The RCRSTF Guide to a Successful Science & Technology Fair

What is a Science and Technology Fair?

Science and Technology fairs are a chance for students to work on a project related to some aspect of science, typically an experiment, innovation or study. The students' work is presented at a science fair and the students are evaluated on their scientific thought, originality, understanding, and the exhibit itself. The best projects in each category are given awards and the best projects in the fair will move on to the Canada Wide Science Fair.

Categories:

The Fair is divided into 4 age groups:

- Grade 6
- Junior(Grades 7 and 8)
- Intermediate(Grades 9 and 10)
- Senior(Grades 11 and 12)

Divisions:

Physical Science

A Physical Science project is one that has as its primary objective a consideration of the cause and effect of any non biological process or activity.

Although living things may bear the consequences of some phenomenon under study, if the focus is on the phenomenon itself, and not on its effect on the organism(s), then the project is a Physical Science one.

Examples:

The meteorological characteristics of a Chinook would be Physical Science, while the effects of a Chinook on living organisms would be Life Science.

The factors affecting the size of a bubblegum bubble (time, brand, etc.) would be a Physical Science project although factors to be considered would include the effect of digestion of enzymes and saliva and the effect of chewing, both of which are life science.

Life Science

A Life Science project attends to some aspect of the life or lifestyle of an organism.

As for those projects which may be derived from a Life Science topic, but have as their major focus a problem in another discipline. These are better placed in a different category

Examples:

> An acid rain project that investigates the effect of acid precipitation on potted geraniums would be Life Science while another that examined precipitation from varying weather patterns would be a Physical Science project.
>
> The effect of microwaves on germinating mung beans would be a Life Science project, while cooking the mung beans using microwaves would not.

Engineering and Computer Science

An engineering project involves to design and/or physical construction of some device, appliance, machine or process, etc., that has an application.

Whereas a Physical Science project looks at the relationship of variables or factors, an Engineering project applies the relationships.

Examples:

- Finding out what keeps an airfoil up - Physical Science
- Designing a better airfoil - Engineering
- Measuring solar energy coming to a given place - Physical Science
- Catching Solar energy for use - Engineering
- Determining the optimum conditions for raising worms - Life Science
- Designing the vermicarium that would have these conditions - Engineering

A Computer Science project is one in which the computer is the focus of the project.

Health Science

A health sciences project examines some biomedical and/or clinical aspect of human life or lifestyle and its translation into improved health for humans, or more effective health services and products. Projects related to the health of specific populations, societal and cultural dimensions of health, and environmental influences on health are also included in this division.

Health sciences projects include those related to human aging, genetics, cancer research, musculoskeletal health, arthritis, circulatory and respiratory health, nutrition, neurosciences, mental health, psychology, metabolism, human development, infection and immunology.

Choosing a Topic

The first, and often most difficult part of a science fair project is choosing a topic that interests you. You might try looking around your home, the newspaper, television, or the internet for a problem that interests you.

Project Types

There are 3 types of science fair projects:

An Experiment:

A project of this type would be an investigation undertaken to test a specific hypothesis using experiments

A Study/Survey:

A project of this type would be a collection and analysis of data to reveal evidence of a fact or a situation of scientific interest

An Innovation:

A project of this type would be one involving the development and evaluation of innovative devices, models, techniques, or approaches in such fields as technology, engineering or computers.

Steps in Creating a Project

The Experiment:

A project of this type would be an investigation undertaken to test a specific hypothesis using experiments, you would normally use the Scientific Method for this type of Project.

The Scientific Method: The scientific method is a way to ask and answer scientific questions by making observations and doing experiments.

The steps of the scientific method are to:

Ask a question:

The scientific method starts when you ask a question about something that you observe: How, What, When, Who, Which, Why, or Where?
And, in order for the scientific method to answer the question it must be about something that you can measure, preferably with a number.

Do background research:
Next, read books from the library look on the internet, and at other resources about your topic. Gather existing information and try to look for unexpected or unexplained results in previous experiments.

Organization & Planning:
Once you're done your research, organize it, and narrow your hypothesis by focusing on a specific idea. After this, you should plan in detail how you are going to do your experiments or tests.

Construct a Hypothesis:
A hypothesis is an educated guess about how things work:

"If _____*[I do this]* _____, then _____*[this]*_____ will happen." You must state your hypothesis in a way that you can easily measure, and of course, your hypothesis should be constructed in a way to help you answer your original question.

Test your Hypothesis by doing an experiment:
While running your experiments, it is important for your experiment to be a fair test. A "fair test" occurs when you change only one factor (variable) and keep all other conditions the same. keep detailed notes of every measurement and observation Also, ensure there are control experiments, in which no variables are changed, and sufficient numbers in both the control and experimental groups.

