PREFACE

This booklet is intended as a guide to the student who is preparing a formal scientific research report. It explains how to:

1) plan a lengthy project and use good time management,
2) write a scientific paper,
3) use the scientific method of investigation,
4) analyze scientific data and draw conclusions,
5) choose a topic from a list of possible topics.

As an introduction to scientific writing, a section on abstracts, literature citations and presentation of illustrations is detailed. Examples of the recommended forms are given for the basic type of reference material that are likely to be encountered. Prior knowledge of introductory writing styles and research methods are assumed.

A research paper is a summary of what others have already said or written on a given subject. Therefore, in preparing the research portion of your science project, you will be making use of information that is already known, rather than adding anything new to existing knowledge or opinion. That is where the similarities of research reporting ends with regard to scientific projects. The scientific project will entail not only research of the choosen topic but also a detailed original study of your own pertaining to the subject. Your experiment, investigation, or study of a particular scientific question will be the most important part of the scientific report.

The scientific research report and project will entail the following:

1) a presentation of known facts and information on a choosen topic,
2) an original investigation or experiment presented in scientific format following the scientific method of investigation,
3) an analysis and conclusion of the investigation, as well as, indications for further experimentation,
4) a visual display of the project and experimentation.

TABLE OF CONTENTS

HOW TEACHERS CAN PREPARE THEIR STUDENTS FOR PROJECTS:
GENERAL SCHEDULE

The following outline is for general purposes only. Teachers and students can organize specific time-lines and expectations to fit their own personal schedules.

I. FIRST/SECOND WEEK OF SCHOOL

1) INTRODUCE THE SCIENTIFIC METHOD OF PROBLEM SOLVING:

*METHODICAL STEP-WISE FASHION OF INVESTIGATION.
A detailed discussion of the scientific method is included in a separate section of this booklet. It should be conveyed to the student that the scientific method can and should be "developed" over the length of a project rather than simply followed. Remember, it is a method of investigation and although project topics may change the method itself will always apply.

*PROCESS vs. PRODUCT.
Each year students and teachers alike struggle with the concept of yet another science project! Two of the most fundamental, as well as, important facts about science and science projects are constantly overlooked by both students and teachers. Each year as a science teacher you must remember to explain to students and remind yourself that science is a process. Science is not memorization of facts but a process of discovery. The understanding of scientific questions and the thinking behind experiments is how to "live" science - and it should be the way to teach and learn science too!

The success that is measurable when the science project is complete will not be the first or second place at the fair. The student's improved thinking and organizational skills, computer literacy, research techniques, analytical skills, ingenuity and craftsmanship, and time-management skills are all reflected in the final product. The final product is the conglomeration of skills and learning that the teacher conveyed and the student utilized during the process of investigating a unique scientific question.

*QUANTITATIVE vs. QUALITATIVE OBSERVATIONS
Both types of measurement will be expected with scientific projects emphasizing the quantitative observation. Examples of data charts and graphical representations will be shown in further sections of this booklet.

*ALTERNATIVE HYPOTHESES
Once again, hypotheses will be considered later in a section of "Writing the Scientific Paper" but it is appropriate to note here that writing hypotheses should be taught as a separate lesson. Knowing the how, what and why of hypotheses makes writing one for a science project much easier - it just takes practice. Of course, we know that the hypothesis is an educated guess, or prediction, that attempts to answer a problem. And, remember, the purpose of our experiment is to test the hypothesis to see if it is right. See the upcoming scientific writing sections for the format of writing hypotheses.

2) DISCUSS VARIOUS HYPOTHETICAL SCIENTIFIC DESIGNS:

*CONTROL GROUP, EXPERIMENTAL GROUPS AND THE SINGLE VARIABLE
Most science students are familiar with the single variable idea. The hypothesizing and testing that takes place in experimental science projects entails focusing on possible relationships. Being able to hypothesize allows the student to focus on the specifics of a relationship. It limits the focus to just two things at a time, the **independent** and **dependent** variables. So once hypothesizing comes easily the student will be able to predict what will happen to the dependent variable when the independent variable is manipulated or changed.

*ORAL AND WRITTEN ACTIVITIES...

-TOPIC & CATEGORY "BRAINSTORMING".
Yes, that old inter-connecting circles concept with everything even remotely related to science projects, scientific method and scientific writing included in the brainstorm. This is a great ice-breaker for students and teachers to discuss "real" science and take the edge off the threatening science project assignment. Literally, dozens of circles can be connected including variables, hypotheses, alternative hypotheses, materials, methods and procedures, alternative procedures, data log, observations, research, etc...

-PROJECT OPTIONS.
Most teachers and science students have their favorite science "project". There are several possible approaches to scientific investigation and ideally students should be given their choice. The formal scientific investigation/experimentation of an original design is what is billed as the "science fair" project. This type of project has its predetermined and essential components and may or may not lead to competition, judging and the potential for advancement to county or state science fair contests. Other projects may entail only research and not require actual student experimentation. The lack of experimentation, however, should not necessarily preclude the lack of analytical thinking, problem solving or data presentation found in an experiment. Posters, displays and demonstrations of scientific phenomena are also valuable learning experiences that all science classrooms should develop and exploit.

-HYPOTHETICAL PROBLEM SOLVING.
Make these up. Science is all around us. If you can look at the world through the eyes of a child you can find wonder and then you can devise hypothetical questions about the wonder you see. Have fun!

-"YOU BE THE JUDGE" PROJECT CRITIQUE.
An excellent tool for students to gauge their scientific expertise and eye for design is to critique projects from previous years. Set up a mini-fair in your lab and allow students to judge "anonymous" projects to get a feel for what they can and should be doing. WARNING! Do not allow this to be a "pick a project" and copy it activity. Students should be nearly completed with their own unique science project designs when this activity is chosen.

II. FIFTH/SIXTH WEEK OF SCHOOL:

3) ELEMENTS OF SCIENTIFIC WRITING:

A) REFERENCES:

*EXPERTS FROM COMMUNITY
*CONSUMER REPORTS
*NEWSPAPERS
*ENCYCLOPEDIAS
*SCIENTIFIC JOURNALS/MAGAZINES
*COMPUTER DATABASES
*"IDEA" BOOKS
*BIOLOGICAL CATALOGS
*GO TO THE "SOURCE" WITH SPECIFICS. FOR EXAMPLE, READ THE CARTONS AND LABELS ON ANY CONSUMER GOODS. MOST COMPANIES PROVIDING SERVICES OR PRODUCTS LIST AN 800 TELEPHONE NUMBER FOR MORE INFORMATION.

B) RESEARCH REPORT REQUIREMENTS: A REVIEW OF THE LITERATURE

*MIN./MAX. NUMBER OF PAGES
*MINIMUM NUMBER OF REFERENCES

*LITERATURE CITATIONS/ANNOTATIONS

This information must be outlined for the student prior to beginning a project. Expectations of the final product should be discussed and understood in order for students to accurately gauge their overall committment and establish a good work ethic. Annotation of all references should be a requirement.

