sample size, method of taking the survey, who conducts the survey, what questions are asked, confidentiality and integrity, and analytical procedures to interpret survey results. Information for survey design is available from various sources[43].

The following can give you an example of why it is very important to plan your survey carefully. A NBC/Wall Street Journal poll asked two very similar questions with very different results: (1) Do you favor cutting programs such as social security, Medicare, Medicaid, and farm subsidies to reduce the budget deficit? (2) Do you favor cutting government entitlements to reduce the budget deficit?[44] In this example, the question with the name of a government entitlement program listed yielded 66% of the participants in opposition to cutting the budget, while aggregating them together in a single word produced 61% in favor. Two very different results from nearly the same question is one of the reasons why surveys can be considered unreliable unless they are carefully designed.



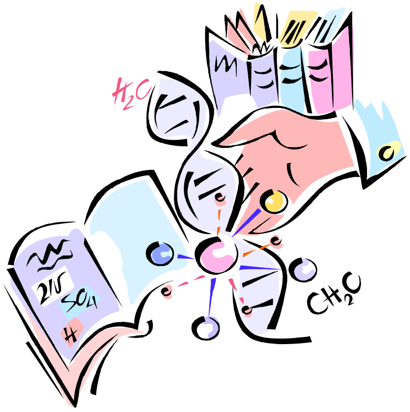
Data Planned to be Analyzed Using Statistics

The web contains many references[45] to help the student consider the important issues that need to be considered before performing a statistical analysis. Appendix F of this student handbook offers some suggestions and examples, but it is strongly recommended that students familiarize[46] themselves with the basics of statistical analysis before they design an experiment that uses this very powerful analytical tool.

When planning an experiment some questions need consideration. Often the first planning question is how many tests or trials should be run to be sure that inferences made from a statistical evaluation are meaningful? However, one or more of the following questions might also need consideration:

- Should pre-test or post-test experiments be included in the planning schedule?
- Which distribution model should be used for the data to be collected?
- Which definition of average (mean, median, or mode) should be used to represent the central tendency of the collected data?
- How should data outliers be treated?
- How should variance in the data be handled?
- Is it likely that a single factor analysis of variance would be adequate, or is a multi-factor analysis of variance required?
- How can the researcher evaluate confidence in the test results?
- If the null hypothesis is proposed for significance testing, then what level of significance (P value = 0.05, 0.02, 0.01, or something else?) should be used to reject the null hypothesis?
- Is a regression analysis warranted, and if so should it be a simple linear regression or a more complex regression analysis?

Design an Experiment



Now it is time to put it all together in your notebook or journal. Referring to your list of variables and their relationships, brainstorm some experiments you could do that would test your hypothesis. Write down as many experiments as you can think of. The more successful science fair projects use more than one experiment to test their hypothesis.

Choose at least one of your experiment ideas, and write down a list of materials and procedures required to perform that experiment. Identify in your procedures, the variables and data that you will collect, theoretical or empirical relationships that you will use, and any methods that you will perform to analyze the data. Be sure to identify sample sizes, and the number of trials that you will be doing to increase confidence in your results and demonstrate repeatability of your experiment(s).

Write a Research Plan

A Research Plan is listed as item 6 of the Scientific Method in Appendix A, and is required to be submitted for all projects at registration time for entry into the WSSEF. It is a formal documentation of what you plan to do for your science project, and MUST be completed before any experimentation is performed. It is submitted as part of the Student Checklist (1A)[47] along with the Approval Form (1B)[48], and the Checklist for Adult Sponsor (1)[49], both of which must be signed prior to experimentation. The Research Plan contains the following five major subdivisions.

Question Being Addressed

It is now time to finalize the draft introduction that you developed while researching your topic. Starting from your draft, make sure you have answered the question; what is the problem? Describe the problem and your justification or purpose for investigating the problem in your own words. Be sure that your description includes known factors (information about the problem from your background search or literature review, for example) and unknowns (what you need to find out in order to solve the problem). Then restate the problem in the form of a question or questions that will guide your research. Finding this problem or question is so important that it is listed as item 2. in the Scientific Method listed in Appendix A.

Hypothesis/Goals/Criteria

Formally documenting your hypothesis is listed as item 4 of the Scientific Method in Appendix A. Finalize the hypothesis or non-inquiry based goals and criteria that you developed in your draft introduction and found to be feasible to investigate from your project planning.

The definition of a hypothesis at the right was taken from a guide to design experiments[50], and the lab report identified in the definition is the Research Report described as item 10 of the Scientific Method in Appendix A and in more detail under the section: Write a Research Report. Add a description of the logic or reasoning that led to your hypothesis, goals, and criteria, using what you know or learned about the basic concepts from your background search or literature review. A research plan is not considered very complete without this additional description.

A **hypothesis** is a scientist's best estimation, based on scientific knowledge and assumptions, of the results of an experiment. It usually describes the anticipated relationship among variables in an experiment. Since dependent variables "depend" on independent variables, there has to be a relationship between the two. The anticipated relationship between the dependent and independent variables is the result you expect when one variable reacts with another.

A hypothesis typically leads to the crucial questions that must be addressed in the lab report: did you find what you expected to find? why or why not? The point of an experiment is to test the hypothesis. Write or sketch your hypothesis, describing the relationship among the variables you listed.

Description of Methods or Procedures

Make a listing of the materials, methods, and procedures that you developed for each experiment that you designed during project planning. Keep this part of the documentation of item 5 of the Scientific Method in Appendix A, simple and straightforward. An excessive amount of detail in this listing may require you to develop, and get approvals for another Research Plan, if you find that some of your materials are not available as anticipated, or something else does not work out exactly as you thought it would before experimentation.

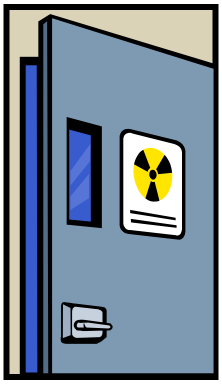
Prepare a Bibliography

This is the first bibliography that you will prepare, with the next bibliography in your Research Paper. It is often helpful when you do a literature review to enter reference information into a spreadsheet program, so that you can go to one place when preparing these bibliographies. The spreadsheet entries can also include comments about the reference that will help you when doing your analysis and drawing conclusions in the Research Report. See Appendix D for references and a general discussion about bibliographies.

The bibliography required in your Research Plan demonstrates that you performed a background search or literature review that is listed as Item 3 of the Scientific Method in Appendix A. **The minimum requirement as indicated on the Student Checklist (1A)[51] form is that you list at least five references.** The Research Plan does not generally require citations, but references are required to be listed in the bibliography, which is typically located in the back.

Address Special Safety Requirements

Any proposed research in the following areas must be reviewed and approved by the WSSEF Scientific Review Committee (SRC) before experimenting: projects involving vertebrates, pathogenic and potentially pathogenic agents, controlled substances and recombinant DNA (rDNA) (Human studies reviewed and approved by a properly constituted Institutional Review Board do not have to be reviewed by the SRC until the Fair competition). All bacteria, fungi, etc. isolated from the environment should be considered potentially pathogenic.



If work was conducted in an institutional or industrial setting any time during the current ISEF project year, the ISEF Regulated Research Institutional/Industrial Setting Form (1C)[52] must be completed. Please refer to the International Rules for Precollege Science Research: Guidelines for Science and Engineering Fairs in the ISEF Forms and Document Library[53] for a complete description of applicable safety requirements, procedures, and documentation.

To assist local fairs, the WSSEF Scientific Review Committee will be glad to review and approve any project needing pre-approval. It is not necessary to be registered to obtain the proper approvals from the WSSEF SRC. Please send an email to Scientific Review Committee[54] for assistance.

Chapter 3: Do It!

Perform Your Experiment/Investigation

Once your Research Plan is approved, it is time to perform the experiment. Plan and organize the experiment. Perform the experiment under controlled conditions. Keep careful records in the bound scientific notebook. The notebook is for your records and notes. Document everything you do, whether talking to a person about the project, visiting a library for research, or doing the lab work.

Before You Start Your Experiment

1. **Outline the procedure and make a timeline.** An outline of the proposed timeline to complete each part of the experimentation is helpful. Ask yourself the following questions to help you prepare for doing your experiment.[55]

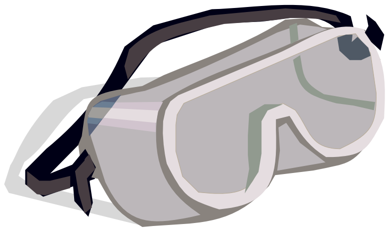
   - ☐ Can the entire experiment be completed at one time? Are multiple time slots needed for completion of experimentation? If so, what plans do you need to make for securing materials safely between the experimentation sessions?
   - ☐ What do you need to measure results? Are the measuring devices in metric units? Do you know how to read them? Do the instruments give precise measurements? Have you recorded the type, name, manufacturer, and any information regarding precision about the instrument in your log? Have they been certified or calibrated, if yes, have you recorded that information in your log?
   - ☐ Do you need other people with you while doing the experimentation? Have you talked to those people about scheduling an appointment at a time convenient for everyone involved so that the experimentation can be carried out?

2. **Keep your scientific notebook/log and graph paper handy.** It is critical that all procedures and observed data be recorded in a manner that is available for other researchers to replicate and verify. Usually, students conducting science fair projects record their data in a bound journal, along with their observations of any possible sources of error, or insubstantial changes in procedure that were approved as a condition of conducting the experiment. Design and set up the tables and graphs you expect to use prior to starting your experimentation. Include units where appropriate.[56]

3. **Keep a camera on location.** Check if it needs batteries or film. The camera is a useful tool for documenting your project. Have another person take photos of you performing the experiment, and use the camera to record the progress and the results of experimentation.[57] Enter who took any pictures, how many pictures were taken, and the subject of the pictures in your log.

4. **Complete all certification forms and compliance forms**. Make certain you have completed the Research Plan and all necessary forms for restricted areas and obtained proper approvals before experimentation begins.[58] This includes any forms required by the laboratory or institution you are using to conduct the experiment.

5. **Observe safety rules.** You should talk about safety issues with your teacher, including appropriate clothing and, if applicable, with the qualified research scientist and/or lab instructor at the research facility. Do not use any equipment that is unfamiliar to you; learn to use it before beginning the experiment.[59] Make sure you know where and how to obtain any goggles, masks, hats, gloves, and aprons that you might need during the various phases of experimentation. Special Projects[60] involving hazardous chemicals are required by ISEF[61] to have Material Safety Data Sheets (MSDS) for those chemicals. Read and follow the safety precautions listed on the MSDS that are required for the storage, handling, use, and disposal of all hazardous chemicals used for your project.



6. **Obtain copies of Standards and Procedures.** Standards and procedures have been developed to reduce systematic errors. Obtain copies of any standards and procedures and place them in your notebook. Read and be familiar with all the steps need to be performed that are used for the apparatus in types of materials you will be using.

Sources of Error

Errors in investigations can be classified as “random” or “systematic.” Random error is intrinsic to all measurement performed by humans. Early astronomers, who were timing the movement of heavenly bodies, noticed that different individuals recorded different times for the same event. Because there is equal probability of producing measurements that are higher or lower than the “true” value, this type of error is said to be random. The second type of error is systematic or non-random error. This kind of error is due to factors that bias the result in one direction.[62]

Random Error

Random errors are statistical fluctuations (in either direction) in the measured data due to the precision limitations of the measurement device. Random errors usually result from the researcher's inability to replicate the same measurement in exactly the same way to get exact the same number. The distribution of random errors follows a Gaussian-shape "bell" curve. The precision is described by statistical methods such as a standard deviation or confidence intervals or limits.[63,64,65]

The most common way to reduce random error is to take more measurements. Random errors can be evaluated through statistical analysis and can be reduced by averaging over a large number of observations.[66]

Systematic Error

Systematic errors, by contrast, are reproducible inaccuracies that are consistently in the same direction. Systematic errors are often due to a problem, which persists throughout the entire experiment.[67] These errors result from biases introduced by instrumental method, or human factors. An example of an instrumental bias is an incorrectly calibrated pH meter that shows pH values 0.5 units lower than the true value. An example of human bias is a student who records titration endpoints beyond the true endpoint due to color blindness.

Systematic errors are difficult to detect and cannot be analyzed statistically, because all of the data is off in the same direction (either too high or too low). Spotting and correcting for systematic error takes a lot of care.[68] Systematic errors can be reduced by analyzing standards that closely match the processes and materials being used in the experiment.[69]

Begin Experimentation

1. **Make entries in your scientific notebook as you go.** You should record data, both quantitative and qualitative, in your logbook. Sometimes what appears to be irrelevant or a failure on one day may become important information at a later date.[70]
2. **Enter measurements in your tables.** As you proceed with your project, make certain you include the units and the precision of each measurement based on the published information or scale(s) of the measuring device. Estimate and record your precision as a ± absolute quantity or fractional part of the quantity measured in percent (%) for each data type.[71] For the difference between accuracy and precision, see page 28 followed by a

discussion of Random Errors of Measurement regarding how to use measures of precision during the analysis of your experimental results.

3. **Make repeated measurements periodically.** Some experiments (e.g., plant-growth projects) require repeated measurements over an extended period. You should take measurements periodically (e.g., every day at 4:00 PM, every third day at noon) to reduce extraneous variables, and make entries into the log when you make the measurements.[72]

4. **Repeat the experiment, if necessary.** If after completing the experiment, you might find that your results do not support your hypothesis. When this happens, you have several options. You might elect to accept your experimental results and reject your hypothesis with discussion in your conclusion. You might decide to repeat the experiment substantially as planned to increase the accuracy of your results. Alternatively, you might elect to clarify or even alter the hypothesis, redesign the experiment, and begin your experiment again with new insights that you have gained.[73]

   Substantial changes to the hypothesis or experiment require revisions to your Research Plan and subsequent approvals prior to experimentation with the changes. In general, a substantial change amends, extends, or redirects the direction of the inquiry. Changes that involve the use of different safety standards, or invoke different ISEF rules and regulations are also substantial changes. Special projects that required WSSEF SRC or IRB approval will also need to be resubmitted and approved prior to repeating the experiment if it contains substantial changes. If you are not sure what constitutes a substantial change, talk about the particular changes you have in mind with your teacher or Adult Sponsor. Members of the WSSEF SRC[74] are available to answer any questions you may have about the need for submittals. Changes that clarify, reduce, or restrict the inquiry into a subset of the former research plan are not substantial enough to require a revised Research Plan and approvals.