Analyze your data and draw a conclusion:
Once your experiment is complete, you collect your measurements and analyze them to see if your hypothesis is true or false.

Once the experiments are done, organize and review the data you collected. Did you get the results you expected from the experiments? What errors might have occurred during the experiments? If possible, you should analyze the data statistically.

Scientists often find that their hypothesis was false, and in such cases they will construct a new hypothesis starting the entire process of the scientific method over again. Even if they find that their hypothesis was true, they may want to test it again in a new way

Communicate your results:

To complete your science fair project you will communicate your results to others in a final report and/or a display board. Professional scientists do almost exactly the same thing by publishing their final report in a scientific journal or by presenting their results on a poster at a scientific meeting

The Study/Survey:

A project of this type would be a collection and analysis of data to reveal evidence of a fact or a situation of scientific interest

Designing an Observation Study

There are many different ways to design an observation study, depending on the objective of your study, the type of data you are trying to collect, and the resources you have available for your study. Following are five different features that you should consider when designing the ideal observation study for your project:

Natural vs. Contrived Settings:
Conducting the study in a natural setting essentially means that you are simply observing your subjects in their "real life" environments. Because you have no way of influencing what your subjects are doing, this method can be time consuming to gather the information that you are specifically trying to obtain for your project. Alternatively, the data that is collected in a natural setting does have more accuracy in reflecting "real life" behavior rather than "contrived" behavior.

A contrived setting is one where the specific situation being studied is created by the observer. The contrived setting offers you, the observer, greater control over the gathering of data and specifically will enable you to gather the information more quickly and efficiently. However, it may be questionable as to whether or not the data collected does truly reflect a "real life" situation.

Disguised vs. Non-disguised Observation:
When subjects do not know they are being observed, this is called a disguised observation. Subjects in disguised observations tend to act more naturally and the data collected tends to reflect their true reactions. The primary concern with disguised observation is the ethical concern over recording behavioral information that would normally be private or not voluntarily revealed to a researcher. However, if you are simply observing a subject's behavior in a public setting then by definition, their behavior is no longer private.

When subjects know they are being observed, this is called a non-disguised observation. Using the non-disguised observation technique alone alleviates ethical concerns, however, since the subjects are aware that they are being watched, the advantages of using the observational technique are neutralized and a survey technique would be equally effective. There is one exception: the non-disguised approach offers the advantage of allowing the researcher to follow up the observations with a questionnaire in order to get deeper information about a subject's behavior.

Human vs. Mechanical Observation:
Human observation is self explanatory, using human observers to collect data in the study. Mechanical observation involves using various types of machines to collect the data, which is then interpreted by researchers. With continuing improvements in technology, there are many "mechanical" ways of capturing data in observation studies, however, these new "gadgets" tend to be extremely expensive. The most commonly used and least expensive means of mechanically gathering data in an observation study is a video camera. A video camera offers a much more precise means of collecting data than what can simply be recorded by a human observer.

Direct vs. Indirect Observation:
Direct observations involve looking at the actual behavior or occurrence rather than a result of that occurrence, which would be an indirect observation. For example, if you were interested in seeing how much candy was purchased by a particular neighborhood, you could gather the information in one of the two following ways:

Direct observation: observe customers in a store and count how many bags of candy they purchase.
Indirect observation: look through trash cans on garbage day to see how many empty candy bags are in each trash bin

Indirect observation tends to be used when the data cannot be gathered through direct means, or when gathering the data through direct observation tends to be too expensive.

Structured vs. Non-structured Observation:
Structured observations are made when the data that is being collected can be organized into clear categories or groups so that the observer can record the data by simply marking off or checking a category on an observation form. Non-structured observations are not looking for specific facts or actions, but rather are capturing everything that occurs. For example, if the US Postal Service were interested in knowing the gender and racial profile of the people that use a particular post office, they could post an observer at the front door and simply record the data as people entered the post office. This would be a structured observation, where the observer would simply be

marking off boxes on an observation form. However, if the US Postal Service were interested in knowing the general level of satisfaction with service in a particular post office, they could post an observer in that office to capture more general data such as the length of the line during various times of day, the general change in customer demeanor as the line grows longer, the change in customer demeanor when there are one, two, or three windows open, etc....

Designing a Survey

The key to obtaining good data through a survey is to develop a good survey questionnaire. Whether you are conducting interviews or mailing out surveys, you will need to know how to design a good survey questionnaire.

What is a survey questionnaire?
Survey questionnaires present a set of questions to a subject who with his/her responses will provide data to a researcher. On the surface, it seems a fairly simple task to write up a set of questions to collect information, but there are many pitfalls that should be avoided to develop a good survey questionnaire. We will focus here on describing some of the key elements in designing a survey questionnaire, and then highlighting some tips and tricks to for creating a good survey questionnaire.