C) COMPONENTS OF EXPERIMENTATION REPORT:

*TITLE PAGE
*ABSTACT
*HYPOTHESIS-INTRODUCTION
*MATERIALS & METHODS
*PROCEDURES/EXPERIMENTAL DATA/RESULTS
*DISCUSSION/CONCLUSION

III. THIRTEENTH/FOURTEENTH WEEK OF SCHOOL:

A) DUE DATE FOR PRELIMINARY RESULTS AND REPORT ROUGH DRAFT.

IV. TWENTY FIRST/TWENTY SECOND WEEK OF SCHOOL:

A) DUE DATE FOR FINAL RESULTS/COMPLETED PROJECT & SCIENTIFIC DISPLAY.

How to Write a Scientific Paper

Scientific papers are written and published in journals in a particular format, a writing style called "Scientific Format". You should follow a scientific format when presenting the scientific findings of your project. Although this format may seem a bit strange at first, using this particular style of writing should become clear after you have had the chance to read several journal articles. The writing is done in an organized fashion unlike normal literary prose and it will be easy to read and write in scientific format once you know the basic structure. The following pages will show the basic format concerning writing scientifically but there is no substitute for reading journal articles. Articles with full text may be supplied by your teacher or you can find example articles in the many scientific journals in your local library. Previewing articles will allow you to understand the style of writing that is expected and provide a resource thoughout your writing if questions should arise.

Scientific writing is a writing style that focuses on a clear, concise, logical, and easy-to-follow written presentation of **what your question was, how you carried out the investigation, what your results were,** and **what you concluded.** Since scientific papers are intended to be studied and used as a reference, the data should be clear and concise in its presentation (no lists of raw data), and the interpretations and data analysis should be supported by the data presented. Futhermore, the paper should be precise enough so that future scientists could replicate your experiment and compare their data and conclusions to yours.

Writing in scientific format is approached differently than many other forms of writing in that you do not start writing with the beginning page and progress to the end. Instead, you will be working on several sections at a time and may repeat yourself in several sections of the paper. A scientific paper includes a title page, an abstract, a problem and hypothesis page, an introduction, a materials page, a methods and procedure page, a results section including graphs, charts and appropriate diagrams, a discussion section, and finally an annotated bibliography and literature citation section. Each section should be clearly identified with appropriate section heading (e.g. "Introduction", "Abstract", "Results", etc.). Each section is important to the paper as a whole and should be written as a complete, stand alone part of the overall paper, because sometimes not all the sections are read. As you write refer to previous sections when appropriate in order to keep your reader focused on the scientific theme of the paper.

The particular sections of a scientific paper that were listed will now be discussed in more detail, giving examples when possible. The information about the different sections of a scientific paper, and the information contained within each section should be read and compared to actual articles from scientific journals. Studying scientific journals before you begin writing and comparing the writing style to your own during the writing process is advised.

TITLE

The title of your project must be precise and only reflect what is to be discussed in the body of your work. It should indicate specifically what organism or system you are studying, the particular aspect or phenomena that you are examining, and **only** the variables that you are manipulating or observing. Inappropriate titles are "The Brain" or "Worms" or "Smoking". Some examples of appropriate titles are:

The effect of smoke on the viability of a Planarian (*Dugesia tigiana*).

The motility of a Planarian flatworm when subjected to nicotine.

Remember, a precise title will focus the reader and allow you to build on an idea throughout your paper. Survey the titles of several journals in order to understand this focusing concept.

ABSTRACT

The abstract should be a three paragraph "summary" of the entire article. This section contains all the important concepts that you included in each of the following sections of the paper. The abstract section of any scientific paper is printed, by itself, in volumes of abstracts (such as *Biological Abstracts*), so it must be complete and make sense in the rest of the paper. This reduction of a long article into a few meaningful paragraphs requires practice. Once again, survey the scientific literature that is available in the library - it will allow you to have a model from which to write your abstract correctly. Since this section summarizes your entire paper, the Abstract can not be finalized until all other sections are completed.

I. <u>ABSTRACT WRITING</u>

A) The Abstract is a 3 paragraph summary of your entire scientific experiment and project.

1) **Paragraph #1: <u>Purpose Paragraph</u>**

   a) State the "problem" to be solved in your project.
   b) Clearly identify your hypothesis.
   c) Show (in words) how the problem is part of the general project **and** how it is related to *science*.
   d) Show (in words) how your project is unique or is a unique approach to solving the problem.

2) **Paragraph #2: <u>Procedure Paragraph</u>**

   a) Identify the equipment and materials used or made.
   b) Explain with detail how you followed each step of the scientific method.
   c) Explain how your procedure to solve the problem was creative, thorough, and scientific.
   d) Identify your "methods" of collecting, analyzing, and interpreting data.

3) **Paragraph #3: <u>Conclusion Paragraph</u>**

   a) Show (in words) how the conclusion and results of your experiment relate to your hypothesis
   b) State your conclusion and how it relates to all your data.
   c) Show that you are aware of questions left unanswered by your research and that there are other possibilities for furture study.

Abstract Example:

Does smoke effect the normal living functions of *Planaria*? Planaria exhibit negative responses and are affected by the addition of unnatural smoke to the environment. Smoke from tobacco has long since been recognized and documented as a carcinogen. Second-hand smoke has more recently been subjected to scientific scrutiny with regards to it's detrimental effects. The effects of smoke on an organism such as Planaria can be extrapolated to explain similar cause and effect conditions on higher organisms including human. There are particular experiments conducted in this project which will show the negative responses and detrimental effects of smoke on an organism.

Planaria and a "smoker" apparatus were purchased through a biological supply catalog. The organisms were kept in optimal conditions according to background research and information provided by the supplier. The scientific method of investigation was meticulously followed by identifying the variables involved, formulating hypotheses, developing experimental and control groups, testing and re-testing each hypothesis, collecting data objectively, and analyzing, interpreting and drawing conclusions. Both quantitative and qualitative data collected depicted growth and condition differences among the groups of organisms used for the project.

Experimental conclusions supported the original hypotheses regarding smoke and it's detrimental effects on Planaria. Normal living conditions of Planaria were disrupted by the "smoker" apparatus thus showing second-hand smoke potential effects. Further investigations can be conducted to extend these findings and show the effects of smoke on higher organisms. Other studies may include non-aquatic species that allow for more exact qualitative data without the water-smoke interactions.

INTRODUCTION

The introduction presents the scientific problem in the form of a question. It discusses your problem and how you are about to hypothesize, study, experiment, analyze, and draw conclusions about the particular problem. Also, in this section present any pertinent bckground information from previous studies and site the information by author and date (see "Literature Cited"). Write this section in third person and assume your reader has no knowledge about this particular topic.

MATERIALS AND METHODS

This section of the paper describes, in detail, the materials and methods used in your study. Be as precise as possible. Future scientists should be able to exactly replicate your experiment procedures. Include details such as organism name (common and scientific), dates, times, volumes, weights, physical conditions, weather, sources and brand names. The techniques that you use and investigative methods that you employ should be of an original design. Be sure to devise a specific approach to testing your problem that can truly be considered your own. This portion of the paper should be written in third person, and is written in paragraph form, **not** in the form of lists or "cookbook" directions. An example of writing in the third person is, "Ten seeds per square meter were planted..." or "Twenty-five parmecia were subjected to...".

