Scientific Method

A science project is an investigation using the scientific method to discover the answer to a scientific problem. Before starting your project, you need to understand the scientific method. This section uses examples to illustrate and explain the basic steps of the scientific method. The scientific method is the "tool" that scientists use to find the answers to questions. It is the process of thinking through the possible solutions to a problem and testing each possibility to find the best solution. The scientific method involves the following steps: doing research, identifying the problem, stating a hypothesis, conducting project experimentation, and reaching a conclusion.

Research Research is the process of collecting information from your own experiences, knowledgeable sources, and data from exploratory experiments. Your first research is used to select a project topic. This is called topic research. For example, you observe a black growth on bread slices and wonder how it got there. Because of this experience, you decide to learn more about mold growth. Your topic will be about fungal reproduction. (*Fungal* refers to plant-like organisms called fungi, which cannot make their own food, and *reproduction* is the making of a new offspring.) CAUTION: If you are allergic to mold, this is not a topic you would investigate. Choose a topic that is safe for you to do.
After you have selected a topic, you begin what is called project research. This is research to help you understand the topic, express a problem, propose a hypothesis, and design one or more project experiments—experiments designed to test the hypothesis. An example of project research would be to place a fresh loaf of white bread in a bread box and observe the bread over a period of time as an exploratory experiment. The result of this experiment and other research give you the needed information for the next step—identifying the problem.

> **Do** use many references from printed sources—books, journals, magazines, and newspapers—as well as electronic sources—computer software and online services.
> **Do** gather information from professionals—instructors, librarians, and scientists, such as physicians and veterinarians.
> **Do** perform other exploratory experiment related to your topic.

Problem The problem is the scientific question to be solved. It is best expressed as an "open-ended" question, which is a question that is answered with a statement, not just a yes or a no.
For example, "How does light affect the reproduction of bread mold on white bread?"

> **Do** limit your problem. Note that the previous question is about one life process of molds—reproduction; one type of mold—bread mold; one type of bread—white bread; and one factor that affects its growth—light. To find the answer to a question such as "How does light affect molds?" would require that you test different life processes and an extensive variety of molds.
> **Do** choose a problem that can be solved experimentally. For example, the question "What is a mold?" can be answered by finding the definition of the word mold in the dictionary. But, "At room temperature, what is the growth rate of bread mold on white bread?" is a question that can be answered by experimentation.

Hypothesis A hypothesis is an idea about the solution to a problem, based on knowledge and research. While the hypothesis is a single statement, it is the key to a successful project. All of your project research is done with the goal of expressing a problem, proposing an answer to it (the hypothesis), and designing project experimentation. Then all of your project experimenting will be performed to test the hypothesis. The hypothesis should make a claim about how two factors relate. For example, in the following sample hypothesis, the two relating factors are light and bread mold growth. Here is one example of a hypothesis for the earlier problem question:
"I believe that bread mold does not need light for reproduction on white bread. I base my hypothesis on these facts:

- Organisms with chlorophyll need light to survive. Molds do not have chlorophyll.
- In my exploratory experiment, bread mold grew on white bread kept in a dark bread box."

Do state facts from past experiences or observations on which you base your hypothesis.
Do write down your hypothesis before beginning the project experimentation.
Don't change your hypothesis even if experimentation does not support it. If time permits, repeat or redesign the experiment to confirm your results.

Project Experimentation Project experimentation is the process of testing a hypothesis. The things that have an effect on the experiment are called variables. There are three kinds of variables that you need to identify in your experiments: independent, dependent, and controlled.
The independent variable is the variable you purposely manipulate (change). The dependent variable is the variable that is being observed, which changes in response to the independent variable. The variables that are not changed are called controlled variables.
The problem in this section concerns the effect of light on the reproduction of bread mold. The independent variable for the experiment is light and the dependent variable is bread mold reproduction. A control is a test in which the independent variable is kept constant in order to measure changes in the dependent variable. In a control, all variables are identical to the experimental setup—your original setup—except for the independent variable. Factors that are identical in both the experimental setup and the control setup are the controlled variables. For example, prepare the experiment by placing three or four loaves of white bread in cardboard boxes the size of a bread box, one loaf per box. Close the boxes so that they receive no light. If, at the end of a set time period, the mold grows, you might decide that no light was needed for mold reproduction. But, before making this decision, you must determine experimentally if the mold would grow with light. Thus, control groups must be set up of bread that receives light throughout the testing period. Do this by placing an equal number of loaves in comparable-size boxes, but leave them open.
The other variables for the experimental and control setup, such as the environmental conditions for the room where the boxes are placed—temperature and humidity—and the brand of the breads used must be kept the same. These are controlled variables. Note that when designing the procedure of your project experiment, you must include steps for measuring the results. For example, to measure the amount of mold growth, you might draw 1/2-inch (1-cm) squares on a transparent sheet of plastic. This could be placed over the bread, and the number of squares with mold growth could be counted. Also, as it is best to perform the experiment more than once, it is also good to have more than one control. You might have one control for every experimental setup.

Do have only one independent variable during an experiment.
Do repeat the experiment at least three times to verify your results.
Do have a control.
Do have more than one control, with each being identical.

Do organize data. (See A Sample Project for information on organizing data from experiments.)

Project Conclusion The project conclusion is a summary of the results of the project experimentation and a statement of how the results relate to the hypothesis. Reasons for experimental results that are contrary to the hypothesis are included. If applicable, the conclusion can end by giving ideas for further testing.
If your results do not support your hypothesis:
DON'T change your hypothesis.
DON'T leave out experimental results that do not support your hypothesis.
DO give possible reasons for the difference between your hypothesis and the experimental results.
DO give ways that you can experiment further to find a solution.
If your results support your hypothesis:
You might say, for example, "As stated in my hypothesis, I believe that light is not necessary during the germination of bean seeds. My experimentation supports the idea that bean seeds will germinate without light. After seven days, the seeds tested were seen growing in full light and in no light. It is possible that some light reached the 'no light' containers that were placed in a dark closet. If I were to improve on this experiment, I would place the 'no light' containers in a light-proof box and/or wrap them in light-proof material, such as aluminum foil."

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Guide to the Best Science Fair Projects, Janice VanCleave (John Wiley & Sons, Inc., 1997)