Objectives
The key to developing a good survey questionnaire is to keep it short while ensuring that you capture all of the information that you need. This is not an easy task. Before you even begin to design your survey questionnaire, you should develop a set of objectives for your research and list out the information that you are trying to capture. This list of objectives and research goals will serve as your plan for the survey questionnaire.

Now that you know what you are looking for, you can begin to structure the questions that will help you capture the information. Once you have developed your survey questionnaire, you can use your objectives to go back through the questions and determine if each of the questions is providing you with information that you need. Any question that is not providing necessary information should be removed.

Types of Questions:
There are two different types of questions that can be used to collect information. The first is called a structured or fixed response question and the second is called non-structured or open question. It is important to understand when and how to use these questions when designing your survey.

Structured (fixed response)
Structured questions are questions that offer the respondent a closed set of responses from which to choose. Structured questions make data collection and analysis much simpler and they take less time to answer. Structured questions are best suited in the following situations: (1) when you have a thorough understanding of the responses so that you can appropriately develop the answer choices (2) when you are *not* trying to capture new ideas or thoughts from the respondent.

Examples of Structured Questions

Do you have a driver's license?
( ) Yes
( ) No

Which subject do you enjoy the most at school?
( ) Math
( ) Science
( ) English
( ) Foreign Language
( ) History
( ) Government
( ) Art / Music
( ) Other

How many hours a day do you spend doing homework?
( ) 0 to 1 hour
( ) 2 to 3 hours
( ) 4 to 5 hours
( ) more than 5 hours

When writing the selection of responses for a structured question, you should make certain that the list covers *all possible alternatives* that the respondent might select AND that *each of the answers is unique* (ie they do not overlap). So for example, in the homework question above, we have included every option on the number of hours (from 0 to infinity). Also, you will notice that we were careful not to overlap the hours when defining the ranges by stating them as "0 to 1 hour" and "2 to 3 hours" rather than saying "0 to 1 hour" and "1 to 2 hours".

Sometimes, including general catch all responses (such as "Other", "Don't know", "None of the above", etc...) at the end of a list of answer choices will help to ensure that the data you are collecting will be accurate. In the school subject example above, you will notice that the last answer choice is "Other". Since the selection of non-required courses varies dramatically from school to school the option of "Other" helps to ensure that you are capturing the responses that do not fit into the broader subject areas already listed, rather than forcing respondents to select one of the other subject areas. Similarly, adding "Don't know" to a response list for a question that some of the respondents may not be capable of answering will help ensure you are collecting valid data. In general however, you want to use the "Don't know" option sparingly. You should try to ensure that your respondents are capable of answering the majority of the questions on your survey questionnaire.

You should also make sure that all of the answers are *relevant* to the question. Irrelevant responses may distract the respondent in addition to adding unnecessary length to your survey questionnaire. Consider the following change to the favorite school subject question.

Example of a Bad Question with an Irrelevant Answer Choice

Which subject do you enjoy the most at school?
( ) Math
( ) Science
( ) English
( ) Foreign Language
( ) History
( ) Government
( ) Art / Music
( ) Football Practice
( ) Other

If we added a choice of "Football practice", we may find that football practice is someone's favorite "activity" at school, but it is not relevant to this particular question which asks "Which *subject* do you enjoy the most at school?"

Consistency is very important in writing the list of responses. All of the responses should be similar so that no single response stands out to the individual except the answer that is true for them. Consistency simply helps to ensure that you are not leading respondents to a particular answer by making that answer different from the others. It also makes it much easier for respondents to find the answer that is relevant to them. Here's an example using the homework question you have already seen above:

Example of a Bad Question with Inconsistent Answer Choices

How many hours a day do you spend doing homework?
( ) 0 to 1 hour
( ) 120 to 180 minutes
( ) 4 to 5 hours
( ) more than 5 hours

In this example, the second choice is exactly the same as what we had before, but it is listed in minutes rather than hours making it inconsistent with the other answer choices. Listing answer choices in this way is very confusing for the respondent and makes it more likely that they will provide you with incorrect information.

Sometimes you will be interested in obtaining a person's opinion on a topic, subject, product, event, etc.... To capture varying degrees of emotion about a subject, it is best to use either a rating or a ranking question. A rating question asks respondents to explain the degree with which they feel about a certain topic, subject, event, etc... For example:

Example of a Rating Question

Please describe how you felt about the Homecoming Pep Rally.

Unsatisfied	Somewhat Satisfied	Satisfied	Very Satisfied	Extremely Satisfied
(1)	(2)	(3)	(4)	(5)

A ranking question asks respondents to explain how they feel about something by comparing it to other items in a list. For example:

Example of a Ranking Question

Please rank the following Homecoming activities in order of preference (starting with 1 for your favorite activity).