   If time permits do not be afraid to substantially revise your science fair project. Now that you have performed the experiment that you planned originally, you have a much better understanding of the phenomenon being investigated. Revisions to the hypothesis or experiment can be made based on the knowledge gained from your previous work. You may learn more and greatly improve your competitive advantage from the process of revision than when all goes "perfectly" as originally planned. **Remember, do not discard, or remove any data from your scientific notebook/logbook. These pieces of data are often valuable later.**[75]

Analyze Your Results

Data analysis is the process of reducing the data collected during an experiment to verify (or not) the hypothesis. If the hypothesis simply asks if a relationship exists between dependent and independent variables, then the goal of the data analysis is to discover if a relationship exists. If the hypothesis predicts a manner in which independent and dependent variables are related (cause and effect) then the data analysis must apply the predicted manner (hypothetical model) to see if it is valid for the data collected. The simplest form of analysis is to graph the data to help identify patterns.[76] However, competitive advantage of one project over another can be gained by using more sophisticated analytical methods or procedures.

Statistical analysis methods that are indicated in Appendix F are often used to test data. Recognizing the variability of measured data, averages can be used to describe a central value that represents a subset of collected data out of a larger set of collectable data. Curve fitting is an extension of the simple graphing technique of the data to find the best-fit relationship between independent and dependent variables. Recognizing that all data has some uncertainty associated with it, any hypothesis that seeks to identify a relationship based on data obtained in an experiment also has uncertainty associated with it. Statistical methods have been developed to quantify the uncertainty in collected data, and estimate the uncertainty in the relationship between the dependent and independent variables modeled in the hypothesis.

Sophisticated statistical analytical methods can be used to test the hypothesis to separate significant effects from mere luck or random chance. Data can be statistically tested to identify the probability that a seemingly proven hypothetical relationship exists, when it does not (rejecting a true null hypothesis), or conversely when a seemingly proven hypothetical relationship does not exist, when it does (failing to reject a false null hypothesis). These more sophisticated statistical analysis methods can be very helpful when it comes to drawing conclusions about the acceptance or rejection of the hypothesis, based on the potential for error or chance in the data collected.[77]

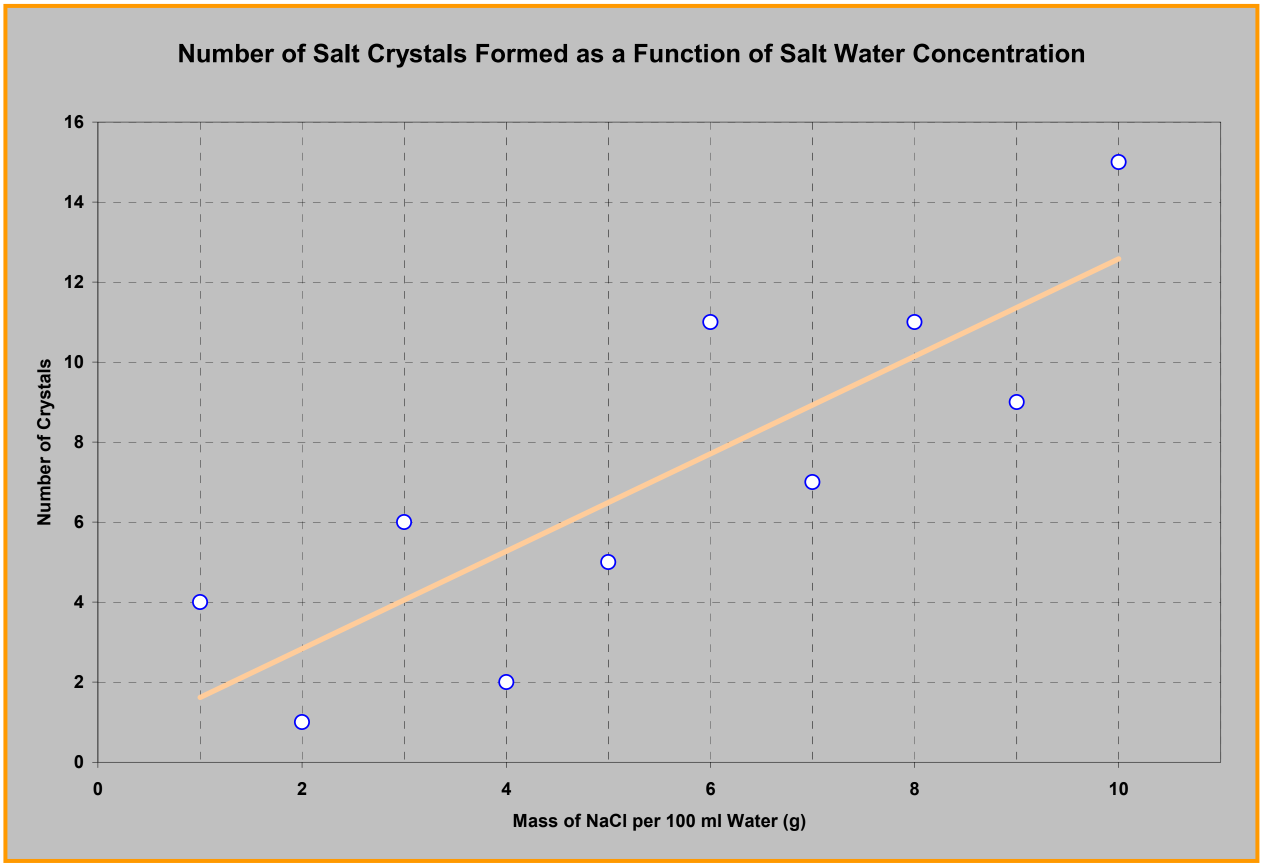
Organizing Your Data

In order to look for any trends, your results should be organized in data tables. Computer spreadsheet programs are useful because the program can graph your data from the spreadsheet.[78] Carefully copy the data from your notebook or journal into a table format that is easy to understand and represents a logical progression of the data. An example would be to list all the data for the independent variables in a column of ascending numbers, which are paired with the measured response of the dependent variable next to it, so that each row represents a data point of an ordered pair of numbers. Be sure to identify the rows and columns of tables correctly with units.

Data in the table at the right contains information about precision. In the left column, the data is listed in whole grams. This may be because of the precision of the instrument used, or it may be that the researcher was going to add these numbers together and was not confident that the scale was capable of anything more than a measurement in whole grams for two or more significant digits. Whatever the reason, this data was measured, and a decimal point is included in the table to indicate the level of precision. The researcher did not include a zero after the decimal point because the data could not be measured to tenths of a gram. The number of crystals was counted and not measured. These numbers are always expressed as integers and the decimal point is not included.

Mass of NaCl per 100 ml Water (g)	Number of Crystals after one week
1.	4
2.	1
3.	6
4.	2
5.	5
6.	11
7.	7
8.	11
9.	9
10.	15

Graphing data often helps to be able to identify trends. Scatter graphs like the one below, which places the independent variable on the horizontal scale and the dependent variable on the verticals are often used. Bar charts, histograms, and pie charts are also used to display data graphically.[79]



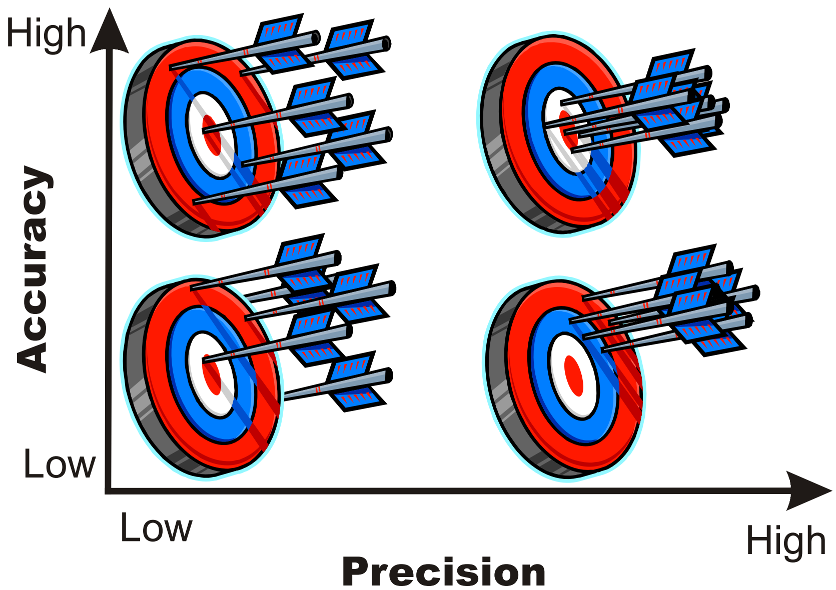
In the graph above a straight line was drawn to see if the dependent variable varies directly or inversely with the independent variable. When drawing a line, make sure that you have as many data points above the line as below, and that the distances of the data points to the line on average are minimized. In this case, as the independent variable increases, the dependent variable increases, and the relationship varies directly. If the line was sloping from high on the left to low on the right then as the independent variable increases, the dependent variable decreases, and the relationship varies inversely.[80]

If your data looks as if it might be describing a line, you can do a linear correlation using computer software. Such programs can provide a correlation coefficient (r), which is a measure of how closely your data is fitted to the line or curve (r = 1 means that all data points are exactly on the line or curve). Other kinds of curves can also be fitted using mathematics or computer software. By fitting your data to an appropriate line or curve, you can obtain an equation that describes your data. Predictions can be made from this equation, which can be used to verify your results with further experimentation.[81]

Remember that each graph should have axes that are properly calibrated (i.e., each increment should represent the same numerical amount). Be sure to include the entire range of your data in the scales of your axes.[82] The scales of the two axes might be different, but at least they should be uniform for their entire length. Some graphs like semi-log and log-log graphs have different scales, but the two axes are still uniform in the major increments for their entire length.

Accuracy and Precision

Accuracy is the extent to which a measured result from an experiment or a data point comes to the accepted or "true value." Precision refers to repeatability and reliability of the measurements. It often corresponds to how many digits your measuring instrument is able to determine, or how many significant digits your instrument can measure. A good-quality measuring device can usually measure more precisely, that is, repeat the same measurement, and give the same values for more significant digits, than an imprecise device.[83]



The graph above shows four targets with arrows in various locations.[84,85,86,87] The center of the target represents the accepted or "true value" and the arrows represent measurements taken in an experiment of the targeted variable. This graph shows both precision and accuracy increasing from the lower left to the upper right. The first two targets on the left represent low precision measurements. Note that the arrows are scattered apart from each other as an indication of low precision, when compared to the arrows that are tightly grouped in the tow targets on the right.

The two lower targets demonstrate low accuracy, in that the central tendency (average) of the groups of arrows is not very well aligned with the center of the target. These two targets are an indication of random errors of measurement. It is possible to have low precision and high accuracy as indicated by the target on the upper left. The upper left target is preferred over the lower right target, which demonstrates a central tendency that is not aligned with the accepted or "true value" creating concern for errors in the measuring process.

Of course, the best target, and the one that every researcher should strive to accomplish is the one in the upper right that has both high accuracy and precision. The central tendency of the arrows in this target is aligned with the accepted or "true value" and the precision of the measurements demonstrate that they are repeatable and reliable. The student researcher should be warned that a greater number of digits recorded for a calculation based on measurements is not an indication of precision.

Example 1:

If you calculate the acceleration due to gravity (g) to be 11.9971 m/s^2, your data is precise but not very accurate. (The number 11.9971 implies that it is based on measurements that are precise to 6 digits. In other words, it has 6 significant figures.) A measurement of 10 m/s^2 is not very precise but it is quite accurate. (The accepted or "true value" for g is about 9.81 m/s^2.)[88]

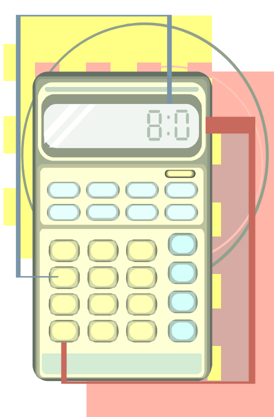
Example 2:

Two students obtained the data in the table at the right when measuring g, the acceleration due to gravity. The first data set is very precise while the second is not. Both data sets give similar mean values and appear to be quite accurate.[89]

Acceleration due to Gravity		
Researcher:	**A**	**B**
	m/s^2	m/s^2
	9.8	10.5
	9.7	9.8
	9.9	8.3
	9.6	11.7
	9.8	7.9
Average=	9.8	9.6
Maximum:	9.9	11.7
Minimum:	9.6	7.9
Range:	0.3	3.8
Standard Deviation:	0.1	1.6

In this case, the range of data from student A is quite small, while the range of data from student B is much larger. In addition, the standard deviation of the data from student A is smaller than the data from student B. The larger range and standard deviation of data from student B may be inherent in the design of the two student's experiments, or it may be due to round off or truncation errors in the measurements and calculations performed to derive the data. It is very possible that student B attempted to read too much precision into the data being collected or calculated.

Random Errors of Measurement



All measurements are either rounded off or truncated due to the finite precision limitations of the instruments being used to take the measurements. Random errors of measurement can be amplified because of calculations that are performed on those measurements. Random errors of measurement are expressed as either absolute or fractional.[90] The level of precision is often written on the instrument or can be found in the manufacture's literature. If the precision of the instrument is not listed, then the researcher must assign an error of measurement based on the precision of the instrument that can be read directly. All random errors of measurement can be both positive and negative and define a range in which the number is most likely to be located.