RESULTS

This section of the paper contains all of the observations that were made during testing. It is important to include both the quantitative and qualitatvie observations that contributed to the outcome of your experiments. A written presentation of the results must be included. Throughout your experiment you observed, measured, counted, or compared something and now is the opportunity to present your findings. This section simply reports your experimental data. Do not discuss, interpret or draw conclusions at this point, that will take place in the following sections. Although graphs, charts, tables and/or diagrams may be used to facilitate the presentation of your results, this same information **must** be presented in pargraph form as well. **No raw data** is included here; your daily log lists the raw data that has not been formulated into actual results. In this section you compare the variables and present the data as averages, means, variances, standard deviations and other forms of descriptive data.

If you think a particular observation or set of data is important be sure to report it; if not. just leave it out. Do not feel that it is necessary to include every bit of data just because you collected it. The reader will be able to find this "other data" in your daily log. If you include data in a graph or table, you **must** include a written discussion of it in this section. If you are going to present material in this section, you will also include it in the "Discussion" section as well. Do not give information in the "Results" section without discussing the observations further in the next section. All graphs and tables should be sequentially numbered, described, labeled and cited in the text (see "Illustrations" section).

DISCUSSION

In the "Discussion" section you analyze the information and observations that your data presented after experimentation. You should discuss your results by considering your original question (the scientific problem). Also discuss the experiments and results of other scientists that have performed similar experiments. You should discuss each of your main conclusions, if there are more than one, and give exceptions and alternate explanations if necessary. Also discuss other possibilities for further research which could be conducted by future scientists or yourself. The discussions here should be more qualitative than the "Results" section, and the interpretations of your results must be supported by your results. Do not make fleeting statements that cannot be coorelated to concrete data in your "Results" section. This section does, however, allow you to make **positive** statements about your findings, even if they contradict your original hypothesis; for example, "The data show a significant effect..." is a much stronger statement than "The data might suggest an effect...".

LITERATURE CITED

All published work from scientific journals, texts or reference materials mentioned in the previous sections of your paper must be listed in this section. The exact format of this section can be different from one journal to the next, but the concept is the same; if you cited someone else's work, the reader should be able to find the particular article or book containing the cited work. You can use the following style:

A) Cite a source **in any section of the text** as follows:

Hamilton (1987) found that planaria when subjected to...

or,

It has been shown (Hamilton, 1987) that when planaria are subjected to tobacco smoke...

B) Cite the same source **in the "Literature Cited" section** as follows:

Hamilton, D.R. 1987. Growth rate of planaria when subjected to adverse conditions. *Journal of Platyhelminthes* 17: 1225 - 1231.

or, if from a book,

Hamilton, D.R. *Animal Life.* Prentice Hall, Needham, Mass.

Citations should be listed alphabetically, and chronologically for multiple articles published by the same author. For more information on citations refer to several scientific journal articles. When you have finished writing your paper, check to make sure that 1) all of the citations in the body of the report are listed in the "Literature Cited" section, and 2) all of the citations listed in the "Literature Cited" section are correctly cited in the paper. This is **not a bibliography** format that you may have learned in other courses.

ILLUSTRATIONS

Most scientific articles use several different types of illustrations to aide in the presentation of data. The illustrations might be maps detailing the location of a study site, simple drawings of apparatus or equipment, charts, histograms or graphs of data and tables summarizing your experimental results. Remember, all illustrations must include detailed captions or explanations, and the illustration should contain labeling detailed enough that is understandable without reading the entire report. Each illustration must also be explained and/or discussed in the body of the paper.
For example:

Table showing measurements of Planaria according to weight

	Control Group	Experimental Group	Difference
	(ranked smallest to largest)		
	118 micrograms	19 micrograms	-99 micrograms
	143	24	-119
	150	32	-118
	186	45	-141
	191	48	-143
	206	52	-154
	214	55	-159
	250	69	-181
	262	74	-188
	280	82	-198
Totals:	2,000 micrograms	500 micrograms	-1,500 micrograms
Mean: (averages)	200 micrograms	50 micrograms	-150 micrograms

Table 1: "Planaria growth when subjected to smoke was 75% smaller than Planaria growing in normal conditions, with a mean mass of 200 and 50 micrograms, respectively."

Tables and figures are numbered sequentially (Table 1, Table 2, Figure 1, Figure 2, etc...). Refer to a copy of any journal article for examples of illustrations.

THE DAILY LOG

The Daily Log is a hand written account of **ALL** activities, tests, procedures, observations, results and general data that you make **during** your experiment. This log can be considered a "scientific journal" of progress on your project. The log should be included as an addendum or final section of the scientific report. Since the log will describe and depict all work anticipated and completed on your project it should include dated information such as, the "problem", your hypotheses as they are originally developed, research conducted. measurements made and results recorded.

Although the qualitative observations made throughout your experimentation will be recorded in this section the most important observations included here will be the quantitative (measurable) results. Also explain the methods used to gather data. The purpose of a daily log is to give other scientists an accurate account of what took place while you researched, worked and experimented. There is no "rough draft" of the log so do not rewrite the log to look better. Present your findings as they are observed in a neat, orderly fashion with legible dates, times and measurement units (metric system) clearly written.

WRITING THE REPORT

After carefullly reading the previous pages and spending some time with several copies of journal articles, you should be ready to begin writing your paper. Rememeber, you should be repeating yourself in several of the sections, so write each section seperately. After experimenting you should first analyze the data to determine exactly what you will be presenting. Then make a detailed list of all points you will include in the Discussion and Results sections of the paper and arrange them in an outline so they flow logically. Then determine how you will arrange the results (charts, graphs, tables, etc...); if charts and tables are used, make them before you begin writing so that your written discussions will refer to them precisely. Make sure you cover all the important findings and results in both the Results and Discussion sections, and that all of the materials and methods pertinent to your study are included in the correct sections. Once you have finished your first (rough) draft, review the paper for clarity and completeness.

Again, refer to a copy of a journal throughout the writing process; use other articles as guidlines for the many questions that may arise such as, "how do I show my results in data form?", "how do I correctly write a citation?", "what do I need to include in the body of my paper, and how do I cite references?", etc. Most importantly, scientific papers are **NOT** written in a single sitting. Your project must be completed or near completion before the report can be well written. Start writing as early as possibe because you will need to revise and rewrite the paper several times. A complete science project entails many experimental and written portions and a well written scientific paper takes time, so ***do not wait until the last minute to begin experimenting or writing!***

The Scientific Method and the Analysis of Scientific Data

Science is a discipline which allows you to **observe and experiment** with nature and the world around you. Although biology is only one of many scientific disciplines which you may encounter as a science student this definition of science includes two very important components that can be applied universally:
1) a **mechanism** -- observation and experimentation, or "The Scientific Method", and 2) a **limit** -- nature and the natural world.