___Homecoming Pep Rally
___Homecoming Parade
___Homecoming Football Game
___Homecoming Dance

In general, if you are trying to get a respondent's opinion about something, it is best to have them do a rating rather than a ranking. A ranking asks respondents to list their responses in order of preference. This type of question leads you to an answer where the respondent is comparing one thing to another rather than giving you their feeling about each individual item. The disadvantage to a ranking is that if the respondent feels the same about two or more items, they are still forced to sort them into a ranking. The results of a ranking basically tell you which is the most preferred and which is the least preferred item on the list, but you do not know from a ranking if the respondent likes or dislikes any or all of the items on the list.

Non-structured (open-ended)
Non-structured questions, or open-ended questions, are questions where there is no list of answer choices from which to choose. Respondents are simply asked to write their response to a question. Here is an example:

Example of a Non-structured Question

What do you like best about the Science Buddies Classroom Scientists Program?

____

____

It is best to use non-structured questions when you are exploring new ideas and you don't really know what to expect from the respondents. In some situations, you may have a partial list of answer choices, but you may still have some doubt or uncertainty about other possible responses. You can create a partially structured question such as the following:

Example of a Partially Structured Question:

Why did you sign up for the Science Buddies Classroom Scientists Program (please select all that apply)?
( ) I really enjoy science
( ) My teacher asked me to sign up
( ) My teacher made me sign up
( ) My parents asked me to sign up
( ) I'm bored in science class & thought this would be fun
( ) I thought it would help me do a better project
( ) I thought it would help me win the Science Fair
( ) I thought having a Mentor to talk to would be fun
( ) I knew other students who were doing it
( ) Other ______________________

Open-ended questions let you get more insight into the respondents' thoughts and ideas about a subject. As we have already mentioned, open-ended questions are useful when you are trying to capture new ideas or information for which you have no basis to develop an all inclusive set of structured responses. The disadvantages to using open-ended questions is that it can be much more time consuming and difficult to analyze the data. In general you should try to minimize the number of open-ended questions in your survey questionnaire. If you find yourself designing a survey questionnaire where the majority of the questions are open-ended, then you may need to do more exploratory research to get a better foundation of knowledge for the subject you are researching.

Tips to creating a good survey questionnaire:

Here are some tips and tricks to help you ensure you are developing a good survey questionnaire:

Clearly state your intentions with the research.
Many people are hesitant to answer questions about themselves and their opinions. If you are developing your survey for a science fair project, people will probably be more willing to help if you clearly state your intentions. At the top of your survey, write a brief statement explaining why you are collecting the information and reassure each respondent that the information is entirely anonymous. If you need to know specifics about a person, respect their privacy by identifying them as subject1, subject2, etc...

Include instructions with your survey questionnaire
What may seem obvious to you probably is not very obvious to someone else. To ensure that you collect valid survey results, make sure you include instructions on how to answer the survey questionnaire. There should probably be a short introductory set of instructions at the top of the survey questionnaire, and additional instructions for specific questions as needed.

Your overall instructions may be something like:

Please mark the appropriate box next to your answer choice with an "x" (X). Please answer all of the questions to the best of your ability.

Don't ask for personal information unless you need it.
Asking individuals to provide you with personal or demographic information (age, race, income level, etc...) may irritate some respondents and prevent them from completing your survey questionnaire. However, in many instances, this information is necessary for the research. If you need to ask for this type of information it is best to place the questions at the END of your survey questionnaire.

Keep the questions short and concise
The wording for survey questions should be short and concise. Each question should be clearly stated so that there is no misunderstanding about what is being asked. The best way to ensure your questions are well worded is to test them by having other people review and test your survey before you distribute it to the full sample.

Ask only one question at a time (the double barrelled question)
This is a very common mistake in survey questionnaires and one that will severely impact the results of your data. When you are writing a question, you must make sure that you are only asking one question at a time.

Here is an example of a double-barrelled question:

Bad Question: Double-barrelled Question	Good Question

How have teachers and students at your school responded to the new 45-minute lunch period? ( ) Satisfied ( ) Unsatisfied	How have <u>teachers</u> at your school reacted to the new 45-minute lunch period? ( ) Satisfied ( ) Unsatisfied How have <u>students</u> at your school reacted to the new 45-minute lunch period? ( ) Satisfied ( ) Unsatisfied

You notice that the double-barreled question is asking about teachers AND students. This means that a "satisfied" response could mean any of the following:

Teachers are satisfied
Students are satisfied
Teachers and students are satisfied

An "unsatisfied" response could mean any of the following:

Teachers are unsatisfied
Students are unsatisfied
Teachers and students are unsatisfied

Since the question was phrased in such an ambiguous way, you will not know what the respondent intended with their response unless you ask them, invalidating your data.

To solve this problem, you simply need to break this question into two separate questions, as shown in the example above.