An absolute error is based on the scale of the instrument and is often taken as one-half of the smallest gradation that can be read directly. In the example below the instrument for determining mass provided a digital display that read to tenths of a gram. The absolute error was taken as one-half of one tenth gram or ±0.05 grams. In a similar manner, the researcher determined the absolute error for the graduated cylinder used to determine the volume as one-half of the smallest graduations.

Fractional error is based on the instruments ability to maintain a number of significant digits when going from very large to very small measurements. Some instruments lose precision as the quantities they are measuring increase. For these instruments the error is presented as a ±percentage of the measurement.

When performing calculations with measured data, the error of measurement is carried through the process for each addition/subtraction and multiplication/division operation in the order they are performed. If two or more numbers are being added or subtracted, then their absolute error is added. If two or more numbers are being multiplied or divided, then their fractional errors are added. In symbolic form, this can be written as:

$A = A \pm a$, where a is the absolute error of measurement A[91]

$A = A \pm \frac{a}{A}$, where $\frac{a}{A}$ is the fractional error of measurement A[92]

$B = B \pm b$, where b is the absolute error of measurement B[93]

$B = B \pm \frac{b}{B}$, where $\frac{b}{B}$ is the fractional error of measurement B[94]

Operations performed during calculations:[95]

$A + B = (A + B) \pm (a + b)$, for addition

$A - B = (A - B) \pm (a + b)$, for subtraction

$A \times B = A \times B \pm \left(\frac{a}{A} + \frac{b}{B}\right)$, for multiplication

$\frac{A}{B} = \frac{A}{B} \pm \left(\frac{a}{A} + \frac{b}{B}\right)$, for division

An example of how to use random errors of measurement in an experiment is included in Appendix E.

Conclusion

Briefly summarize your results, state your findings and accept or reject your hypothesis.

Accept or Reject Your Hypothesis

Your conclusion should accept or reject your hypothesis. It should then go on to interpret the meaning of your project.

In interpreting the meaning of your project, you should ask yourself a number of important questions, starting with the specifics about the data itself and ending with inferences about your results including how others can use your project. Try to ask and answer as many of the following questions as honestly and objectively as possible.[96]

- ☐ Did the variable(s) tested cause a change when compared to the standard you are using, or were your variables and control improperly designated?
- ☐ Which variables are important?
- ☐ Did you collect enough data? Alternatively, do you need to collect more data?
- ☐ Were there sources of error in your data collection that may have caused significant differences in your data analysis? If so, identify them.
- ☐ Has your experiment tested your hypothesis?
- ☐ Do you need to conduct more experimentation?
- ☐ What patterns do you see from your data analysis that exist between your variables, or are there any trends in your quantitative/qualitative data? If yes, what might explain these patterns or trends?
- ☐ How do your results compare with other studies?
- ☐ Do your results seem reasonable?

Applications for Your Project

Can you think of any practical applications that can be made from this research project, or how might the results of your project be relevant to society or to others? **Judges view applicability of research results as an important part of any research project.**

Next Steps

At the end of your conclusion, you could explain how you would improve the experiment and what you would do differently, given the chance to do it over again.[97]

Write a Research Report

There are two types of science research reports, and they may be separate or combined. The first type is a literature review. In the literature review, you compile and summarize large amounts of scientific research done by others that cover the topic chosen for investigation. You do not include your own laboratory investigations in the literature review. The review should be extensive, citing as many sources as you can locate on the topic. A separate literature review often contains a written summary of an annotated bibliography that can also include copies of the cited materials.[98]

The second type of research paper describes the specific experimental project you have completed. It should contain an abbreviated (summary) or full literature review as part of the background search information as well as your hypothesis, experimental design (methods and materials), experimental results, brief data summary, discussion and analysis of the results, and bibliography.[99]

You can do both types of paper separately, or put them together in one inclusive report. A thorough search of the scientific literature published on the topic covered in the project helps to make you an "expert" in your particular field of study, and prepares you to discuss the area of study with others.[100]

Use scientific terminology in the paper. It will help you to feel more at ease with the topic. **Your job is to convey the facts and information you have gleaned in an organized, readable, and concise manner.**[101]

Components of a Research Report

A good research report should be written in the past tense and have the following components:[102]

- ☐ Title and/or Title Page - The title page and table of contents allow the reader to follow the organization of the paper quickly.
- ☐ Abstract, Summary Page/Index
- ☐ Introduction, including Literature Review - The introduction sets the scene for your report. The introduction includes the purpose, your hypothesis, problem or engineering goals, an explanation of what prompted your research, and what you hoped to achieve.
- ☐ Hypothesis or Statement of Purpose
- ☐ Materials and Experimental Methods - Describe in detail the methodology you used to collect data, observe, design apparatus, etc. Your report should be detailed enough so that someone would be able to repeat the experiment from the information in you paper. Include detailed photographs or drawings of self-designed equipment.
- ☐ Data and/or Results
- ☐ Discussion and Analysis of Data or Results
- ☐ Conclusions - Briefly summarize your results. State your findings in relationships of one variable with the other. Support those statements with empirical data. (One average compared to the other average, for example). Be specific, and do not generalize. Never introduce anything in the conclusion that has not already been discussed. Also, mention practical applications.
- ☐ Acknowledgements - You should always credit those who have assisted you, including individuals, businesses and educational or research institutions.
- ☐ Bibliography - Your reference list should include any documentation that is not your own (i.e. books, journal articles, websites, etc.). See an appropriate reference in your discipline for format or refer to the Instructions to Authors of the appropriate publication.

Writing a Research Report

After you have gathered all your information, you may find the following steps helpful:

1. **Produce a report outline that provides a skeletal structure for the entire paper.** A good outline will give direction, cohesiveness, and orderliness to the paper, and convey the information in a concise format. Be descriptive but brief. Reduce large quantities of information into brief "bullet statements" for use throughout the paper. Organize them into a systematic description to walk the reader through the project in an orderly progression. Use your sources to "work for you" and distill information into a reasonable length. When you write from the outline, each paragraph should have a topic sentence and a concluding sentence to direct the reader.

2. **If you use note cards, organize these by sequencing them in a desired order.**

3. **Write an introductory paragraph that acquaints the reader with the research paper.** Give a preview of information that is covered in the paper. Briefly highlight the main points of the paper (50 - 75 words).

4. **Take material from the note cards and put it into written text.**

5. **Footnote or cite sources properly.** Cite references directly within the paper with the citation set off by parentheses, and cross-referenced in the Bibliography or List of References. Use citations when you give facts such as numbers, data, and statistics, quote a source directly, cite another researcher's results, or cite information received from another expert in the field. See Appendix D for citations and reference styles.

6. **Integrate support material.** Be certain that pictures, diagrams, tables, and graph axes are properly labeled and include units of measure.

7. **Write a summary paragraph as your conclusion.** Make a concluding statement and end the paper. It should state whether the results supported the hypothesis.

8. **Be careful to acknowledge all borrowed material, whether paraphrased or directly quoted**.

9. **Be careful to give proper credit. Use quotes and citations where appropriate**.

10. **Reference sources in the Bibliography, which may also be called the List of References, References Cited, Literature Cited, or Sources Cited**

11. **Check spelling, grammar, and punctuation. Do not rely on software alone to do these checks.**

12. **Read the paper aloud and check for clarity and readability.**

13. **Have someone else read the paper.**

14. **Correct errors.**

15. **Use standard size (8½ x 11) white paper.** Use standard margins, and type on one side only.

16. **Have your report(s) with you as a part of your display when presenting your project.**

Write an Abstract

The abstract is a summary of your science research project in 250 words or less. It should be single spaced in black 12 pt. font. It should fit within a box that is 5.5 inches tall by 6 inches wide. It should include a title written in Title Case; your first name, middle initial and last name (include all team members), and your school, city and state within the top 0.75 inches of the box. It should contain the following information:

- ☐ purpose of the research project/engineering goal(s)
- ☐ procedures used
- ☐ data
- ☐ conclusions

An abstract may also include any possible research applications. Only minimal reference to previous work should be included. An abstract should not include: acknowledgments (including naming the research institution and/or mentor with which you were working), or work or procedures done by a mentor[103]

Template for an Abstract

The following template can assist you in preparing an abstract. The numbers in [brackets] correspond to the same numbers located in the following sample abstract.[104]

[1] Write 1-2 sentences which introduce the research topic (broad statements)

[2] Write 1-2 sentences, which focus on the particular intent of this research topic

[3] Write 1-2 sentences indicating the specific problem to be solved/engineering goal(s)

[4] Write a brief paragraph describing the procedures/methods used

[5] Write 2-3 sentences which indicate the data resulting from the research (these sentences summarize the results, discussion and conclusions)

[6] Count the number of words you used in the sentences you prepared for sections 1-6. If needed, edit the sentences to bring the word count within the required 250 maximum.

Sample Abstract

The Influence of Mycorrhizal and Fertilizer Treatments on Tree Seedlings
in Fire-Affected Soils[105]

[1] Tree planting success after a wildfire may be poor due to the changed environment. Wildfire-affected soils can have increased pH, reduced native mycorrhizal inoculum and decreased nutrient levels (especially nitrogen). [2] Planted tree survival and growth may be increased with mycorrhizal inoculum and/or fertilizer application at the time of planting. Research on the effectiveness of these treatments for Douglas-fir and ponderosa pine planted on a range of soil burn severities is lacking. [3] The purpose of this study was to determine the effectiveness of slow release fertilizer (24:10:6 plus micronutrients) and/or mycorrhizal inoculum at the time of planting on the first-year success of planted Douglas-fir and ponderosa pine on sites with low, medium, and high soil burn severities.

[4] Treatments were applied to rows of 10 trees and replicated three times in each burn severity. Measurements included mortality, budbreak, nitrogen and carbon content, shoot growth, root and stem volume growth, diameter growth and percent latewood. [5] Nutrients were more limiting on these sites than native mycorrhizal inoculum. No treatments increased survival; fertilizer treatments increased growth significantly compared to control and mycorrhizae-only treatments. Non-fertilizer treatments (control and mycorrhizae only) had significantly greater numbers of mycorrhizal root tips per cubic centimeter of root volume.

Chapter 4: Present It!

Presenting your project at the Science Fair is the final step in the process. To encourage more students to develop science and engineering projects, Science Fairs have evolved into competitions. These competitions are between students within a category and for the Science Fair overall. Judges are used for the competitions that perform a process similar to peer review based on verbal presentations and visual displays. **Communication is the purpose of the verbal presentation and visual displays.** To communicate effectively, it is important that you understand the expectations of the judges. The following sections will help you to prepare your visual display, verbal presentation, and provide some insight as to what you can expect in the judging process.

Visual Display

You want to attract and inform. Make it easy for interested spectators and judges to assess your project and the results you have obtained. You want to 'catch the eye' of the judges and convince them that the research is of sufficient quality to deserve closer scrutiny.[106]

You should take pride in the assembly of the board and it should reflect your work, as you want it represented. Neatness, completeness, and clarity are very important. The board and visual display should help you to present your project logically and serve as a prop for you to illustrate what you have done.[107]

The primary focus of the WSSEF judges will be your research, not the display. Do not spend an excessive amount of time or money on the board that would be better spent on the quality and quantity of information presented for the research project. You are being judged on the science not the show![108]

Parts of the display board:

- ☐ Title - an attention grabber to make someone want to know more about the project
- ☐ Introduction or background search/literature review
- ☐ Problem or Purpose
- ☐ Hypothesis
- ☐ Procedure and Methods
- ☐ Materials Used
- ☐ Data & Results (charts, diagrams, graphs, pictures of the results, etc.)
- ☐ Analysis
- ☐ Conclusions

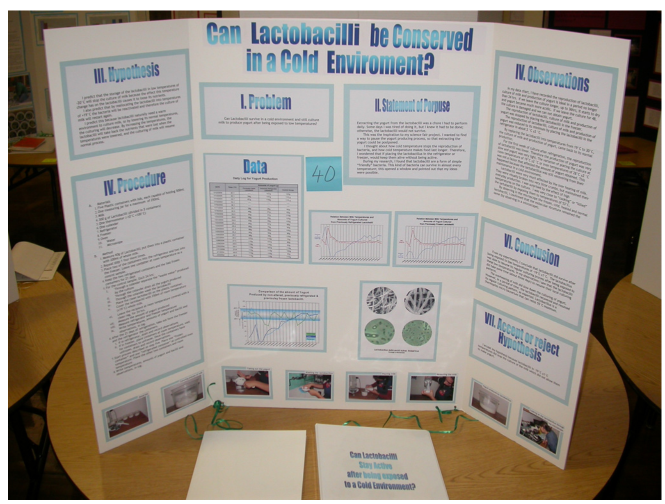
☐ Bibliography (Optionally our bibliography may be placed in the notebook instead)

Sample Visual Display Boards

Most displays or boards have three sections and are free standing. For the most part, the displays are put on a table. Many judges get a chance to look at the display boards before the interviews. Make the most of your space using clear and concise displays. **You never get a second chance to make a first impression!**[109]

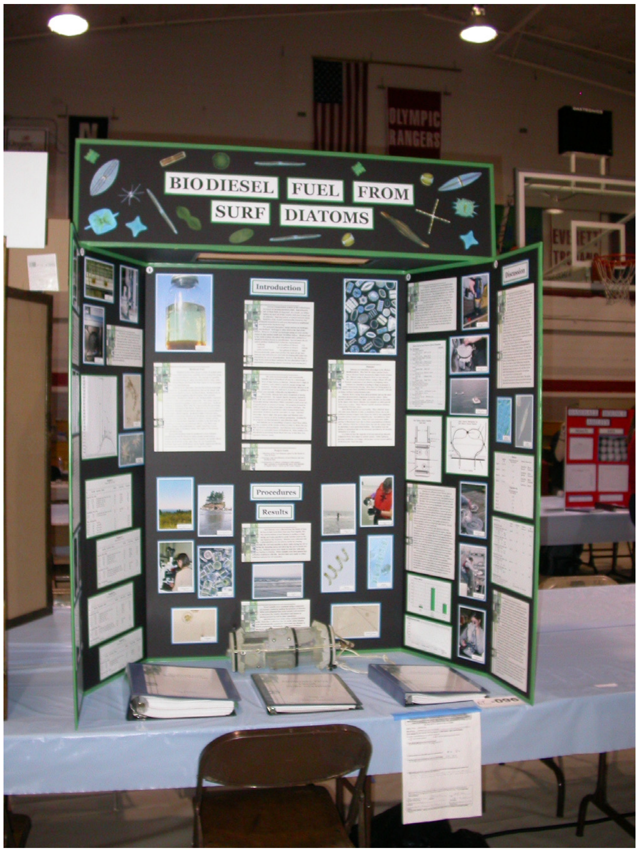
The board can be organized like a book to read the left panel first, then the center and finally the right panel, but always top to bottom. This approach generally has data such as photographs, charts, and graphs in the center panel.