By following the Scientific Method of investigation you will be involved in a *process* which requires curiosity, perception, logic, problem-solving techniques, research methods, intuition, quantitative skills, experience and creativity. The process can be summarized as follows:

— Defining a problem

— Formulating a scientific question and identifying the variables to be studied

— Formulating hypotheses (**all** possible answers to your question)

— Designing experiments to test **each** hypothesis

— Collecting experimental results in data form

— Analyzing and interpreting the data objectively

— Drawing conclusions from the experimental results

— Reporting and displaying your research and experimental findings

Real science for you as a student is when you are thinking critically. Real science entails a special type of critical thinking. Like all critical thinking, there must be a **purpose** for thinking. For scientists the purpose may be "how or why something works in a particular way" or "what is the difference between two things?". Scientific critical thinking entails development of specific questions and concepts, evolving and refining hypotheses, and evaluating and analyzing sets of data after testing or experimenting. The science project is a unique opportunity for you as a student to do **real** science.

Laboratory exercises and research assignments are designed to give you practice in using the scientific method. Remember that the labs and assignments are designed to train you in the *methods* and *skills* required to really understand and do science. Even though the actual questions asked, observations required or phenomena investigated throughout your science courses may seem trivial, it is the *process* which is important. You want to learn how to **DO** science! Only after you understand the process of scientific investigating during laboratory exercises in the classroom can you begin to investigate more complex natural phenomenon. Once understood, scientific investigation can be developed into a unique science project that you can call your own. The following is a guide to train you in the process of scientific investigation.

Defining a Scientific Problem

Getting started - this is often one of the toughest parts of scientific study. This first step requires a sound understanding, as well as, an interest and curioisity about the natural world. Not all questions can be answered by the scientific method; questions which do not deal with the natural or physical world, such as "does heaven exist?", can not be answered by scientific investigations. Furthermore, overly broad questions, such as "what causes death?", are not usually investigated scientifically; rather, a general question is usually broken down into a number of more precise questions, such as "will smoking cause death?" and "will eating unhealthy foods cause death?", and each of these questions is investigated individually. As a beginning scientist you must remember to ask simple questions.

While defining the scientific problem and formulating the questions you want to investigate, it is important to identify exactly what factors you want to investigate; these different factors are called **variables**. Before you can formulate hypotheses or design scientific experiments, you must carefully state which variables are to be observed, tested and/or measured.

Variables are the parts of a scientific experiment that are either **kept the same, changed** or are a **measurement of change** for comparative purposes. For example, if you investigated the question "will tobacco smoke cause the death of an organism", you would establish several variables such as "subjected to smoke", "not subjected to smoke", and "causes of death." You would also want to include other variables such as "the sex of the organism subjected to tobacco smoke", "amount of tobacco smoke", "length of time an organism is subjected to smoke" and so on, because they all could be associated with your original question. It is important to explicitly state the important variables before you begin experimenting; if you have too many variables, your question is too complicated and the investigation can not be conducted sufficiently.

Constant variables are the factors in the investigation that **are kept the same**. In subjecting an organism such as paramecia to tobacco smoke all factors must be kept constant except the smoke factor. **The independent variable** is the factor that **is changed** and therefore tested. There are several possibilities when considering the effects of tobacco smoke in an organism such as Planaria. The independent variable should be considered only one change at a time for instance, "length of time subjected", "amount of potency of nicotine", etc. A thorough experiment will envelop all possibilities in a discrete manner. Finally, **the dependent variable** is the comparative **measurement of the change**.

Formulating Hypotheses

Hypotheses are predictions, educated guesses or possible explanations that you think may answer your problem. If your question is "will smoking cause death", two simple hypotheses could be: 1) "smoking will increase the probability of death", and 2) "smoking will not increase the probability of death." These two "alternative hypothesis" would be investigated during your scientific experimentation.

The first step in answering questions in a scientific study is to make a complete accounting of ALL the possible hypotheses you can think of (all hypotheses must be related to the original question). Always keep in mind that the purpose of your experiment is to test your hypotheses to see if they are right. Make a hypothesis for your control group and one for each experimental group. Write your hypotheses in your daily log for future reference. Also, each hypothesis has two parts. The first part is a statement telling what you predict. The second part will explain why you think this. Be sure to give specific reasons from your research on the topic that support your hypotheses.

Surprisingly, to a young scientist, science proceeds by the *rejection* of the hypotheses, *not* by their proof. Rather, than "proof" and "disproof" of hypotheses, your interests lie in the data "supporting a hypothesis" or "failing to support a hypothesis." If the data does not support a particular hypothesis then throw out the hypothesis (but, keep the data!) and investigate another hypothesis; this process of testing a question and accepting or rejecting hypotheses continues until all possible hypotheses are considered.

So, you have come up with a bunch of possible hypotheses related to your original question, and you are now going to try to support or reject them. But don't jump right in and start conducting experiments on all hypotheses at once; the investigation would be large and the results often insignificant. What you must do is test one hypothesis at a time, starting with the most likely hypothesis and working through the rest. Every time you test a hypothesis you are actually testing a *pair* of **alternative hypotheses** - the "experimental hypothesis" and the "alternative hypothesis." To avoid repetition, the pair of hypotheses tested must meet two criteria:

1) the hypotheses must be **mutually exclusive**, meaning both cannot be correct (one must be wrong), and
2) the hypotheses must be **exhaustive**, meaning that both cannot be wrong (one must be correct).

Meeting these criteria is not as hard as it may seem. For example, consider the hypothesis - "smoking increases the probability of dying." An alternative would be "smoking does not change the probability of dying." These two are both exhaustive and mutually exclusive, so they are useful for experimental testing.

In order to analyze the results, you can set up the pair of alternative hypotheses in a methodical way that should not be confusing after a little practice. The experimental hypothesis is the one you are really testing and is called your **Null Hypothesis**, and can be abbreviated Ho; the null hypothesis states that "there is no difference between experimental groups." Also, the alternative hypothesis (**Ha**), which should be accepted if you failed to support the null hypothesis, would state the "there is a difference between experimental groups." To use the example of smoking and death, the easiest way to test the pair of alternative hypotheses raised would be to set them up as follows:

Ho = there is no difference in the probability of dying between smokers and non-smokers.

Ha = there is a difference in the probability of dying between smokers and non-smokers.

This pair of alternative hypotheses meet the criteria (exhaustive and mutually exclusive). The null hypothesis (Ho) is much easier to subject to statistical analysis than is the alternative hypothesis (Ha). If you do in fact fail to support the null hypothesis, you have supported (but NOT "proven") the alternative hypothesis; if your statistical analysis shows there IS a difference in death rates between smokers and non-smokers, then you can state that " smokers have a higher death rate than non-smokers" or "smokers have a lower death rate than non-smokers", depending on your data.