You will also notice that the two rephrased questions above are very similar and that the key word (which differentiates the two questions) has been underlined. This is a good technique to ensure that the respondents are reading the questions correctly when the structures are so similar.

Make sure the questions are unbiased
When developing your survey questionnaire, you want to make certain that you are asking the questions in a neutral way, ie that you are not leading them toward a particular answer. This may seem simple, but when you are writing questions you will often find that the way you phrase the question may reflect your underlying opinion. Here is an example of a leading question:

Example of a Leading Question and How to Correct it

Bad Question: Leading

Do you think that the new cafeteria lunch menu offers a better variety of healthy foods than the old one?
( ) Yes
( ) No
( ) No Opinion

Good Question: Neutral

How do you feel about the new cafeteria lunch menu compared to the old one?
( ) The new menu offers a better variety of healthy foods
( ) The old menu offers a better variety of healthy foods
( ) The selections are similar
( ) No opinion

The leading question drives the respondent to the conclusion that the new menu is healthier than the old. A yes response to this question is the easiest, and many respondents may simply take the path that requires the least amount of thinking. The neutral question presents a better way to phrase this question by removing the bias.

Ask questions that can be answered by your subjects
Make sure that the questions you are asking are questions that people will be able to answer. The most common mistake is to ask questions that most people simply cannot remember. Here is an example:

How much did you spend on school supplies last year?
( ) $0 - $10
( ) $11 - $20
( ) $21 - $30
( ) over $30

While this question appears to be perfectly acceptable, it is unlikely that many students will really remember how much they spent on school supplies. Most responses will probably be guesses rather than actual numbers, and many respondents may become frustrated trying to calculate in their heads how much they spent. If a guess is all that you are looking for, then simply rephrasing the question to the following will make it much easier for the respondent.

How much do you estimate you spent on school supplies in the last year?
( ) $0 - $10
( ) $11 - $20
( ) $21 - $30
( ) over $30

Order/group questions according to subject
If you have more than six questions in your questionnaire, then you should make an effort to organize your questions so the respondents can answer them as quickly as possible. A good way to organize the questions is to group them together by subject. This way your respondents can focus their thoughts and answer a series of questions around these thoughts.

Present the questions in a clean and organized layout
A clean layout will make it much simpler for people to respond to the questions and for you to collect the data. Make sure that your method for marking answers is well explained and that your answer boxes are consistent throughout the questionnaire. See the following links for some sample survey questionnaires from Science Buddies.

Test the survey questionnaire
Once you have developed your survey questionnaire, you should conduct a small test (5 -10 people) to make sure that respondents clearly understand the questions you are asking and that you are capturing the information that you need for your study.

Reference List

http://www.sciencebuddies.org/mentoring/project_ideas/Soc_survey.shtml
http://www.sciencebuddies.org/mentoring/project_ideas/Soc_observation.shtml

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You can find more documents of this type at:
http://www.sciencebuddies.org
Science Buddies Sample Survey 1: Advisor Survey
Science Buddies Sample Survey 2: Teacher Survey

The Innovation:

A project of this type would be one involving the development and evaluation of innovative devices, models, techniques, or approaches in such fields as technology, engineering or computers.

Outline

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- Do a Materials List & Preliminary Designs Instead of Materials List & Experimental Procedure
- Build & Test a Prototype Instead of Conducting an Experiment
- Redesign & Retest versus Data Analysis & Graph

Comparing the Scientific Method and the Engineering Process

Scientists study how nature works; engineers and computer programmers create new things such as machines, programs, and techniques. Because engineers and computer programmers have different objectives than those of scientists, they follow a different process in their work.

Comparison of the Scientific Method and the Engineering Design Process

The Scientific Method	The Engineering Process
State your question	Define a need
Do background research	Do background research
Formulate your hypothesis, identify variables	Establish design criteria
Design experiment, establish procedure	Prepare preliminary designs
Test your hypothesis by doing an experiment	Build and test a prototype
Analyze your results & draw conclusions	Test & redesign as necessary
Present results	Present results

This guide will describe the engineering process in detail and highlight how it can be applied to a science fair project in many areas of engineering and computer science. Note: If you are doing an engineering or programming project, it's still important for you to read the other "how-to" material for non-engineering projects. It contains a lot of important information that we do not repeat in this document.

Overview of the Engineering Process

One important concept comes up again and again in the engineering process; it's called *iteration*. Iteration is a procedure in which you repeat a sequence of steps, each time coming closer to your goal. While it would be nice to do everything once and have a perfect design, there are actually some pretty good reasons why iteration is the norm. We will be iterating our description of the engineering process (see, we can't even describe the process without iterating), and by the end of this document you should have a good understanding of why iteration is a normal and in fact desirable part of engineering design!