Introduction	**TITLE**	Materials Used
Background Problem or Purpose Hypothesis Procedures & Methods	Data & Results Graphics & Tables Pictures (captioned) Analysis	Conclusions Bibliography (optional)



[110]

A more popular approach is to put the information you want to be read first in the upper center panel, then the next most important in the left panel, with the remainder in the right panel, also presented top to bottom. This approach is typically used on more complex projects that use data from several different experiments to investigate a hypothesis.



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Display Tabletop

1. All exhibit materials should fit within a tabletop area that is 48 inches wide by 30 inches deep. The total height of the display cannot exceed 108 inches from the floor (including 30 inches from floor to tabletop).
2. Although exhibits can be displayed directly on the floor, it is recommended that they be placed on the tabletop.
3. The tabletop provided by the Science Fair may or may not have tablecloths. Each entrant can optionally provide a tablecloth in a color that accentuates the theme colors of the display board.
4. The tabletop should have at least one display board, a log or journal of the project listing activities and a copy of a research paper with reference materials included or separately.

5. Other items that pertain to the project maybe displayed on the tabletop provided they do not detract from the overall presentation of the project or violate the WSSEF [112] or ISEF[113] rules and safety regulations.

Helpful hints for displays:

Only material from this year's project can be placed on your board. If your project is a continuation project, a short background statement (1 to 2 paragraphs) can summarize the preceding year's work as background only.[114] Prior year's data books are permitted at your project.[115]

Read the rules[116] that govern visual displays exhibited at WSSEF before you begin. Be sure to adhere to the size limitations and safety rules when preparing your display. Also, be sure to review the Display and Safety Regulations of the most current ISEF Rules and Regulations.[117,118]

Your project title and section headings on your board should be large enough to be easily read from six feet away.[119] Your title is an extremely important attention grabber. A good title should simply and accurately present your research and depict the nature of the project. The title should make the casual observer want to know more.[120]

The regular text displayed on your board should be readable from a distance of three to four feet. Although you may be tempted to make your board larger, remember that your board should not be mostly empty space. A smaller size board that is nicely laid out and tells the story is far more attractive than a large one that is not filled.[121]

Be creative. Make your display stand out. Use color combinations that are pleasing to the eye. Arrange the board in several ways before attaching all of your materials. Keep background spaces to a minimum. However, do not crowd tightly so that everything seems too packed. Keep it simple. Make it easy for the judges and others to assess what you have done. Anyone should be able to understand the visuals without further explanation just by looking at your display board.[122, 123]

Carefully check for safety and size before you cut your board to size. Make sure your display is sturdy, as it will need to remain intact for quite a while. Poster board may need to be reinforced so it can stand-alone. Mat-board, and foam-core boards are easy to work with and are lightweight.[124]

Make sure your display follows a sequence and is logically presented and easy to read. Reach out to the 'skim-reader'. A glance should permit anyone (particularly the judges) to locate quickly the title, hypothesis or goal, experiments, results and conclusions. When you arrange your display, imagine that you are seeing it for the first time. Highlight your results using key graphs that show the relationships of the two variables tested. Use the graphs to give a 'picture' of the data for your viewers. These graphs will provide an easier method of viewing the data rather that just seeing the recorded quantitative data.[125]

Use neat, colorful headings, charts, and graphs to present your project. Correctly and clearly, label graphs, diagrams, and tables. Pay special attention to the labeling on graphs, charts, diagrams, photographs, and tables to ensure that each has a title and appropriate label describing what is being demonstrated. Make certain that the graphs are titled and have both axes labeled clearly and accurately.[126]

Use photographs to validate and help explain parts of the project that would be difficult to explain, or that would require time to explain. Many projects involve elements that may not be safely exhibited at the Fair, but are an important part of the project. You might want to take photographs of important parts/phases of your experiment to use in your display. Captions should be clear and indicate the point being made by the photo or image. **Photo or image credit lines must be used, and should be of the form: "Photograph taken by..." or "Image taken from...")**[127]

Photographs or other visual images of human test subjects must have informed consent (Please see the current ISEF Rules[128] for display and safety regulations). Decide if photographs of this type would be better placed in your notebook or a photo album rather than on your board. In addition, you must have permission to use pictures from books or other sources.[129]

Presentation

What do Science Fair Judges want to know?

Science Fair judges are volunteers that have set aside a portion of their time to communicate with you about your project, and rank it with respect to all the other projects that have entered the Science Fair in your category or that meet specific special awards criteria. It is important for you to remember, that these judges may be experts in the field of study that includes your project, or they may be scientists, educators, and engineers that have an interest in that field. **All of them have an interest in communicating with you about your project, and are responsible for ranking your project for recognition and awards based on what they consider good science or engineering.**

WSSEF Judging Criteria

The major judging criteria[130] used at WSSEF include the following:

1. Knowledge of the Project Topic
2. Knowledge of Scientific Principals or Engineering Goals
3. Journal and Records
4. Creativity and Originality
5. Visual Display

Each of these major criteria are judged based on points to indicate its importance in the overall ranking process, but judges are allowed to consider this criteria as a guideline and are given freedom interpreting and applying them to your project.

The previous judging criterion is for WSSEF awards[131] and includes ribbons for first, second, third, and honorable mention rankings within each category. A Best of Category award will be selected for each judging category. In addition, the top individual projects for Grades 9 through 12 are judged against all other categories for the Washington State Gold, Silver, and Bronze Medalists awards. The Gold and Silver Medalists will represent Washington State at the next ISEF, and the Bronze Medalist will do the same if either of the other two is not available to attend. Since these students will be representing the State of Washington at ISEF, special consideration is made by the judges in the medalist selection process with respect to best chances to do well under the ISEF judging criteria.

ISEF Judging Criteria

The major criteria[132] used for judging at ISEF are:

1. Creative ability
2. Scientific Thought or Engineering Goals
3. Thoroughness
4. Skill
5. Clarity
6. Teamwork if applicable

It is important to note the similarities between the WSSEF and ISEF judging criteria, when making a presentation. Creativity is very important in both competitions, and you should be able to demonstrate how your project is uniquely based on your ingenuity rather than the manipulation of sophisticated apparatus. "Knowledge of Project Topic" in the WSSEF judging criteria is very similar to the "Skill" ISEF judging criteria. Both are involved with your ability to present a strong case for your project. The WSSEF "Knowledge of Scientific Principals and Engineering Goals" judging criteria is virtually the same as "Scientific Thought or Engineering Goals" at ISEF. Both WSSEF and ISEF concentrate not only on your knowledge, but also that the project demonstrated the use of the scientific method or an engineering process. "Journal and Records" in the WSSEF judging criteria is similar to "Thoroughness" in ISEF criteria with WSSEF targeting the thoroughness of your project's written documentation, while ISEF allows for a broader interpretation. Similarly, the WSSEF "Visual Display" judging criteria concentrates on the ability of the display to represent your project, while the ISEF "Clarity" judging criteria is evaluating the same things, but also includes your verbal presentation in the evaluation process of this criterion.

Special Awards

At WSSEF, special awards fall into two groups. The first are school awards. An all school award is dependent upon the evaluation of all projects submitted by a single school. These awards[133] are offered in groupings by grades with two to four grades in each group, and for the best performance at the WSSEF for all grades.

The second grouping is for students and is awarded by various criteria. Each of these awards is offered by an individual, governmental agency, or businesses that have specific criteria that are generally unique to those offering the award. An example of this type of award is the People's Choice Award, which is offered to students in grades 1 through 6, by WSSEF based selections by fair participants and attendees. Other special awards are given to students that include college scholarships, scientific field trips, prizes, plaques, certificates, and unique award packages. An example listing of organizations that have offered special awards in the past is as follows:[134]

- American Meteorological Society[135]
- American Psychological Association[136]
- ASM Materials Education Foundation[137]
- Association for Women Geoscientists
- Herbert Hoover Presidential Library Association[138]
- Intel Excellence in Computer Science Award[139]
- Mu Alpha Theta, The National High School and Two Year College Mathematics Honor Society[140]
- National Oceanic and Atmospheric Administration - NOAA[141]
- National Society of Professional Engineers & Professional Engineers in Industry[142]
- Office of Naval Research on behalf of the U.S. Navy and Marine Corps[143]
- Ricoh[144]
- Society for In Vitro Biology[145]
- WEF/ITT Stockholm Junior Water Prize[146]
- U.S. Department of Health and Human Services/U.S. Public Health Service
- U.S. Metric Association
- U.S. Army - Regional Award[147]
- Yale Science & Engineering Association[148]

What can you do before talking to Science Fair Judges?

You know more about what you did for your science fair project than anyone else. It is now time for you to communicate the important aspects and ideas about your project to the judges. The following steps will help you to prepare for communicating information that you know to the judges that not only have a responsibility to rank your project against others in your category, but also have a very real interest in wanting to communicate with you about your science fair project.

Preparation

Considering the judges' criteria, what can you say that will convince them that you deserve a strong rating in each of the criteria? Make a list of the most important talking points for each of the judges' criteria that are applicable to your project. Sort them in order of the strongest to weakest for your project, and develop an outline, which includes the strongest in the following suggested format.

Format

The best format is the simplest one that communicates your story. Start your story by writing down and memorizing a single sentence that tells the judges what your project is about in a few simple words. Then from that general introductory sentence write down an outline of the following:

1. the question you investigated
2. your hypothesis or engineering criteria
3. specifics about the procedures your experiment or design
4. the data you collected
5. methods of analysis you used, their results, and your final conclusions

It is now time to insert the strongest talking points that you developed in the first step as bulleted lists under the appropriate headings in your outline. If you follow this format, then you should have a general opening sentence and a list of your strongest talking points sorted by the process that you followed in developing your project, to tell your story in a general to specific way.

Visual Aids

Your visual display, research report, references, and journals are your visual aids, and they can help you tell your story concisely. The visual display and the written materials were previously developed as part of your science fair project.

Insert to the right of the bulleted list you developed as part of your format, an arrow and one or two words that will remind you to point to a graphic on your visual display. You can also use some other gesture, such as opening your journal during your presentation, to draw the attention of the judges to prototype designs or other items if they demonstrate one of your strong points.

Visual aids provide variety to your presentation, allowing for the use of eyes in addition to ears to facilitate your communication with the judges. Some visual aids, such as headings on your visual display, can help you remember the order of your outline during your presentation. Graphs and pictures can take the place of hundreds of words to explain a concept or show an experimental apparatus. Visual aids, such as a binder filled with highlighted reference literature or a long bibliography, also provide an object for the judges to focus on when evaluating your knowledge of the topic or thoroughness in literature review, which if done well, might also be one your strong points.

Practice

If you followed the presentation process above, and once you have completed your visual display, you will have everything you need to practice your presentation. The first time you deliver your presentation will always be the worst. Practice in front of a mirror the first time to make sure your worst presentation is not in front of the judges. Nervousness is common in making presentations, and the best way to avoid it is to practice often. Practice with your parents, teachers, mentors, siblings, and peers at school. Use good eye contact and practice using voice inflections, body language, and hand gestures for emphasis. In making a presentation, you are communicating. Good communication requires a sender and a receiver. The best communication is a two-way street with you as both a sender and a receiver. Gauge your audience's reactions and comprehension by asking for feedback and suggestions for improvement, and then adjust your presentation. Parents, mentors, and teachers may be able to get speaking engagements for you and others to present your science project to groups in your community. These often take some time to schedule, but are very beneficial in developing your skills at presenting your story and communicating. **The more times you practice, the more confidence you will gain and the better you will perform in front of the judges.**

After you have practiced a few times, start using a timer to see how long it takes you to deliver your story. The best presentations are simple and concise. The length of time is an important part of your presentation. You need to cover all your strongest talking points while leaving enough time for the judges to ask questions. If you can communicate your story in a minute or two then that would be ideal. If you need to take longer to cover your strongest talking points, then do so, but try not to go over four or five minutes in your presentation. You will have an opportunity to elaborate on some of your talking points during the question and answer period after your presentation.

Question and Answers

Following your presentation, the judges[149] will usually have two or three questions to help them evaluate your project according to the ranking criteria for the science fair. Anticipate these questions to be based on your presentation and get prepared in advance. Usually the number of questions depends on the amount of time the judges have, considering the number of students they need to interview, and the complexity of your project and its presentation. Sample interview questions have been listed in Appendix G.