Designing Experiments

Experiments are designed to test hypotheses. They do not necessarily have to be elaborate or expensive, they just have to be able to support or reject hypotheses. When you conduct a test, you are actually trying to support or reject the experimental hypothesis; if you do not support the experimental hypothesis then you accept the alternative hypothesis. If your hypotheses are constructed correctly, the experiment will involve the manipulation and testing of a single variable at a time - *only one variable per hypothesis!* All other variables should remain constant. Usually a **control** is maintained; a control is a group that does not have a particular experimental variable manipulated, and is otherwise subjected to the same conditions as all the experimental subjects. As an example, consider the question "does smoking cause death?". It is not enough to show smokers do, in fact, die. To support the hypothesis that "smoking causes death", you would need to show that smokers have a *higher probability* of dying than do non-smokers, or that the average life span of smokers is lower than that of non-smokers. The "non-smokers" would be your control group against which you would compare the death rate of "smokers." Remember, you would try to make sure that the *only* difference between "smokers" and "non-smokers" was the act of smoking (the sex ratio, ages, health status and other variables which may affect death rates must be similar in both groups).

Collecting the Experimental Data

This portion of your experiment is dependent on the particular question asked as well as the means of analysis you are going to use. Make sure you understand what and how you are going to be collecting *before* beginning any experimentation. It is a good idea to write down all of your variables and the methods you will use to measure each variable before beginning your experiment, and go over these with a peer, lab partner or teacher to make sure your procedure will answer your question. If you fail to gather data correctly, or fail to gather the correct data, you will have to repeat the entire experiment, so a moment of review BEFORE beginning can often save a lot of time and frustration.

There are several ways to view the types of data to be collected. You may collect **quantitative data** such as mass, temperature or time, or **qualitative data** such as dark or light, sweet or sour, tall or short. The data may be distributed in a **discrete** manner, where there are distinct groups with no intermediates (makes of cars, sexes or species), or it may be **continuous**, where there is a continuous distribution of data (time, length, weight or temperature). Make sure that you understand exactly what type of data you are going to be collecting before you begin!

Regardless of the type of data you collect, make sure you are using appropriate methods of collection and that you are measuring all of the subjects in the same manner. If you fail to collect data appropriately, the conclusions you draw will be incorrect or meaningless.

Analyzing the Data

It is not sufficient to "just find a difference." If you found that smokers die, on average, one year earlier than non-smokers, what would you conclude? Most non-scientists would tend to jump to the conclusions that this somehow "proves" (or at least "supports") the hypothesis that smoking causes death. Scientists, however, would need to know more to come to a conclusion - they would need to know more about the data in order to analyze it **statistically**.

To explain, consider a simpler example. Suppose your hypothesis was "a penny will land on 'heads' half of the time, and on 'tails' half of the time" (an alternative would be that a penny would *not* show a 50/50 ratio of 'heads' to 'tails'). Or, set up the hypotheses like this:

Ho = there should be **no difference** between the number of 'heads' and the number of 'tails'

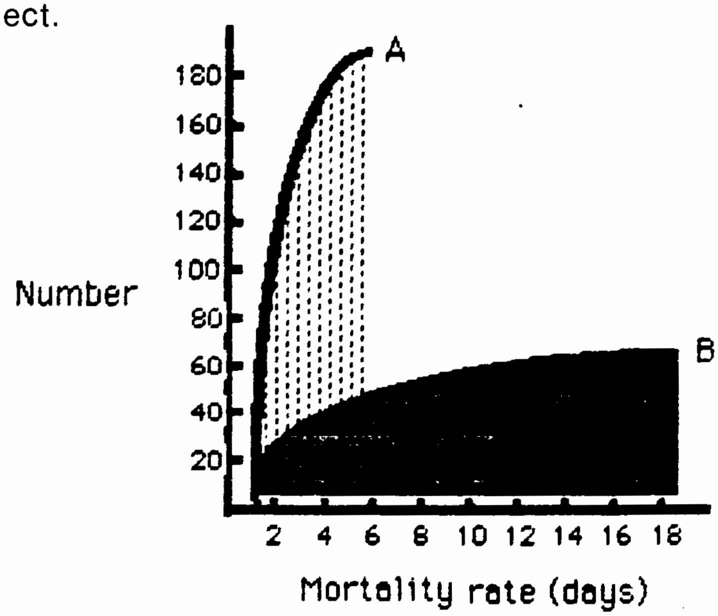
Ha = the number of 'heads' **will be different** than the number of 'tails'

Suppose you flipped the coin 2 times and got two tails; you could claim that "every time you flipped the coin it came up tails" (i.e. that the data supported your alternative hypothesis). Does this prove anything? Obviously not. By analyzing your data you would quickly realize that you had not flipped the coin enough. Suppose you then flipped the coin 10 times and got 6 'tails' and 4 'heads'. Does this mean that you have supported your alternative hypothesis? The data does support the hypothesis! It is still obvious that you have not flipped the coin enough (or, conversely, that a 60/40 ratio is *expected* from a true coin flipped so few times). What if you flipped it 100 times and got a 53/47 ratio? How about a 525/475 ratio from 1,000 flips? Do you have to get *exactly* 50/50 to show the coin is "true"? If not, *how close is "close* *enough"*? Arriving at a conclusion as to "how close is close is close enough?" is hard, and the answer will most likely vary depending on who you ask, which doesn't lead to "good science." Another example is what if you were asking whether males in the class differ in height than females:

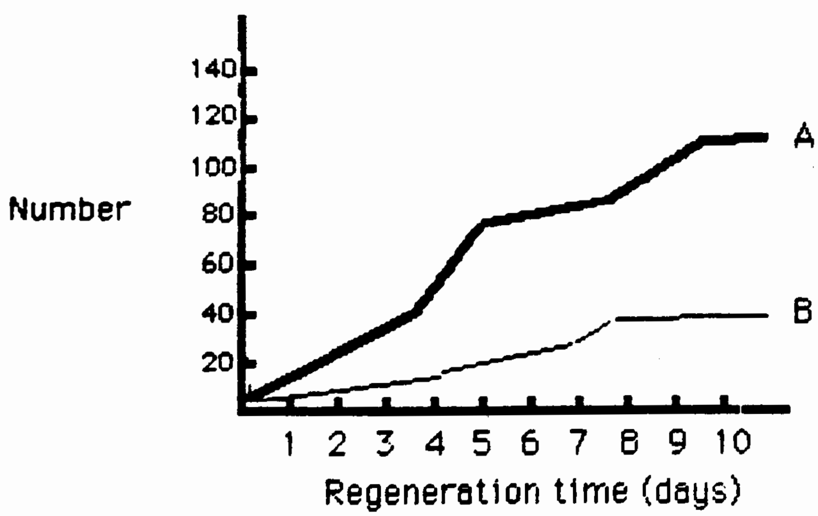
Ho = male height is not different than female height

Ha = male height is different than female height

It is very probable that, if you were to measure the height of males and females on campus, you would find that they were different. But there is still the question, how different do the average heights have to be before you accept them as "different enough"? There is no single answer to these questions, except to say that statistics tell us "how much is enough" and "how close is close enough." Regardless of whether you are asking questions about flips of a penny, death due to smoking or the heights of students, statistics allow you to make straightforward, unbiased decisions as to "how much is enough." The labs you will be conducting throughout your science classes will apply some very basic statistics to data sets that you will collect.