Let's look at the engineering process in more detail:

Define a Need:
What do users of your product need? Is it a new version of an existing product that has more speed, lighter weight, or lower cost? Or, is it a product with an entirely new combination of features never before seen, like the first light bulb invented by Edison in the 1800's.

Do Background Research:
Investigate what others have already learned about your idea. Gather information that will help you design your invention. Don't reinvent the wheel.

Establish Design Criteria:
Design criteria are requirements you specify for your design that will be used to make decisions about how to build the resulting product. For example, you might set out to design a baseball bat that has design criteria calling for the same strength and size as an aluminum bat, but half the weight. These criteria would rule out making the bat from balsa wood (not strong enough) or steel (too heavy). They would lead you to look at materials like carbon fiber composites (very cool stuff, but expensive).

Prepare Preliminary Designs:
Good engineers look at a variety of different possible designs before moving forward. It's much faster and cheaper to look at alternatives on paper before actually building something. At the same time, a good set of plans will uncover problems that are expensive and time consuming to fix once you're actually building something. Each preliminary design is likely to have some good points and some bad. As you continue to generate new designs you incorporate more and more of your best ideas. You guessed it -- you iterate your designs!

Build and Test a Prototype:
A prototype is the first full-scale and functional model of your invention. You build it from what you think is the preliminary design that best meets your design criteria. Sometimes it is impossible to meet all your design criteria and you need to choose a compromise.

Redesign & Retest as Necessary:
Almost every prototype has unanticipated flaws, things you overlooked or design features that did not work the way you intended. Engineers redesign their products to "get the bugs out," and retest them until everything is as it should be. This process of redesign and retest is another example of iteration.

Present Results:
In a science fair you present your results as with any other science fair project, by showing your work on a display board and by demonstrating your invention if possible. Of course, engineers working in industry present their results by putting the product into manufacturing so that others can buy it.

Who Should Use the Engineering Process for Their Science Fair Project?

In real life, the distinction between science and engineering is not always clear. Scientists often do some engineering work, and engineers frequently apply scientific principles, including the scientific method. Much of what we often call "computer science" is actually engineering -- programmers creating new products. Your project may fall in the gray area between science and engineering, and that's OK. Many such projects can and should use the scientific method.

However, if the objective of your project is to invent a new device, procedure, computer program, or algorithm, then it may make sense to follow the engineering process.

Below we highlight some things you would do differently for the steps or assignments of completing a science fair project if you follow the engineering process.

Important Note:

Most but not all science fairs accept engineering projects completed using the engineering process. Some even encourage it. However, if in doubt, you should check with your fair before you follow the engineering process instead of the scientific method.

Define a Need Instead of Asking a Question

Instead of stating a question, engineers state a customer need. What is it that you think customers want? Later you'll have an opportunity to refine what you believe are the customer needs when you specify the design criteria.

Background Research Plan & Bibliography

If you follow the engineering process your bibliography will be the same as for other projects, but you need to ask additional questions in your background research plan. In addition to understanding the science of how your invention will work, you also need to:

Define your target user or customer.
Everything man designs is ultimately for the use of another human. (Think about it, even products designed for animals or plants are first purchased by another human being!) Your choice of target user will sometimes have a big impact on your design criteria. For example, let's think about our baseball bat example. Imagine you want to design a bat with the same strength and size as an aluminum bat, but half the weight. If your target user is a child, then cost would also be very important. If your target is a professional baseball player, cost might be less important, but league rules about what materials can be used for bats would be very important. You might specify your target user in any number of ways. Here are some examples:

- Age (old, young, infant)
- Gender (in America you wouldn't sell many dresses made for boys!)
- Occupation

- Hobby interests
- Amateur or professional
- Disabled or not disabled
- First time user or experienced user

Research what already exists to fill the need you defined, or needs that are very similar.
No one wants to go to all the trouble of designing something they think is new, only to find that several people have already done it. Jeeez, would that be depressing? So, you want to investigate what's already out there, only then can you be sure that you're making something that better fills a need. And, keep in mind that what is "better" depends on your criteria. You might want to build something that's been around for hundreds of years, but do it with recycled materials from around the house. The device might be old, but the construction materials new (or used!).

Do research that will help you establish your design criteria.
Defining your target user and researching other products set the stage for your next step -- researching possible design criteria.

Now let's look at how to generate actual research questions.

These are some example questions that will help you understand the science needed for your design.

- How does a __________ work?
- What are the different parts of a __________?
- What are the important characteristics of a __________?
- Why is __________ made from or using __________?
- What is the best material, component, or algorithm for building ________? [You may even ask this for different parts of your device or program.]

After you clarify the definition of your target user, you'll want to ask questions like this:

- What does my target user [a child, an elderly person, whomever your target user is] need in a _________?
- How much would my target user be willing to pay for a _________?