Be prepared for differences in judging styles. Some judges will appear to misunderstand something about your project or presentation as part of a technique to test your knowledge and skills at communication. Other judges will seem to know a lot about your topic and ask very specific questions about a technical term or procedure that you used in your

presentation, visual display, or research report. Creativity is difficult for judges to ask questions about, but you may get open ended questions asking why you developed this particular method of investigation or experiment, or how do you think your work can be used by others. **Carefully listen to the question being asked and design your answer to respond to what the person asking the question wants to know, rather than what you want to tell them.** Give the judges as much information as possible within the time limits that you think they may have. Be enthusiastic and proud of your project! Interviews can be fun, and you might even learn something about your project that you did not know before, or get a new idea of how to take the project further.[150]

First Impressions

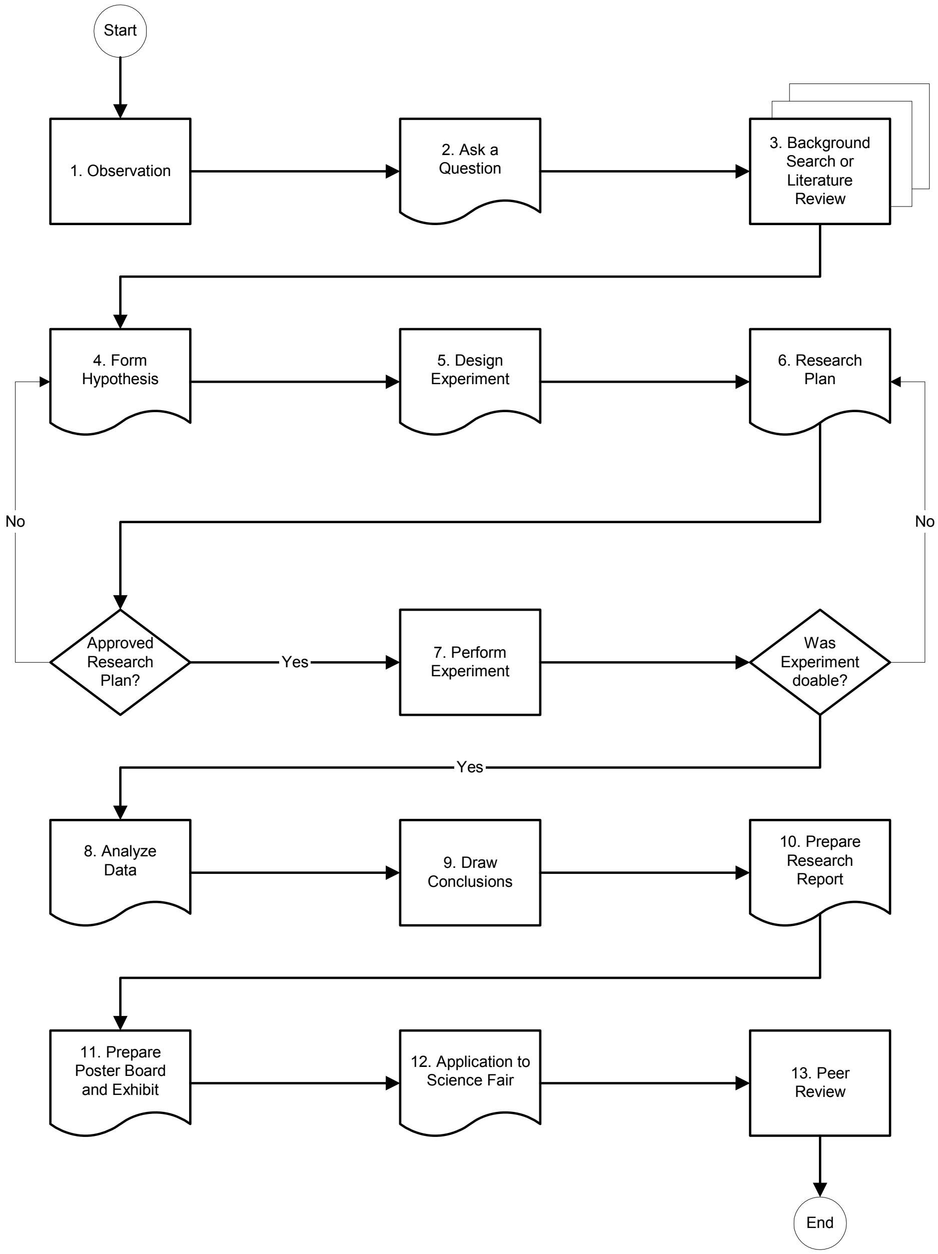
You can decide on how best to dress for a class presentation, but for the science fair, it is wise to make a special effort to make a good impression. You are representing your work. In effect, you are acting as a salesperson for your project, and you want to present the very best image possible. **Your appearance shows how much pride you have in yourself and that is the first step in introducing your product, which for you is your science fair project.**[151]

Appendices

Index

Appendix A: Scientific Method

Example – Work flow diagram of the steps performed in a typical inquiry project submitted to the WSSEF.



Numerous people have defined the Scientific Method in various ways. The following steps in the list below are just one of many ways taken from several sources, but it can help you produce a good inquiry based scientific experiment:

1. **Observation and description of a phenomenon or a group of related phenomena** - When an investigator has little prior information, the first step is often description. This is the stage when qualitative methods may provide considerable information about the world.[152] **Keep a journal and write entries about the phenomena that you are investigating.** Observe the world around you and look for cause and effect relationships. Consider those relationships and ask yourself, is there a cause and effect that you can perceive? Explore with all of your senses, not just your eyes. Listen, feel, smell, and taste your world and then explore with your mind by asking yourself why this cause consistently leads to the effect you sense. Think about phenomena and relationships between things you find in your environment, your school textbooks, news media, and the people around you. When you find phenomena of interest to you, and you want to know or understand the cause and effect relationship better, move onto the next step.

2. **Ask a question about the phenomenon** - You should be curious, choose a limited subject, identify, and originate/define a problem. It is important that this question be a 'testable' question. A testable question is one in which one or more variables can be identified and tested (by the collection of data in an experimental procedure) to see the impact of that variable on the original set of conditions. The question should not merely be an 'information' question where the answer is obtainable through literature review.[153] Write your question down so that you can refer to it during each of the following steps.

3. **Background search or literature review** - Review published materials related to your phenomenon with a focus on what others have said or done about your problem/question. This stage is often called background search or literature review.[154] At least five separate sources of information should be researched/reviewed and you will need to prepare a bibliography listing all of the sources of information that are relevant to the formation of your question. Most projects include more than the required five cited sources.

4. **Formulation of a hypothesis to explain the phenomena** - Evaluate possible solutions/answers to the problem/question and write down why you think your solution/answer could be valid. The hypothesis may be one that merely asks whether a relationship exists (co-relational research), or the hypothesis may state a cause-and-effect relationship. Speculate about which variables might be related to other variables and in what manner (directly or indirectly).[155]

5. **Experimental design (procedure and materials)** - In designing an experiment to test your hypothesis, it is critical that only one variable – a condition that may affect the results of the experiment – is changed at a time.

This makes the experiment a 'controlled' experiment.[156] The variable that is deliberately changed is called the independent (manipulated) variable. The other measurable variable(s) that are predicted to change as a result of changing the manipulated variable are called the dependent (responding) variable(s).

Write down the procedure and all the materials you plan to use in the experiment so that others can duplicate your process and verify your results. Include a description of the procedures and methods you will use to analyze the data (values of the dependent and independent variables) you obtain from your experiment to answer the question and support, or not support, your hypothesis. A competitive advantage can be gained by designing more than one experiment to test the hypothesis. Conducting more than one experiment in a rigorous manner can significantly increase the amount of time spent, but the results often demonstrate significant depth in investigating the question being considered.

6. **Write a Research Plan** – All Research Plans contain the question that you developed in step 2 above, the Hypothesis you developed in step 4 above, and a description in detail of the procedures you developed in step 5 above. Your Research Plan must also include the bibliography that you developed in step 3 above.

7. **Perform the experiment** – Conduct your experiment and collect data according to the procedures and methods indicated in your Research Plan. A general rule to follow is to collect as much data as is reasonably possible. Large amounts of data reduce the potential for error, and increase the potential for the data's ability to be a valid test of the hypothesis.[157]

> **WSSEF** is very concerned that students perform their experiments in a safe manner by adhering to the ISEF guidelines and any State or Local Regulations. Each student entering a science fair project at WSSEF must prepare a Research Plan in accordance with the ISEF rules and regulations found on the documents page of the ISEF website, and have it pre-approved prior to the start of an experiment by an Adult Sponsor.
>
> Some special projects require additional information to be submitted for approval with the Research Plan to a Scientific Review Committee (SRC) or Institutional Review Board (IRB) if the project involves human subjects, vertebrate animals, potentially hazardous biological agents, hazardous chemicals, hazardous activities, or hazardous devices. The WSSEF SRC will review and approve any special projects, prior to experimentation. Please send an email to the WSSEF SRC for assistance.

If for any reason you are unable to perform the experiment substantially as listed in your Research Plan, modify your experimental design and the corresponding procedures in your research plan, and resubmit it to your Adult Sponsor for approval before proceeding with your experiment. For special projects resubmit your Research Plan to the SRC or IRB if modifications are made to your experimental design.

Data collected under experimental conditions may verify a hypothesis or not. If the predictions stemming from a hypothesis are not verified by repeated experimental tests, the hypothesis has to be ruled out, accepted in part, or modified. No matter how elegant a theory or hypothesis may be its predictions must agree with experimental data before it can be considered a valid description of the world. If experiments by independent investigators replicate the results, then the hypothesis may be regarded as a theory. Keep in mind that theories and hypotheses can never be proved, only disproved, for it is impossible to experiment on everything across all time and space to provide all possible replications. The next experimenter may disprove a widely accepted theory.[158]

8. **Analyze the data** – In order to look for any trends, your results should be organized in data tables. Computer spreadsheet programs are useful because the program can graph your data from the spreadsheet. Analysis of data involves finding trends or relationships between the numerical values of the data collected. The methods of analysis should include appropriate consideration for possible sources of error(s) in the data and recognition that some data might have errors that are so significant that they should be dismissed from consideration of trends or relationships. Statistical methods are often used to analyze data. The more sophisticated the problem is the more sophisticated the statistical analysis.

9. **Draw Conclusions** – A conclusion briefly summarizes you project, accepts or rejects your hypothesis, then interprets the meaning of your project. At the end of a conclusion, you should discuss any potential applications of your project, and indicate any next steps that you suggest to further the research.[159]

10. **Prepare a Research Report** - Your report will provide interested readers with a comprehensive look at your topic and research project. Your research report should include information collected during the research as well as a complete description of your experiment, data, and conclusion.[160]

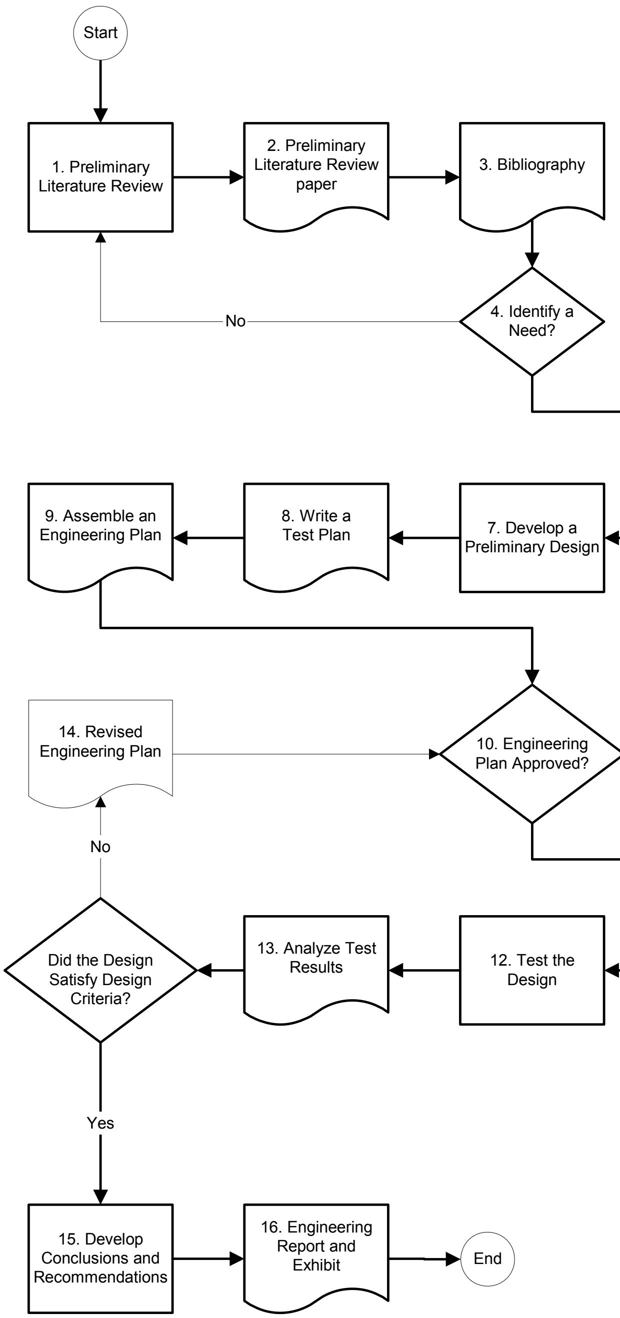
11. **Prepare a Poster Board and Exhibit** - The visual display on the board is meant to attract attention and provide information. Your visual display should challenge onlookers to want to know more about your project. Photographs, graphics, and tables, along with the written text should be included. Also included as part of your exhibit are your research report, journal, any forms required for participation in the fair, and literature review if bound separately from your research report. A well-thought-out and interesting title can also attract attention.[161]

12. **Apply to the Science Fair –** At WSSEF, projects are registered as either individual or team projects. At a minimum, four entry forms are required to be submitted. All projects require approval by an Adult Sponsor prior to start of an experiment, and Special Projects may require approval by the WSSEF Scientific Review Committee prior to experimenting. Special Projects are those, which for safety considerations require additional forms submitted at the time of registration. Registration[162] can take place online. All forms can be printed out in Adobe® Reader® format and copies along with an entry fee are required to be turned in by mail not later than the date on the WSSEF website[163].

13. **Peer Review at the Science Fair** - Formal judging sessions are scheduled at the Science Fair. In addition to being evaluated for awards at the science fair, this is your opportunity to discuss your project and its findings with peer group/professional scientists. New question(s) may arise from your discussions, which can lead to more research that extends your project further.

Appendix B: Engineering Projects

Example – Work flow diagram of the steps performed in a typical Engineering Project



Explanation of the steps indicated in the previous example of a typical Engineering Project.