Graph 1: Indicates death rates of planaria subjected to smoke, (A) as compared to planaria not subjected to smoke, (B).



Graph 2: Shows regeneration times for planaria subjected to smoke (B) and not subjected to smoke (A). Not all planaria regenerated.

Drawing Conclusions From Your Data

If you have set up, carried out and analyzed the experiment correctly, this step should be rather straightforward. If your data does not support your experimental hypothesis, you then accept the alternative hypothesis. Remember, this single experiment in and of itself did not "prove" anything, it just ruled out or supported one possible answer out of many possible answers. Even though the data may support your first hypothesis, you must continue to test all others to make sure they do not also provide an "answer" to the original question; in other words, you must rule out *all* possible hypotheses rather than find one that the data supports. In closing you will advise and recommend any potential directions of further experimentation.

SCIENCE PROJECT TOPICS

(Compiled by the Centennial High School Science Staff)

Listed on the following pages are sample topics which can be used to atleast get you thinking about possible projects that might interest you. A science project MUST interest you and is only limited by your own creativity. So, be creative!

Science Project Topics:

1. How effective are the pesticides that naturally occur in plants?
2. How effective are various antiseptics?
3. What changes occur in the successive stages of regrowth following a fire -- (succession)?
4. Which has greater biomass and variety of species -- chapparal or riperian biome? Or desert or Hudsonian or ...
5. Is the grass really greener on the other side -- a comparison of the alterns of a mountain.
6. How effective are warm-ups in improving athletic performance?
7. What is the animal concentration of antigens which will elicit an allergic reaction in a sensitive indivdual?
8. A study of three lakes -- how do 3 interconnected lakes differ and why?
9. Are some diseases more prevalent in males than females and why?
10. Does extensive exercise suppress the immune system?
11. What is the minimal concentration of plant hormone that produce effect based on species?
12. What makes freeway daisies open and close?
13. What adptations does the peripheral circulation in ________ in response to cold?
14. What is the relationship between dosage and effect of caffeine?
15. What factors effect the fecundity (maximal reproductive rate of) of fleas?
16. How host specific are fleas or other pests?
17. Biological insect -- send a thief to catch a thief -- how can you maximize their effectiveness?
18. Integrated insect control -- use of pesticides with pesticide resistant biological controls/sterile males?
19. How effective are flea collars -- what is kill range and can they produce resistant fleas?
20. Microwaves as mutagens on carpet beetles?
21. Television radiation does it produce mutations? (using beetles/fruit flies/microrganisms...)
22. How effective is fur/skin/fat as an insulator?
23. Food additives as mutagens -- saccharin in fruit fly food.
24. What effect does dehydration have on physiology of an exercising individual?
25. How does rate of basal metabolism change as caloric intake is reduced?
26. What is the rate of caloric expenditure for various activities?
27. How much does caloric expenditures increase for exercise as weight increases?

28. What is the relationship between heart rate and anaerobic respiration?
29. How are the brain waves effected by exposure to violence on television?
30. How are the brain waves effected by exposure to various types of music -- will music really tame the savage beast?
31. Are identical twins really identical? Gel electrophoresis examination of proteins of identical twins/exam of their DNA.
32. What is the actual nutritional content of various fast foods? Analysis for protein, fat, carbohydrates.
33. Blood sugar level and the various athletic replacement drinks versus time and without exercise.
34. Effect of pollutants on plants -- modification of plant structures based on exposure to pollutants.
35. Sun tan -- healthy glow or just cancer in the making -- effect of solar radiation as a mutagen on various organisms.
36. Persistent chemical -- how long after pesticide application are traces still evident?
37. What physiological adaptations occur as a subject tries to hold breath longer?
38. What are the physiological symptoms of stress?
39. Is the air pollutant level significantly higher on a freeway during rush hour to effect the commuter?
40. Drought resistant plants -- how are they produced?
41. Can solar energy be used to economically extract fresh water from seawater?
42. How is the EKG effected by various activites?
43. How is the EEG effected by various activites?
44. Aerodynamics and bike racing -- the racers edge or just expensive hype?
45. Comparison of the traditional house and an energy effecient house -- cost versus savings -- through actual construction models.
46. What is the difference in coeffecient of friction for various types of tires and that effect on mileage, wear, and performance?
47. Survey of the animal kingdom -- does your dog really need color TV or is black and white OK? Color or only black and white vision?
48. How do crabs know where to migrate? Where does there homing sense come from?
49. More bounce for your buck -- an analysis of motion control and cushioning in various running shoes.
50. When is it time to retread? Have your shoes lost their soul? Graph of mileage on shoe and its' cushioning ablility.
51. Structural design and stablility in earthquakes -- construction of model bridges or buildings and rate their ability to withstand a simulated earthquake.
52. Are you really better off with breakfast -- food for thought. An analysis of test scores and EEG of students with and without breakfasts prior to school.
53. Vitamin uptake good idea or just an expensive way of producing nutritious urine? Does it just whiz through?
54. What are the effects of steriods on muscle mass rate? Dosage versus effect.
55. Will animals adjust their diet -- given the opportunity to feed on a variety of foodstuffs -- will they balance?

56. Altitude versus biomass and speciation in the local mountains.
57. What foods can help you nutrilize lactic acid in the body?
58. What is the relationship between the depth of kelp and the type of pigmentation and the uptake of light?
59. Gel electrophoresis analysis of proteins of closely related organisms?
60. Gel electrophoresis of the proteins of cloned organisms?
61. Gel electrophoresis of toxins of arthropods?
62. Make an analysis of tree rings relate width of rings to weather conditions.
63. What causes tooth decay -- bacterial culture on teeth, effects of plaque and pH?
64. Ultrasonic sounds -- how are they used and how effective are they in pest suppression.
65. Can you dig it? Fossil evidence for what happened in Corona's past.
66. What effects does herbicide have on the invertabrates in the soil?
67. How does the EEG change when students are subjected to stress?
68. Alcohol production by yeast -- what factors effect yield and when does it stop?
69. Muscle tetanus -- factors which effect its onset.
70. Nutritional analysis of Km and other nutritional supplements.
71. Comparison of diet of owls found in the Chapparal and those in increasingly urbanized Corona.
72. Survey of the numbers and location of edible plants and medicinal native plants in the hills outside Corona.
73. High school athletes and analysis of physiology of top level performance in various sports (aerobic, anaerobic, rxn., body fat, etc.).
74. Can a vertical leap be used as a predictor of ability in various events?
75. Do any of the common facial cosmetics contribute to bacterial growth?
76. What is the relative effectiveness of various acne/pimple preparations in bacterial suppression?
77. How can you predict the tides from the observation of the moon and sun?
78. Alcohol ingestion over the long haul and its effect on the physiology of fish (they absorb it through their gills -- they sort of drink like fish).
79. How can antibiotics be used to prevent wilting in flowers?
80. How does the size of the tank limit the size the fish grows to -- if you rather, be a big fish in a little pond (it won't work).
81. Do pheronomes exist in humans -- holey moley what's that smell?
82. Does the uptake of amino acid supplements actually lead to higher blood serum level of amino acid -- if so, for how long?
83. Cuz' I'm blond yea yea -- are blonds really dumb?
84. Are you in your right mind -- different functions of the two hemispheres of the brain ... different abilities and EEG's?
85. How accurate are the over the counter pregnancy tests?
86. Caffeine as a mutagen?
87. Does caffeine effect the reproduction rate of lower vetebrate animals?
88. Colors and emotions -- study the mood and color and EEG.