Then, ask questions to help you understand products or programs that fill similar needs to the need you identified:

- What products or programs fill a similar need? [Duh, that question is pretty obvious.]
- What are the strengths of products or programs that fill a similar need?

- What are the weaknesses of products or programs that fill a similar need?
- Why did the engineers that built products or programs that fill a similar need design them the way they did?
- How can I measure my design's improvement over existing designs?

All the above questions seem fairly straightforward, don't they? Now things get a little trickier when we start thinking about possible design criteria to research. Anything that can be measured or perceived by your senses can be a design criteria for an invention, the possibilities are truly limitless. Limitless! That probably reminds you of that bad dream you had with your teacher asking you to write a 500-page paper by tomorrow morning. But, don't panic. Only a handful of potential design criteria are likely to be important for your project; the trick is deciding which ones.

A good place to start is your need statement. In your need statement you probably called out a need that either specifies or at least suggests some design criteria. For example, if we want to design a bat with the same strength and size as an aluminum bat, but half the weight, then likely research questions would be:

- What materials are lighter, but at least as strong as aluminum?
- How can I measure the improvement coming from a material that is lighter and stronger than aluminum?

You'll probably want to do part of your research plan and part of your research, and then iterate. Understanding the science, customer needs, and products or programs that fill similar needs will give you more ideas for design criteria that you should research.

Nonetheless, just to help you brainstorm, here are several lists of possible design criteria. It would be rare if all the ones important to you were here; it would be equally rare (but still possible) that none of yours are here.

Sample Design Criteria

Cost is almost always a design criteria - Cost to purchase - Cost to use - Cost to repair	How does it look (we call this aesthetics) - Style (art deco, Victorian, modern, medieval) - "Fit and finish" (is it built with care and attention to detail)
Geometry - Size, overall dimensions - Curvature	Capacity (how many and how big are the things it can work with)
Physical characteristics - Weight	Performance characteristics - Accuracy

- Density
- Melting, boiling point
- Color- Transparency
- Reflectance
- Surface texture (polished, rough)
- Elasticity
- Hardness
- Ductility (capable of being drawn out or hammered thin)
- Magnetic properties
- Electrical properties (resistance, impedance, etc.)
- Impact resistance
- Bending strength
- Viscosity

- Strength
- Reproducibility, repeatability (does it always do the same thing given the same input)
- Speed
- Acceleration
- Deceleration, braking
- Rolling resistance
- Friction
- Adhesion
- Absorbency
- Permeability (do things leak through it)
- Resolution
- Flammability
- Insulation value

Inputs
- Energy consumption
- Fuel consumption
- Labor

Outputs
- Product produced
- Power
- Pollution
- Undesirable side effects ___________

Manufacturing considerations
- Difficulty of making
- Equipment or manufacturing techniques required to build the invention (you don't want to build something from metal if all you have is a woodworking shop)
- Number of component parts
- Labor requirements
- Means of shipping or delivery

Environmental requirements
- Operating temperature range
- Storage temperature range
- Water resistance
- Resistance to corrosion
- Compatibility with ___________
- Ability to withstand radiation (called radiation hardness)

User requirements
- Ease of learning
- Ease of use
- Operator training

Regulatory & licensing considerations
- Meets government rules
- Meets league rules (a sporting product)
- Does it require paying a patent or license fee

How does it hold up?
- Service requirements
- Ease of repair

Acoustic characteristics
- Pitch
- Sound transmission

- Reliability - Lifespan - Disposability	- Resonance

Sample Design Criteria for Software Programs

Software Products & Programs	The Computer Environment for Software Products & Programs
- Functionality or feature set - Capacity (how many and how big are the things it can work with) - Type of user interface (command line, standard Windows or Mac look & feel, totally unique) - Customizability - Speed, responsiveness (be specific: speed of what) - Ability to communicate with other programs (data import / export) - Type of error handling (none -- *not recommended!*, error number, messages with help) - Programming language written in - Portability (ability to move to another operating system) - Ability to modify to work in other spoken languages (this is often called localization)	- Operating system - CPU speed - Memory size - Display size and number of colors supported - Single user or network environment - Peripherals required (scanners, printers, disk drives) - Other software required (language interpreters, browsers, etc.)

Every product area has some of its own criteria; these are just a few examples:

Clothing - Comfort, wear ability - Fabric - How to clean (dry clean or throw it in the wash) - Iron or permanent press	Aircraft & Rockets - Lift - Drag - Thrust
Food Products - Taste	Genetically Engineered Bacteria - Gene to be added or deleted

- Nutrition value - Perish ability (how and how long can it be stored)	- Characteristics of gene expression

Summary

For a project in engineering or programming, follow these steps to complete your background research plan:

- Identify the keywords in the needs statement (question) for your science fair project.
- Generate questions to help you understand the science needed for your design.
- Define your target user or customer.
- Ask questions to help you understand products or programs that fill similar needs to the need you are trying to fill.
- Use your needs statement to identify some likely design criteria to research, and review the above list of design criteria to see if some apply to your project.
- Iterate!