1. Perform a Preliminary Background Search or Literature Review of all information that you can find about your topic.
2. Write a Preliminary Literature Review paper about your research efforts. Be specific about what you learned. Include references to any codes or standards used to establish performance criteria or procedures. Organize it to identify a need, provide a basis for justification, or the purpose for your Engineering Project from the literature that you reviewed.
3. You are required to have at least five separate sources of information (e.g., science or engineering journal articles, books, internet sites, interviews, etc.). At the end of your Preliminary Literature Review paper, include a bibliography listing of the sources you used.
4. Identify a need by answering the question "What have you found from your literature review that is needed, and has not yet been developed?"
5. Develop a Design Criteria from your literature review by asking yourself "What kinds of performance levels or goals might reasonably be expected if the need was satisfied?" Answer this question with both qualitative and quantitative evaluations. The evaluation of qualitative and quantitative factors is discussed in the section Types of Data on page 14.
6. Write down the Design Criteria that defines what factors need to be considered when developing a solution that satisfies the need that you have identified. In your Design Criteria, list qualitative factors separately from quantitative factors.
7. Describe a preliminary design or prototype that might satisfy the Design Criteria. Include in your description of the preliminary design any physical or mathematical model(s) that maybe necessary to show how to build your prototype. Drawings with dimensions are often used to describe your design. Include any mathematical modeling that might be necessary to determine how you developed your preliminary design.
8. Develop a Test Plan for your preliminary design that demonstrates how it will satisfy the levels of performance or goals of the Design Criteria. The Test Plan is usually a written listing of a test procedure similar to the procedure used for scientific inquiry in experimental design.
9. Prepare a written Engineering Plan that presents the description of your preliminary design, the Design Criteria including levels of performance or goals and the Test Plan of how you expect to confirm that your preliminary design meets the Design Criteria. An Engineering Plan is similar to a Research Plan in inquiry based scientific projects.
10. If entering your engineering project in the WSSEF, you must first obtain approval from an Adult Sponsor. Present your Engineering Plan as a Research Plan attached to a Student Checklist (ISEF Form 1A) for approval.

This step is necessary to make sure that your project is safe and does not violate any laws or rules of the organizations that regulate science fair projects.

11. Build your preliminary design. If for some reason, you need to change your preliminary design in a substantial way to get it built (i.e. unavailability or excessive cost of specific materials or services), make sure you go back to step 10 above, to get your changes approved.
12. Test your current design according to your Test Plan. Test your model often and collect as much data as you can of the type that was listed in your Design Criteria that you were able to quantify or qualify.
13. Examine your test results and look for uncertainties, inconsistencies, and errors. Variations in test results from your Design Criteria may be either systematic (something about your design that regularly produces the variation) or random (some factor that was not considered is affecting the test results in a random or irregular way). Write an analysis of your test findings to rationalize if the variances were large enough to negate or modify your current design or not.
14. If your analysis concludes that your prototype or current design did not satisfy the goals or performance levels you established in your design criteria, then:
    - 14.1. redesign your current design, or change your performance goals in the Design Criteria to something that your current design and test results suggests maybe more realistic
    - 14.2. revise the Engineering Plan that you developed in step 9,
    - 14.3. obtain approvals of your changes similar to step 10,
    - 14.4. if you redesigned your current design then build your new design similar to step 11,
    - 14.5. retest your new design similar to step 12,
    - 14.6. reanalyze your new test results similar to step 13, and repeat step 14 until you meet the Design Criteria
15. When your designs satisfies the design criteria, write a Conclusion that summarizes your final test results and makes any recommendations for improvements or future extensions of your design to other applications.
16. Write a final Engineering Report from your Engineering Plan that presents and describes the results of your literature review, ending with the need that you identified in an Introduction section. Include sections in your final Engineering Report on your final Design, Design Criteria, Test Plan, Analysis of Test Results, Conclusions, and Recommendations. Prepare a poster exhibit to summarize the information in your Engineering Report.

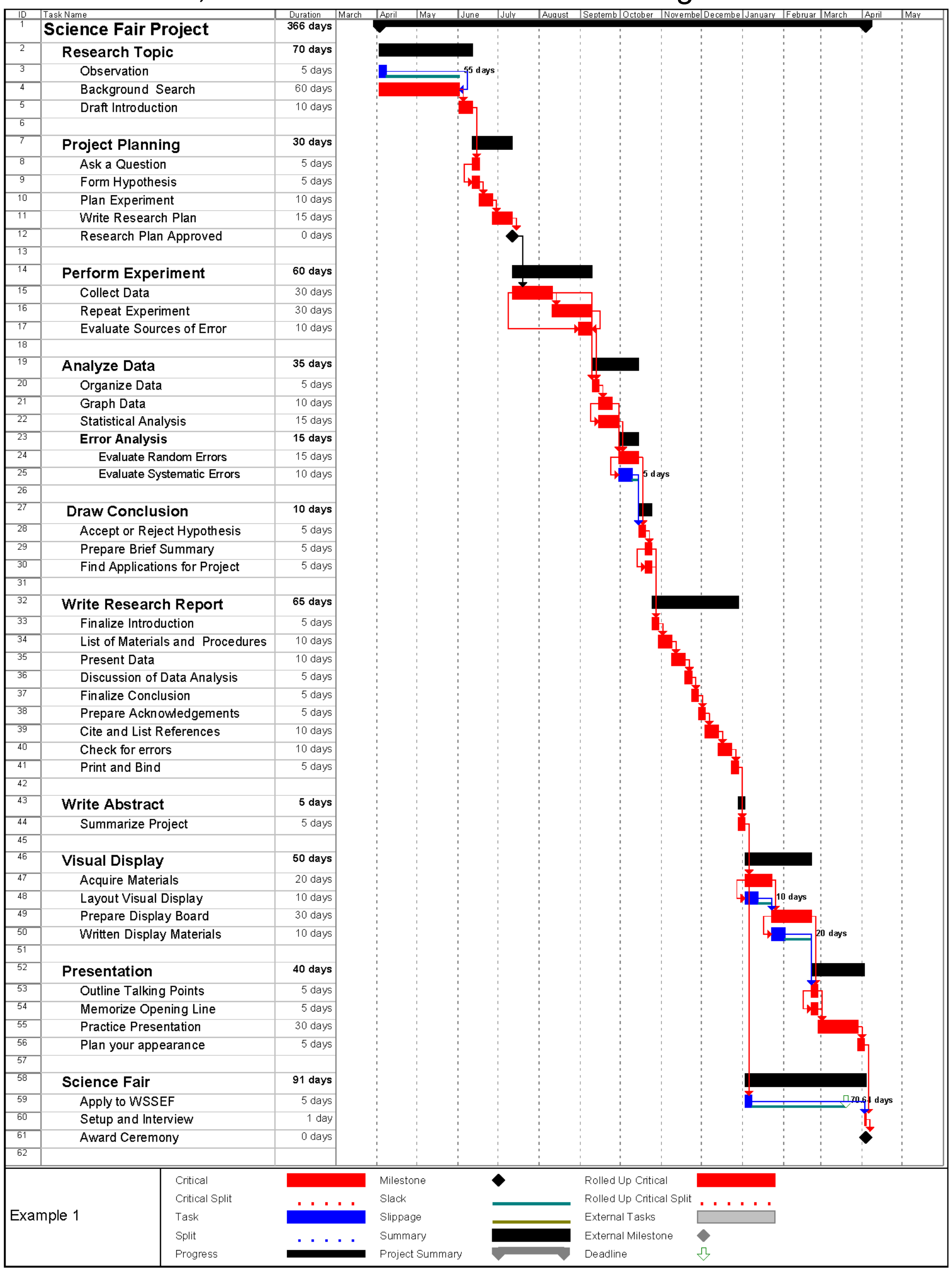
Engineering Report - Consider using the following format for your engineering report.

1. Title Page
2. Abstract or Summary Page
3. Introduction - Background from reading about similar devices or systems, how they work, their history etc.
4. Statement of Purpose - What was the device or system designed to do?
5. Materials and Test Plan
6. Describe the structure and parts. How does the device, or system work?
7. Include a detailed schematic or algorithm.
8. Give measurable characteristics of the device or system (for example dimensions, weight, power supply, voltage generated, and software and hardware requirements).
9. Test Data or Results - How did you test your device or system?
10. Discussion and analysis of the Test Data

Appendix C: Schedules

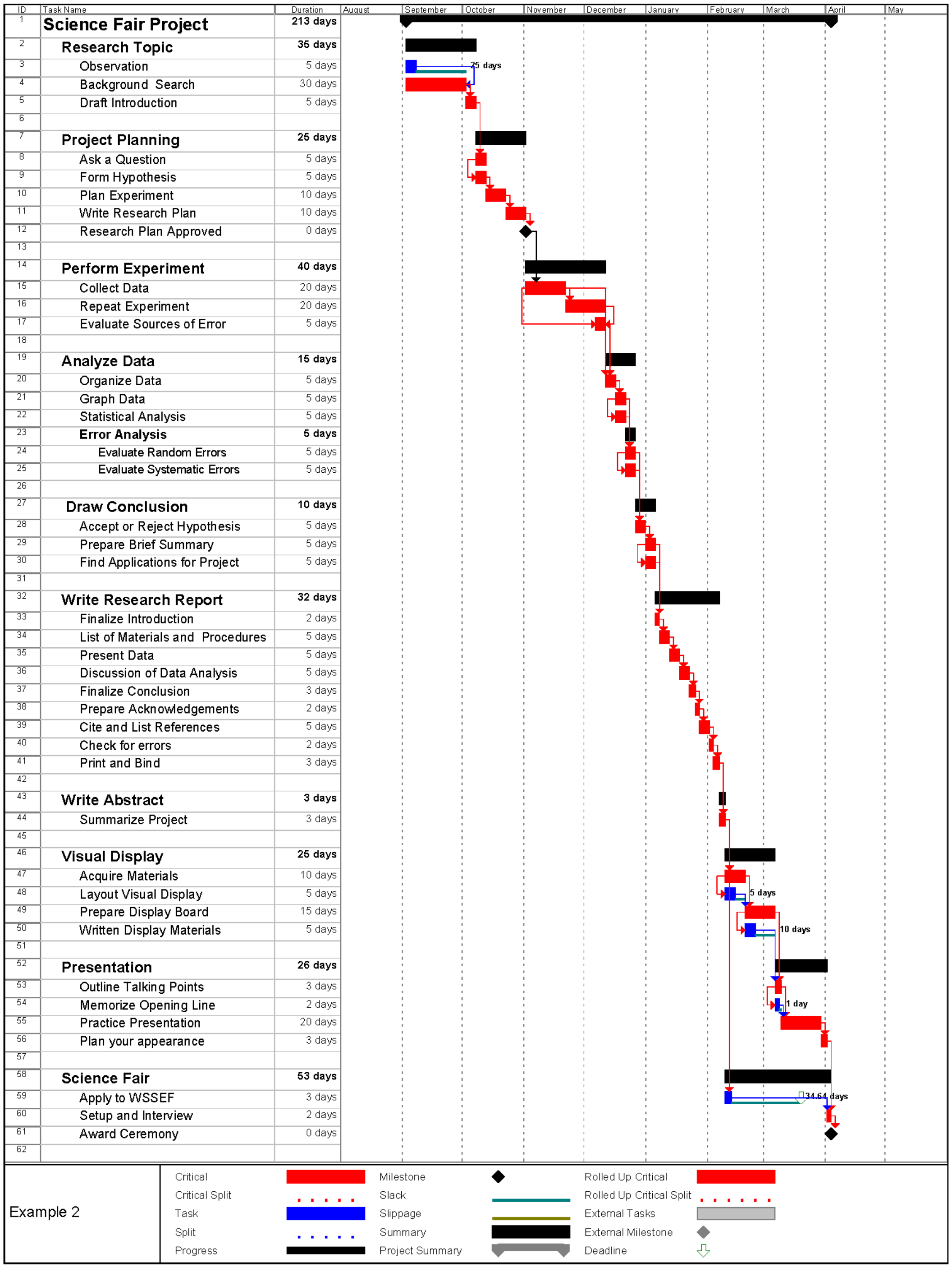
Major Time Commitment

In Example 1 below of a major time commitment schedule, the black bars are the subprojects discussed in Time Commitments and Schedules. The critical tasks are shown with red bars and those tasks that have slack time shown with blue bars. The blue bars have their slack time quantified in days on the right. Arrows that start at a preceding task and point to a succeeding task indicate task interdependencies. In general, a preceding task needs to be completed before a succeeding task can either start, if the arrowhead is shown on the left or finish, if the arrowhead is shown on the right.



Common Time Commitment

Example 2, below the schedule is more commonly constrained to the start of the school year. That constraint of 213 calendar days of available time reduces the amount of time available for each of the subprojects and their tasks. This schedule, like all schedules made prior to performing work, is a planning tool and represents one way to be successful at preparing a science fair project. Your actual schedule may be very different from the one shown on this Gantt chart, but it is included here only to demonstrate how to schedule your time.



ID	Task Name	Duration
1	**Science Fair Project**	213 days
2	**Research Topic**	35 days
3	Observation	5 days
4	Background Search	30 days
5	Draft Introduction	5 days
6		
7	**Project Planning**	25 days
8	Ask a Question	5 days
9	Form Hypothesis	5 days
10	Plan Experiment	10 days
11	Write Research Plan	10 days
12	Research Plan Approved	0 days
13		
14	**Perform Experiment**	40 days
15	Collect Data	20 days
16	Repeat Experiment	20 days
17	Evaluate Sources of Error	5 days
18		
19	**Analyze Data**	15 days
20	Organize Data	5 days
21	Graph Data	5 days
22	Statistical Analysis	5 days
23	**Error Analysis**	5 days
24	Evaluate Random Errors	5 days
25	Evaluate Systematic Errors	5 days
26		
27	**Draw Conclusion**	10 days
28	Accept or Reject Hypothesis	5 days
29	Prepare Brief Summary	5 days
30	Find Applications for Project	5 days
31		
32	**Write Research Report**	32 days
33	Finalize Introduction	2 days
34	List of Materials and Procedures	5 days
35	Present Data	5 days
36	Discussion of Data Analysis	5 days
37	Finalize Conclusion	3 days
38	Prepare Acknowledgements	2 days
39	Cite and List References	5 days
40	Check for errors	2 days
41	Print and Bind	3 days
42		
43	**Write Abstract**	3 days
44	Summarize Project	3 days
45		
46	**Visual Display**	25 days
47	Acquire Materials	10 days
48	Layout Visual Display	5 days
49	Prepare Display Board	15 days
50	Written Display Materials	5 days
51		
52	**Presentation**	26 days
53	Outline Talking Points	3 days
54	Memorize Opening Line	2 days
55	Practice Presentation	20 days
56	Plan your appearance	3 days
57		
58	**Science Fair**	53 days
59	Apply to WSSEF	3 days
60	Setup and Interview	2 days
61	Award Ceremony	0 days
62		

Appendix D: Bibliography

Your reference list should include any documentation that is not your own (i.e. books, journals articles, websites, etc.).[164] Citations and references tell the person reading your plan or report where specific information came from, adding credibility by showing that you consulted others that may be considered experts in the topic. Portions of your plan or report that are not cited and referenced are considered your word, and you should be prepared to defend them.