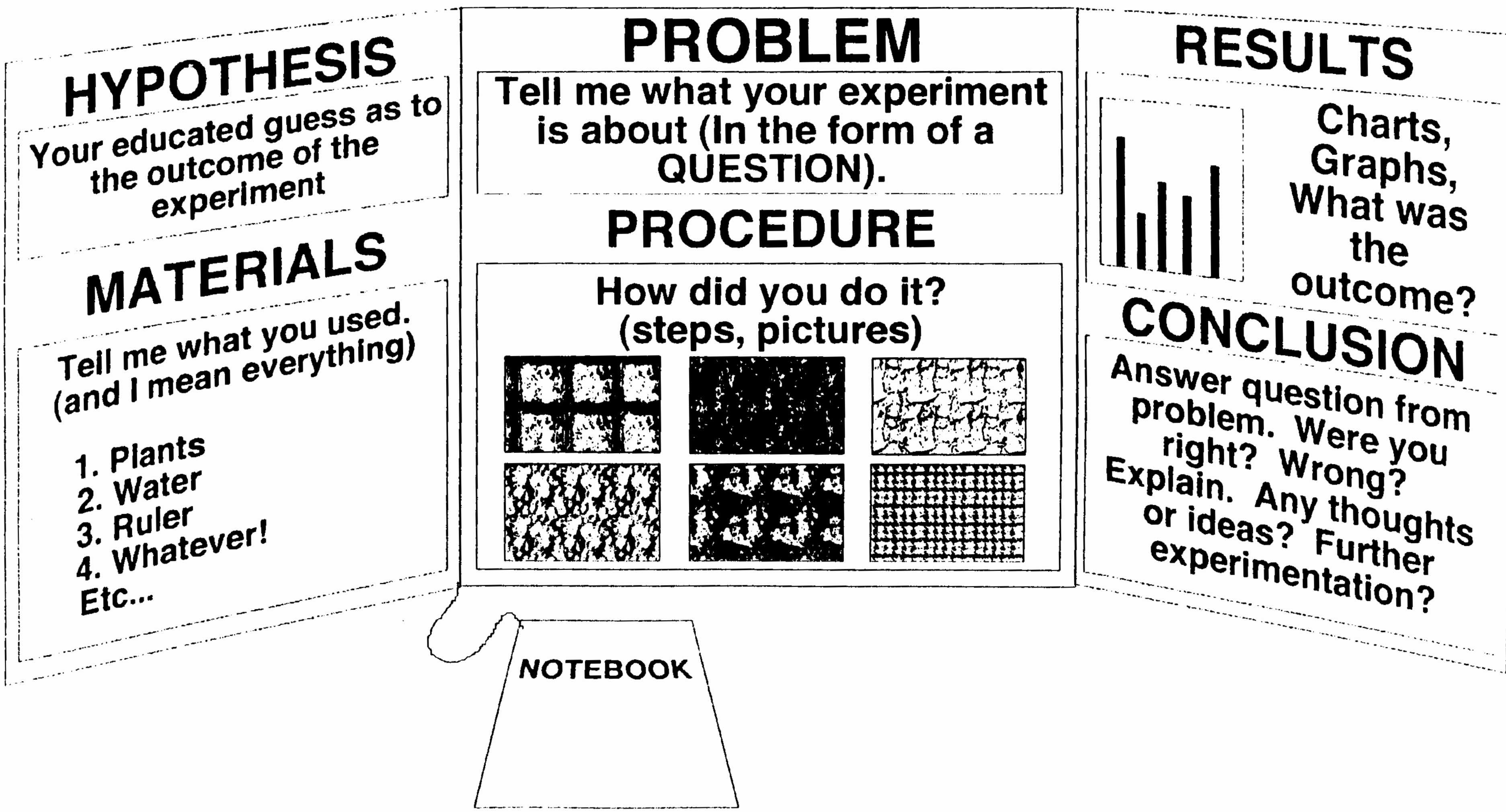
89. Regeneration of flat worms -- can the regenerated worms learn from the training of their predecessor?
90. How does skin change with aging? Analysis of epidermis and elastic fibers of skin.
91. Animal I.Q.'s -- are dogs really smarter than cats?
92. What are the factors which effect the rate of photosynthesis (quant measurements)?
93. Take pollution levels of the Santa Ana River at 10 locations to locate its source.
94. Fish parasites as a function of pollution level.
95. How can the species present be used to predict the level of pollution present?
96. PH level and heart rate -- how do they relate?
97. Relate cholesterol level of the blood and diet of students at your school?
98. White sugar and I.Q. -- the twinklie made me do it -- check for white sugar and EEG test scores.
99. Quantitative analysis of water of various sources and bottled water.
100. Hyperhydration and exercise -- will it lower core temperature during exercise?
101. What seasonal population variations can be observed in _________?
102. How does temperature affect the growth of _________?
103. How does light affect the growth of _________?
104. How does magnetism affect the growth of _________?
105. How does gravity affect the growth of _________?
106. What organisms initiate a feeding response in _________?
107. What organisms initiate a defense response in _________?
108. Which is the stimulus for initiating a feeding reponse in _________?
109. What chemical factors limit the growth of _________ in ponds?
110. What factors limit the territory size of _________?
111. What is the food preference of _________?
112. What physical factors are the determiners of food choice in _________?
113. What factors stimulate willow leaf gall formation?
114. Can a culture method for growing willow leaf gall insect larvae in vitro be developed?
115. Can microbes which produce antibiotic compounds be isolated from soil at Prado Park?
116. How well does syrphid fly mimicry of venomous insects protect it from _________?
117. What factors affect the water quality of the Santa Ana River?
118. Where along the Santa Ana River is the water quality the poorest?
119. How does the concentration of _________ in the water affect populations of _________ in the Santa Ana River?
120. What are the different soil types to be found in the Corona-Norco area?
121. How does the type of soil affect the populations of _________?
122. What is the biomass productitvity of various soils at Prado Park?
123. How does U.V. radiation affect the fresh water population of plankton?
124. How does exposure to U.V. radiation affect the development of _________ larvae?
125. Can a chemical compound be developed to protect organisms from the harmful effects of U.V. radiation?
126. What physical factors limit the activity of _________ at Prado Park?
127. What is the method for studying populations of ground squirrels at Prado Park?