Review of Literature

For an engineering or programming project, the Review of Literature should include:

- The definition of your target user
- Answers to research questions about the science behind your design area
- Answers to research questions about user needs
- Answers to research questions about products that meet similar needs
- Answers to research questions about design criteria
- And, a brief discussion of any important design tradeoffs

What's a design tradeoff? Sometimes you will have design criteria that "fight each other" or tend to move in opposite directions. For example, materials to make our baseball bat lighter in weight are probably more expensive the lighter they are. You can't have the lowest weight and the lowest cost at the same time; therefore, when we design our bat we will have to make a tradeoff between cost and weight. Design tradeoffs are very, very common. Almost every project has some.

Establish Design Criteria Instead of Variables and Hypothesis

As we mentioned in the beginning, engineering projects (at least the ones involving the invention of a new product or program) don't really have variables and a hypothesis, instead the next step is to establish design criteria.

We already discussed design criteria a couple times, so we must be iterating. Yup, we are. Hopefully, by now you have a much better understanding of what the most important design criteria are to successfully meet the need called out in your question.

How many criteria should you have? That's a really good question, without a good answer. You should have neither too many nor too few. (Oh, that's a big help!)

The reality is that experience is very important in deciding how many design criteria are important. It's another good time to ask your mentors, parents, and teachers for advice, but do so by asking specific questions. Tell them the design criteria you are considering and ask them which ones you might be able to do without.

Here are some other thoughts to help you. If you have too many design criteria, it can become very difficult to actually design and build a product. Imagine having a friend whose parents have set ten times as many rules as your parents. (Wow, scary thought.) Such an imaginary friend might have difficulty doing things because he or she would always be violating one of the rules. Having too many design criteria (criteria are a type of "rule") creates a similar situation. With too many criteria, design tradeoffs increase and many design decisions become unnecessarily complex.

What is "too many" depends on the product. An airliner might have thousands of design criteria and that could be just right. For a project that you have time to complete for the science fair, two or three, maybe five design criteria are appropriate.

Why might too few design criteria be a problem? If you have too few criteria you might get a result that you don't really want. Let's say we built our lightweight, high-strength baseball bat, but it cost $10,000 for the prototype. When your parent gets the bill, you would experience a very bad result! The baseball bat should have at least one more criteria, one for its cost. So, don't be a slacker on your design criteria.

By the way, professional engineers call a design with too many criteria *over constrained* (as if it had too many rules) and one with too few criteria *under constrained* (as if it had too few rules).

Do a Materials List & Preliminary Designs Instead of Materials List & Experimental Procedure

Engineering projects have a materials list, programming projects probably don't. While both engineering and programming projects *could* have a procedure, it makes more sense to prepare preliminary designs at this stage of the process.

You might be asking why you need a design, let alone need to iterate your designs. Iterate, schmiterate; you might think you've got it all in your head. You wouldn't be the first person to feel this way. In a book he wrote, here's what the founder of Science Buddies said about building things during his youth:

"Being extremely impatient, I hated to draw plans before I started building--it took too much time! My dad was an excellent draftsman and he always drew a sketch before building anything. He tried to teach me to do the same, but instead I liked to just visualize everything in my head, then hammer away. As the things I built became more and more complex, the lack of adequate plans became troublesome. I remember when I first tried a telescope mount I was building. As I swung it around the polar axis, it clanged into another part of the mount and I had to rebuild it so I could look at the whole sky. Eventually, I learned what my father had been trying to teach me: it's important to have a plan" (Hess 2001, 3).

Rarely is your first design the best (often it won't even work). Iterate until you have a good plan.

And, just in case it's not obvious, you need to put your designs on paper (or type them into a computer). You'll see things you wouldn't see in your head, and you'll be able to refer back to your plans to remember details you would otherwise forget. Written or printed designs and plans also let you share your ideas and get feedback from other people.

Build & Test a Prototype Instead of Conducting an Experiment

When others are conducting their experiment, Investigators doing an engineering or programming project should be building and testing a prototype of their best design.

Important tip:
Make sure you involve some of your targeted users in your testing. It's vital to get their feedback about your design.

Redesign & Retest versus Data Analysis & Graph

When engineers and programmers test and retest their creations, they too are doing data analysis. For example, they might measure the performance or improvement of their creation. So, even though we call this step "Redesign and Retest," it usually involves data analysis, just like for a project using the scientific method. Almost always, you will want to present the results of your testing and retesting in a graph.

Reference List

Hess, Kenneth L. *Bootstrap: Lessons Learned Building a Successful Company from Scratch.* Carmel, California: S-Curve Press, 2001.