Reference Styles:

Three common reference styles are:[165]

APA (American Psychological Association) **Style**[166] This organization provides manuals and software that interfaces with various word processing programs to help you write citations and references in APA Style.

The Owl APA Formatting and Style Guide[167] This resource, revised according to the fifth edition of the APA manual, offers examples for the general format of APA research papers, in-text citations, endnotes/footnotes, and the reference page.

MLA (Modern Language Association) **Style**[168] This organization provides a handbook for writers of research papers and style manual and guide to scholarly publishing.

The Owl MLA Formatting and Style Guide[169] This resource, updated to reflect the MLA Handbook for Writers of Research Papers (6th ed.) and the MLA Style Manual and Guide to Scholarly Publishing (2nd ed.), offers examples for the general format of MLA research papers, in-text citations, endnotes/footnotes, and the Works Cited page.

Chicago Manual of Style[170] The Chicago Manual of Style presents two basic documentation systems. Those in the physical, natural, and social sciences have long used the more concise author-date system. In this system, sources are briefly cited in the text, usually in parentheses, by author's last name and date of publication. The short citations are amplified in a list of references, where full bibliographic information is provided.

A link on the home page to a Quick Guide[171] is offered, which provides examples of citations and references in the Chicago-Style.

Citations and References:

Generally documenting your sources involves two steps. The first is a citation that is located in the body of your text, and a corresponding reference at the end of the section, plan, or report.

Three general methods are used, and you should select the one method that is typically used by those submitting articles or research papers to professional journals on the topic of your research. The three general methods of documenting include **name-and-year**, **alphabet-number**, or **citation-order** systems.

In the **name-and-year** system, the citation can be included in a sentence or in brackets or parenthesis at the end of a sentence.

Citation: 1.) The theories and tests results by Royles (1966) predict moment-curvature relations and low-endurance flexural fatigue of beans having a square cross section. *2.)* The theories and tests results predict moment-curvature relations and low-endurance flexural fatigue of beans having a square cross section (Royles 1966).

Reference: Royles, R., 1966, "Mild Steel Beans under Low Cycle Fatigue Conditions," *Proc. Internatl. Symp. Effects of Repeated Loading of Materials and Structures*, RILEM-Inst. Ing., 4.

In the **alphabet-number** system, you give a number in parentheses that corresponds to the number of the source in the alphabetical listing in the references.

Citation: 1.) The theories and tests results (28) predict moment-curvature relations and low-endurance flexural fatigue of beans having a square cross section. *2.)* The theories and tests results predict moment-curvature relations and low-endurance flexural fatigue of beans having a square cross section. (28)

Reference: 28. Royles, R., 1966, "Mild Steel Beans under Low Cycle Fatigue Conditions," *Proc. Internatl. Symp. Effects of Repeated Loading of Materials and Structures*, RILEM-Inst. Ing., 4.

In the **citation-order** system, you cite the sources in the report with a number in brackets that corresponds to the number of the source listed in the references in the order in which they appear in the report. This Student Manual is an example of the **citations-order** system with the references listed in Appendix H at the end.

Appendix E: Random Errors of Measurement

Example

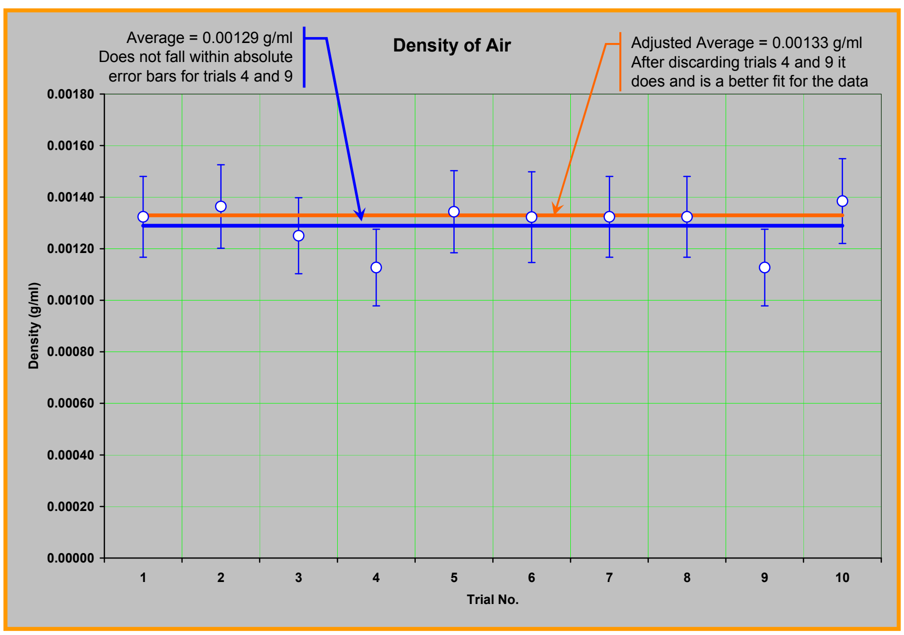
The following is a spreadsheet example of how to use random errors of measurement in an experiment to determine the density of air in a bottle. The row across the top indicates the source of the entry in each column. The second row indicates the label and units of the items listed in the column. The third row is a letter identifier and in the case of calculated data an arithmetic expression of how the data in that column was calculated from the data in other columns.

	Measured Data	Assigned Error	Measured Data	Assigned Error	**Calculated Data**	Calculated Error	Calculated Error
Trial	Bottles Mass w/ air (g)	Absolute Error (±g)	Bottles Mass w/o air (g)	Absolute Error (±g)	**Mass of air (g)**	Absolute Error (±g)	Fractional Error (±%)
No.	A	B	C	D	**E=A-B**	F=B+D	G=F/E
1	111.3	0.05	110.4	0.05	**0.9**	0.1	11.1%
2	110.3	0.05	109.4	0.05	**0.9**	0.1	11.1%
3	112.1	0.05	111.2	0.05	**0.9**	0.1	11.1%
4	109.3	0.05	108.5	0.05	**0.8**	0.1	12.5%
5	114.1	0.05	113.2	0.05	**0.9**	0.1	11.1%
6	110.1	0.05	109.3	0.05	**0.8**	0.1	12.5%
7	122.3	0.05	121.4	0.05	**0.9**	0.1	11.1%
8	110.8	0.05	109.9	0.05	**0.9**	0.1	11.1%
9	107.3	0.05	106.5	0.05	**0.8**	0.1	12.5%
10	110.8	0.05	109.9	0.05	**0.9**	0.1	11.1%

The measured values are listed in columns A and C with their corresponding absolute errors in columns B and D. The calculated data in column E includes a subtraction operation, yielding only one significant digit. Column F indicates the calculated absolute error for column E, and column G contains the calculated fractional error for column E. Notice the increase in absolute error from the measured values to the calculated values, and if the calculated value is small, that increase can result in a large fractional error. Also, note that the number of significant digits in the calculated data dropped from four in the measured data to only one in the calculated data because the operation was addition/subtraction.

	Measured Data	Assigned Error	Calculated Error	**Calculated Data**	Calculated Error	Calculated Error	Is the Average within Range?
Trial	**Volume (ml)**	Absolute Error (±ml)	Fractional Error (±%)	**Density (g/ml)**	Fractional Error (±%)	Absolute Error (±ml/g)	
No.	**H**	J	K=J/H	**L=E/H**	M=G+K	N=L*M	Yes/No
1	**680**	5	0.7%	**0.00132**	11.8%	0.00016	Yes
2	**660**	5	0.8%	**0.00136**	11.9%	0.00016	Yes
3	**720**	5	0.7%	**0.00125**	11.8%	0.00015	Yes
4	**710**	5	0.7%	**0.00113**	13.2%	0.00015	No
5	**670**	5	0.7%	**0.00134**	11.9%	0.00016	Yes
6	**605**	5	0.8%	**0.00132**	13.3%	0.00018	Yes
7	**680**	5	0.7%	**0.00132**	11.8%	0.00016	Yes
8	**680**	5	0.7%	**0.00132**	11.8%	0.00016	Yes
9	**710**	5	0.7%	**0.00113**	13.2%	0.00015	No
10	**650**	5	0.8%	**0.00138**	11.9%	0.00016	Yes
			Average =	0.00129	for all 10 trials		
			Adjusted Average =	**0.00133**	**for 8 of 10 trials (w/o #s 4 & 9)**		

The measured value in column H is large, and as a result, the calculated fractional error in column K is small. The calculated values in column L are reported to three significant digits because of the two numbers being multiplied the largest had three significant digits. The fractional error in column M is being driven by the large fractional error in column G, but the small absolute errors in column N justify the use of three digits in column L. The number of significant digits in column L is limited by addition/subtraction in determining the range of the calculated densities. The column on the far right tests to see if the average that was calculated from all ten trials falls within the range of measurement absolute error for each trial as demonstrated in the graph below. The average does not satisfy this test for trials 4 and 9, and the average is adjusted to discard them.



Once the trials are evaluated in this way, the researcher must go back and look for potential problems in the measurements of trials 4 and 9. If no systematic or random errors can be found, then these two trials are thrown out for random errors of measurement and the data analysis proceeds with the central tendency indicated by the adjusted average.

Appendix F: Statistical Analysis

Measures of Central Tendency

The statistics listed below are used as a measurement of the central tendency in a data set. Most scientific calculators will calculate these statistics for you.

- ☐ Mode - the most common data point
- ☐ Median - the middle data point
- ☐ Mean or average [172]

The mode is defined as the value of a variable at which a relative or absolute maximum occurs in the frequency distribution. In the table at the right, the two columns on the right are frequency distributions, and the mode is the value of the number listed in the first column that corresponds to the maximum in one of the two columns on the right. More than one mode may exist, but it is always equal to one of the variables in the list.

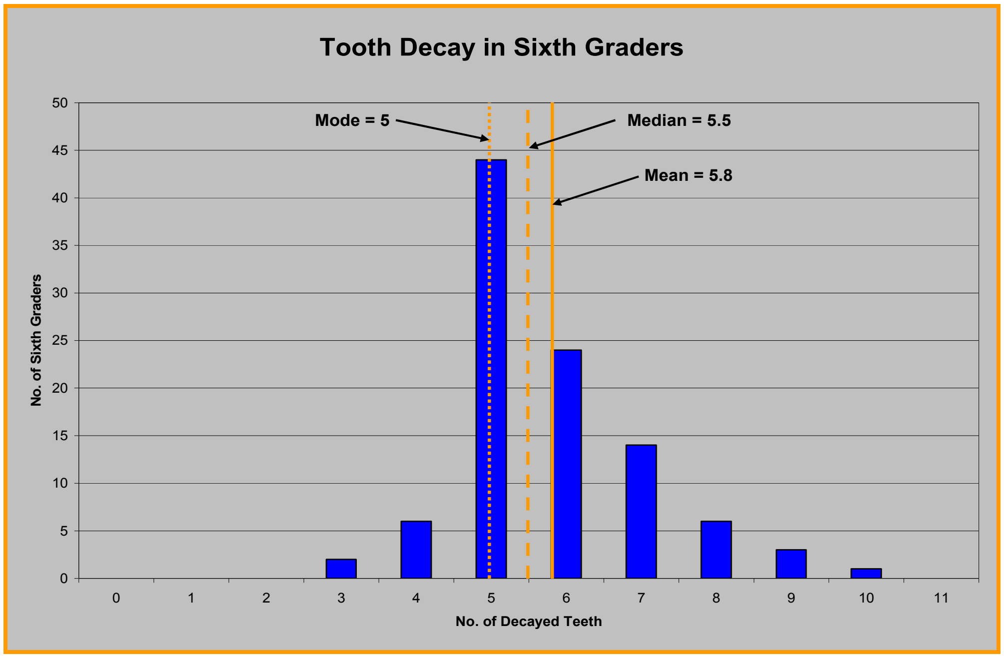
	No. of decayed teeth		No. of sixth graders	Total No. of Decayed Teeth
	0		0	0
	1		0	0
	2		0	0
	3		2	6
	4		6	24
Mode=	5		44	220
	6		24	144
	7		14	98
	8		6	48
	9		3	27
	10		1	10
	11		0	0
Totals=	12		100	577
Median=	5.5	Mean or Average=		5.8

Note: This data was fabricated for example purposes only.

The median is the middle of an ordered (i.e. smallest to largest) list of variables. Since there are 12 numbers from zero to 11, the median is the average of the middle two numbers (5 and 6) or 5.5. It is always the case when a list has an even number of variables that the median is in between the variables in the list. If the number of variables is odd, then the median will always be the one variable that is in the middle of the list.