128. What is the seasonal variations of dominant plants at Prado Park?
129. How does _________ limit the growth of other species?
130. What factors allow _________ to successfully compete with other plants at Prado Park?
131. What trends in air quality can be derived from testing air samples?
132. Considering cost, availablility fo equipment, and effectiveness, can a reliable test for _________ be developed for use by Corona-Norco students?
133. Which organisms are repelled by the secretion of elodea?
134. How can gel electrophoresis be used to determine the presence or absence of _________?
135. How does visual input affect respiration and heart rate?
136. How does auditory input affect respiration and heart rate?
137. How does tactile input affect respiration and heart rate?
138. How does taste or olfaction affect physiological factors?
139. How well do natural pesticides produced by _________ work on _________?
140. What is the most productive mixture and technique for generating methane?
141. What effect does bee venom have on the development of D. Melanogaster?
142. What effect does spider venom have on populations of P. Caudatum?
143. Can an antidote be found to counteract spider venom so that it can be used as an insect anesthetic?
144. What methods can effectively be used to control weed growth in crop plants without using chemical herbicides?
145. Are natural herbicides produced by eucalyptus environmentally safer than "round up"?
146. U.V. effects on invertebrates?
147. Bacterial growth on antibiotics?
148. D.N.A. testing (gel electrophoresis).
149. Amoeba, paramecium, protozoa effects with any single variable.
150. Cloning plants.
151. Malathion effects on _________? Is spray really the only way?
152. Nature versus Nurture on personalities.
153. Multi-vitamin effects on mammalian physiology. Will "super" vitamins, amino acids, anabolic steriods, etc... create super rats?
154. Quantify your plaque. Is just brushing OK or should you floss too?
155. Effective mouthwash versus bacteria. Compare all brands.
156. Different strokes for different folks. Does open or closed fingers provide the most propulsion for various swim strokes?
157. Pro-vitamin shampoo versus actual hair vitamins.
158. Optimal temperature for guppy reproduction? When your HOT your HOT.
159. Can sound waves be seen? Watch your flame flicker.
160. Does electricity stimulate the growth of plants?
161. Fuselage design and its effect on lift.
162. Wing design and its effect on lift.
163. Which fabrics (synthetic or natural) are most readily damaged by pollutants?
164. Schooling behavior in fish. What makes them go, even when you don't?

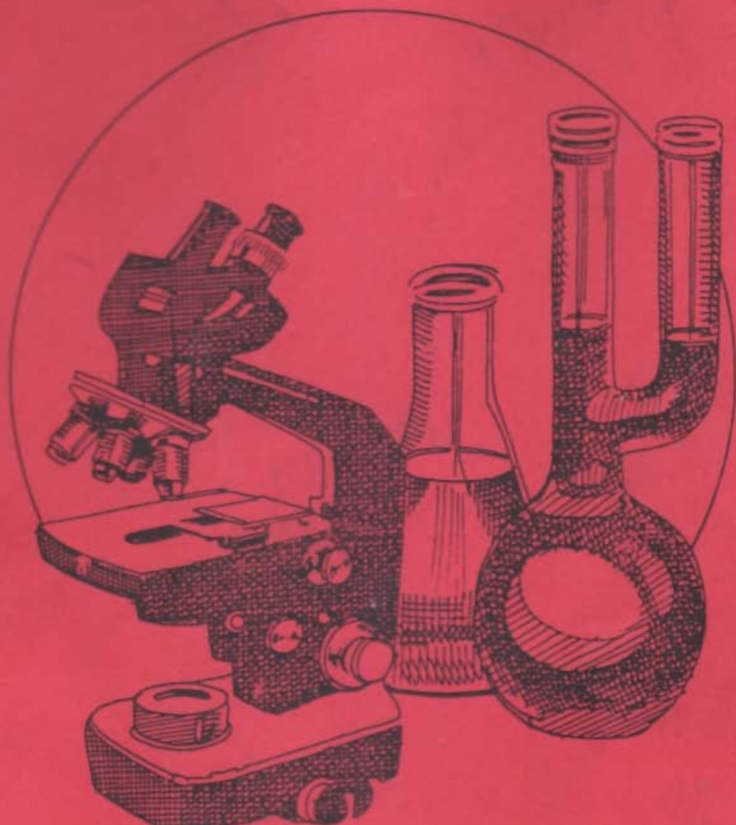
165. Regeneration in planaria -- effects of magnetism, U.V., etc...
166. Topical effects of aspirin/acetominophen on plant growth.
167. What is the effect of a magnetic field on ...
168. Hyroglyphics -- analysis of language development.
169. What effect do sight and smell have upon taste?
170. How do the taste buds of young and old vary in sensitivity?
171. Effects of crowding on organismal behavior?
172. Effects of temperature and concentration on conductivity of electrolytic solutions.
173. Do differing electrophoresis matrices change the distance of protein or DNA molecular markers?
174. Coorelation between weight gain in mothers and birth weight of their babies.
175. Potentiality of adaptation for air ferns in soil, water.
176. Social behavior in a bee or ant colony.
177. Carcinogenic comparisons of smoke versus smokeless tobacco.
178. Study of anorexia.
179. Study of bolemia.
180. Study of asthma.
181. Study of scoleosis.
182. Effects of elevated carbon monoxide on plant development/growth.
183. Effects of cold-snaps on citrus fruit cellular tissues.
184. Adaptation of plants -- compare rate of evaporation in desert, tropical, and temperate plants.
185. Exxon Valdez revisited -- Are oil degrading microbes efficient in spill clean-up?
186. Effects of sunscreens on DNA replication.
187. Desalination potential utilizing various techniques.
188. The pattern of fingerprints and its genetic relationship conclusiveness.
189. Does birth order affect your basic personality?
190. Is there a coorelation between a detergents cleaning effectiveness and its ability to reduce the surface tension of water?
191. Figuring Fat: Relationship of calorie intake, physical activity, and weight gain.
192. Culturing ________ by hydroponics.
193. The physiology of ciliary action and the effect of cigarette smoke in the respiratory tract.
194. Comparative study of skin cell condition and regeneration with and without the use of skin lotions.
195. Are other kernels as poppable as popcorn? A test for your taste.
196. Effect of food supply on fruit fly density.
197. Degregation effects of various consumable liquids on tooth enamel.
198. Morphological and molecular comparisons of closely related organisms.
199. Kinetics of different golf swings, baseball bat swings with regard to angle/arc/size/power etc...
200. Analysis of optimum stride length in regards to conservation of energy and peak performance of distance runners.

Science Fair Project Display

MAX. DISPLAY SIZE FOR TABLE PROJECT: 4 FT WIDE X 2.5 FT DEEP X 5 FT TALL
MAX. DISPLAY SIZE FOR FLOOR PROJECT: 4 FT WIDE X 2.5 FT DEEP X 7.5 FT TALL



THE COMPLETE SCIENCE PROJECT



Don Hayes
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CORONA-NORCO UNIFIED SCHOOL DISTRICT
ACTION TOWARD EXCELLENCE

- A Mentor Teacher Service -