The most common of the three measures of the central tendency is the arithmetic mean or average. The sample average ($\bar{x}$) is obtained by totaling or summing (Σ) up all the data (i.e. $x_1+x_2+x_3+ \ldots +x_n$) and dividing that sum by their number (n). The arithmetic mean or average is defined symbolically as:

$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$ In the table above $\bar{x} = \frac{577}{100}$ or an average of 5.8 cavities per sixth grader



The arithmetic mean or average also lends itself much more readily to further statistical analysis. For this reason, most statistical studies of data collected in scientific research report the arithmetic mean as the average. However, the arithmetic mean has the disadvantage of being more affected by extreme values in the data set being analyzed. Whenever there are extremely high variations or extremely low variations, the median or the mode may be preferred over the arithmetic mean as a measure of central tendency.[173]

Measures of Variation

In addition to central tendency, the variability of data from the central tendency is also an important parameter of a set of data. If a set of data consisted of all one number, then the average would be that one number and the data would not vary from, or have a measure of variation of zero. In scientific research, data seldom consists of all one number, and two measures of variation become important when comparing one set of data with another.[174]

The first is range, and is simply the difference between the highest and lowest number in the set of data. This measure of variability is limited because it says nothing about all the numbers between the highest and lowest.[175]

A more important measure of variation is the standard deviation, which is noted by the lower case Greek letter sigma (σ). The standard deviation measures the average deviation of each piece of data from the mean (μ) and is calculated as the square root of the average square deviation of each piece of data from the arithmetic mean. Standard deviation is useful because it has the same units as the mean, and is more intuitive than some other measures of variation.[176]

The standard deviation is defined symbolically as: $\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n}}$

Another measure of variation is variance. Variance is the square of the standard deviation and the units of the mean squared. This measure of variation is useful because it is sensitive to small variations, but its units are less intuitive than the standard deviation.[177]

The variance is defined symbolically as σ^2

Note: In general Greek letters are used in this handbook to represent statistical parameters for entire populations, while alphabetic letters are used to represent statistical parameters for sample populations that are subsets of larger populations.

Hypothesis Testing

In the last example, the researcher ended up with eight samples of air to calculate its density and calculated a statistical average density for that sample of, $\bar{x} = 0.00133 g/ml$. The size of each sample ranged from 650 ml to 720 ml. That amount of air represents a very small portion of all the air in the world at sea level that is available to test. The student researcher recognizes the fact that it is very impractical if not impossible to test all of the available air. How can the researcher be assured that this statistical average is accurate, or at least close to the "true value" or accepted value for the density of air if many more or much larger samples were taken that included a larger portion of the air that is available to test?

One answer that has been developed and accepted is a more sophisticated statistical process called hypothesis testing. In this process, the researcher often states the question or its inverse as a null hypothesis.[178]

The null hypothesis for the previous example is that the researcher's average density is equal to an accepted average density, or is at least close enough to be within an accepted level of confidence to be considered of the same value. The assumption is that many other researchers have tested for the density of air and have agreed upon a central value that includes the results of those many other experiments. Looking through standards for the density of air, this student researcher found that a value of $\mu = 0.00129 g/ml$ is an accepted average for the density of air at 20° C and at sea level.[179] The null hypothesis is formed that says in symbolic form If $\bar{x} = 0.00133 g/ml$ and $\mu = 0.00129 g/ml$, then the null hypothesis is $H_0 : \mu = \bar{x}$. In other words, there is no statistical difference between the results of the student's research and the accepted average of all those other researchers.[180]

The outcome of this hypothesis test is to accept or reject H_o based on the potential for error or chance in the data collected. The method involves selecting a probability distribution and evaluating the probability that the difference between the student's average density from the eight samples and the accepted average density is within reasonable confidence intervals.

If the number of samples was large (i.e. greater than about 30) then it would be reasonable to use a normal distribution when calculating the density of air from samples. If the number of samples was small (i.e. less than about 20) then the t-distribution or Student's t-distribution should be used as a probability function that is symmetrical about its average, μ. As the sample size increases from 20, the t-distribution assumes the shape of the normal distribution. In the case of the previous example, the sample size is eight and a t-distribution is required.[181]

To use the t-distribution the student must have a value for the sample average ($\bar{x}$), the accepted population average value (μ), the sample size (n), the degrees of freedom which is $n-1$, and the sample standard deviation (s).[182]

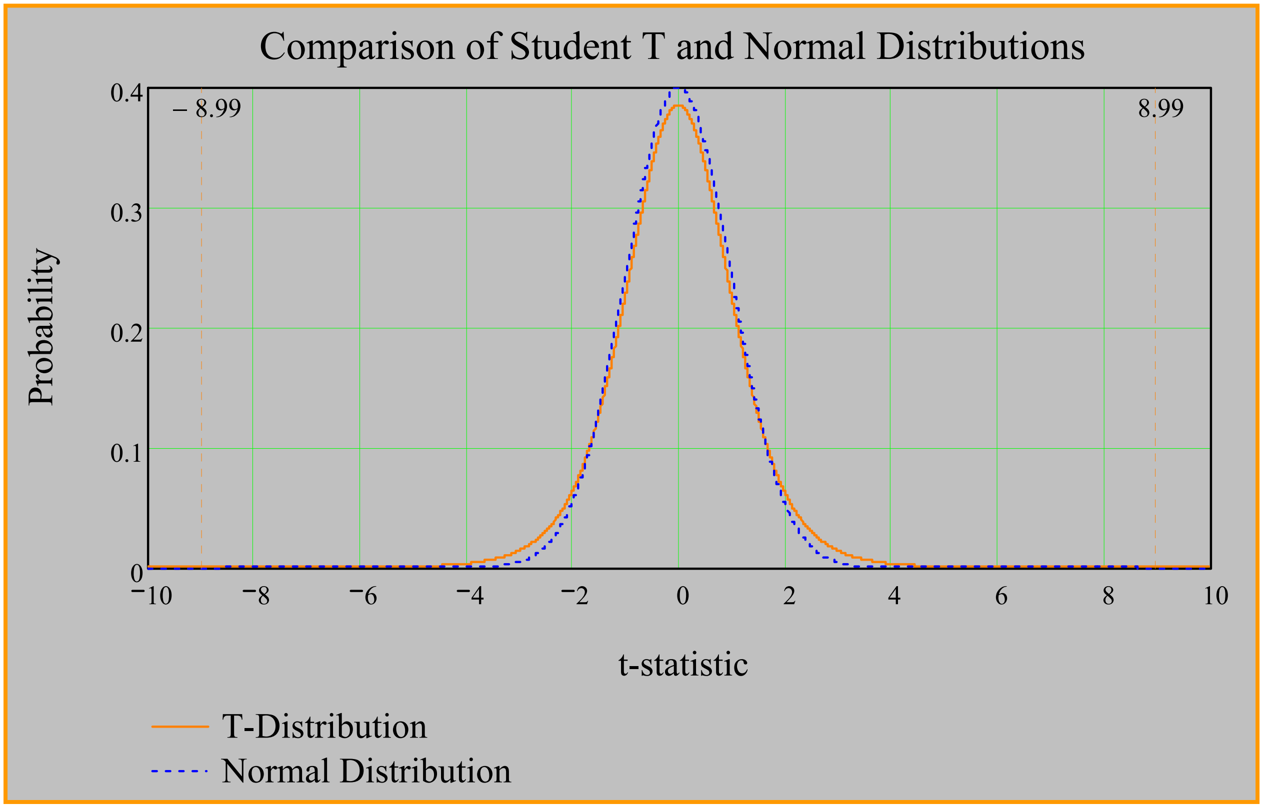
The standard deviation of a sample is similar, but not the same as the standard deviation for an entire populations, (σ).

The standard deviation for a sample is defined as $s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$,[183] or $s = 0.0000394$ for the previous example.

Calculating the t-statistic or t-score from $t = \frac{\bar{x} - \mu}{\frac{s}{\sqrt{n}}}$,[184] $t = \pm 8.99$

At this point, it is best to use one of several aids that are available for calculating the probability as the area under the t-distribution function. You can use the Federal Government standards by following the link to the Engineering Statistics Handbook 1.3.6.7.2[185]. You might also try the Stat Trek T Distribution Calculator: Online Statistic Table[186], which calculates the probability of accepting the null hypothesis. The Table of Percentage Points of the T-Distribution near the end of this appendix is also provided if other sources of this information are not available. Enter the body of the table with 7 degrees of freedom and move to the right until you see the number greater than $t = \pm 8.99$. If you come up against the right edge of the table without finding a larger number, then go to the head of the last column, and the probability will be expressed as a fraction for a two-tailed analysis. In this example, the probability of rejecting the null hypothesis is less than 0.001 or less than 0.1% based on the potential for error or chance in the data collected.

Stated another way with more precise calculations using, $t = \pm 8.99$, the probability for accepting the null hypothesis is the area under the solid orange curve in the graph above, and is greater than 99.998%. It would be reasonable to assume that these calculations which are based on the number of accepted trials and their standard deviation, the value for the average density of air in this example should not be rejected based on the potential for error or chance.[187]



The graph above also contains a plot of the normal distribution that the student t-distribution would resolve to if an infinite number of samples were used to calculate the average density of air. This comparison demonstrates the difference between using a few trials and a large number of trials are greater when the t-statistic is less than about four.

PERCENTAGE POINTS OF THE T DISTRIBUTION

Tail Probabilities									
One Tail		0.10	0.05	0.025	0.01	0.005	0.001	0.0005	
Two Tails		0.20	0.10	0.05	0.02	0.01	0.002	0.001	
D	1	3.078	6.314	12.71	31.82	63.66	318.3	637	1
E	2	1.886	2.920	4.303	6.965	9.925	22.330	31.6	2
G	3	1.638	2.353	3.182	4.541	5.841	10.210	12.92	3
R	4	1.533	2.132	2.776	3.747	4.604	7.173	8.610	4
E	5	1.476	2.015	2.571	3.365	4.032	5.893	6.869	5
E	6	1.440	1.943	2.447	3.143	3.707	5.208	5.959	6
S	7	1.415	1.895	2.365	2.998	3.499	4.785	5.408	7
	8	1.397	1.860	2.306	2.896	3.355	4.501	5.041	8
O	9	1.383	1.833	2.262	2.821	3.250	4.297	4.781	9
F	10	1.372	1.812	2.228	2.764	3.169	4.144	4.587	10
	11	1.363	1.796	2.201	2.718	3.106	4.025	4.437	11
F	12	1.356	1.782	2.179	2.681	3.055	3.930	4.318	12
R	13	1.350	1.771	2.160	2.650	3.012	3.852	4.221	13
E	14	1.345	1.761	2.145	2.624	2.977	3.787	4.140	14
E	15	1.341	1.753	2.131	2.602	2.947	3.733	4.073	15
D	16	1.337	1.746	2.120	2.583	2.921	3.686	4.015	16
O	17	1.333	1.740	2.110	2.567	2.898	3.646	3.965	17
M	18	1.330	1.734	2.101	2.552	2.878	3.610	3.922	18
	19	1.328	1.729	2.093	2.539	2.861	3.579	3.883	19
	20	1.325	1.725	2.086	2.528	2.845	3.552	3.850	20
	21	1.323	1.721	2.080	2.518	2.831	3.527	3.819	21
	22	1.321	1.717	2.074	2.508	2.819	3.505	3.792	22
	23	1.319	1.714	2.069	2.500	2.807	3.485	3.768	23
	24	1.318	1.711	2.064	2.492	2.797	3.467	3.745	24
	25	1.316	1.708	2.060	2.485	2.787	3.450	3.725	25
	26	1.315	1.706	2.056	2.479	2.779	3.435	3.707	26
	27	1.314	1.703	2.052	2.473	2.771	3.421	3.690	27
	28	1.313	1.701	2.048	2.467	2.763	3.408	3.674	28
	29	1.311	1.699	2.045	2.462	2.756	3.396	3.659	29
	30	1.310	1.697	2.042	2.457	2.750	3.385	3.646	30
Two Tails		0.20	0.10	0.05	0.02	0.01	0.002	0.001	
One Tail		0.10	0.05	0.025	0.01	0.005	0.001	0.0005	
Tail Probabilities									

This analysis of the previous example is a single variant statistical analysis of the average of data collected. More complex projects have multiple variants and the statistical analysis of their results require the use of a collection of statistical models and their associated procedures. The amount of space in this Student Handbook precludes an explanation of multi-variant statistical analysis. The student is encouraged to consider Fisher's ANOVA or Fisher's analysis of variance. Computer programs are available to assist the student in performing one or more ANOVA test of statistical significance.[188]

An ANOVA test of statistical significance is not required, to enter a project into the science fair. Nor are all of the steps indicated in this analysis of your results section of this handbook necessary. Nevertheless, it is clear from projects entered into previous science fairs in the high school grades that those students wishing to have a competitive edge over other science fair projects have developed the use of these sophisticated statistical evaluations of their data.

Appendix G: Interview Questions

Many science fairs have a judge's handbook, guidelines, or a list of questions for judges to use to evaluate the students against the judging criteria for that science fair. The following questions demonstrate the types of questions a judge might ask students in the interview process.[189]

- How did you come up with the idea for this project?
- What did you learn from your background search?
- How long did it take you to build the apparatus?
- Did you have help in building this apparatus?
- How did you build the apparatus?
- How much time (days, weeks, months) did it take to run the experiments (i.e., grow the plants, collect each data point, record observations, etc.?
- How many times did you run the experiment with each configuration?
- How many experiment runs are presented by each data point on the chart?
- Did you take all data (run the experiment) under the same conditions, e.g., at the same temperature, time of day, lighting conditions?
- How does your apparatus (equipment/instrument) work?
- What do you mean by : _______________(terminology or jargon used by the student)?
- Do you think there is an application in industry for this knowledge (technique)?
- Were there any books that helped you do your analysis (build your apparatus)?
- When did you start this project? Alternatively, how much of the work did you do this year? (Some students bring last year's winning project back, with only a few enhancements.)
- What new questions did your results suggest?
- What is the next experiment to do in continuing this study?
- Are there any areas that we have not covered which you feel are important?
- Do you have any questions for the judges?

Appendix H: References

This handbook used many fine references from the internet to develop its content. The references listed below were available online at the URL indicated on the date listed. Some of these references may become unavailable later, but a search for keywords within the paragraph being cited, should yield these or other references that the student can follow.

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