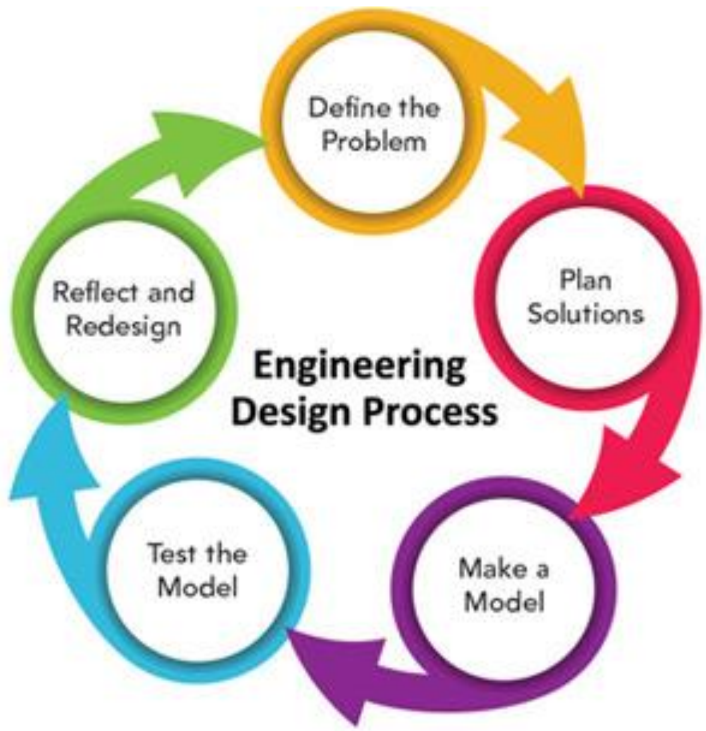
# 2016-2017 Ashford Park Fifth Grade STEM Fair
# Engineering Design Project Guide

## The Engineering Design Process




- The engineering design process is a series of steps that engineers follow to come up with a solution to a problem. Many times the solution involves designing a product (like a machine or computer code) that meets certain criteria and/or accomplishes a certain task.
    - This process is different from the Steps of the Scientific Method, which you may be more familiar with. If your project involves making observations and doing experiments, you should probably follow the Scientific Method. If your project involves designing, building, and testing something, you should probably follow the Engineering Design Process.

- The steps of the engineering design process are to:
    - **Define the Problem**
    - **Do Background Research**
    - **Specify Requirements**
    - **Brainstorm Solutions**
    - **Choose the Best Solution**
    - **Do Development Work**
    - **Build a Prototype**
    - **Test and Redesign**
- Engineers do not always follow the engineering design process steps in order, one after another. It is very common to design something, test it, find a problem, and then go back to an earlier step to make a modification or change to your design. This way of working is called **iteration**, and it is likely that your process will do the same!

Engineers and designers use the engineering design process, shown in the diagram and table, to solve a problem by creating new products, systems, or environments.

# One: The Problem

**Define the Problem.** The engineering design process starts when you ask the following questions about problems that you observe:

- What is the problem or need?
- Who has the problem or need?
- Why is it important to solve?
- [Who] need(s) [what] because [why]?

Finding an idea for your engineering project requires you to identify the needs of yourself, another person, or a group of people. The act of looking at the world around you to identify these needs is called **need finding**.

To help you find an idea for your engineering project:

- Create a list of all the things that annoy or bother the people around you. Record this bug list in your Design Notebook. (See "Design Notebook" for further explaination)
- Mind Map possible design problems, ideas, or areas of interest to you. (See "Mind Map" for further explanation")

Once you have found an idea for your engineering project, describe the problem by writing a **problem statement**. Your problem statement must answer three questions:

- **What** is the problem or need?
- **Who** has the problem or need?
- **Why** is it important to solve?

The format for writing a problem statement uses your answers to the questions and follows these guidelines:

- **Who** need(s) **what** because **why**.
- _____ need(s) _________ because ________

## Finding an Idea for Your Engineering Project

You know that you want to do an engineering design project, but how do you come up with an idea or find a problem to solve? How do you uncover a new problem that no one has tried to solve yet? Or how do you pick and choose, from all of the products, systems, and environments already out there, one that you might want to improve? This process of uncovering a problem, or identifying the need for change or improvement to an existing solution, is called need finding.

One really great way to start the need-finding process is to make a "bug list." Think about all of the things that bug you or bug other people around you. Write them down. They may seem like small and silly problems, but they can spark ideas for a project or lead to larger problems that you may not have noticed otherwise.

Here are some examples of things you might find on someone's bug list:

- Uncomfortable airplane seats
- When one light on a string of Christmas lights goes out
- How quickly chewing gum loses flavor
- Moving (packing boxes, cleaning, unpacking, etc.)
- Public restrooms without toilet paper
- Long lines at amusement parks
- When food gets stuck in vending machines
- Dog or cat hair that gets stuck on clothing
- Sharing armrests with strangers at the movies
- Wasting water in the shower
- Losing one earring
- Draining tuna fish cans

Challenge yourself to come up with as many bugs as you can. They don't all have to be things that bother you; think about other people and the problems that they face as well. You will be surprised at the number of bugs you can identify in the world around you. Start this list in your design notebook, and spend a few days recording your ideas.

Notice that there are two different types of potential project ideas that you have come up with on your bug list. First, there are the unsolved problems that don't currently have a solution. Second, there are poorly solved problems that have solutions, but the solutions are not entirely successful.

***Still need help selecting a project idea? Take a quiz on sciencebuddies.org for awesome STEM project ideas tailored to your interests! However, encourage your child and his/her group to think of their “own problems” as this will make their projects more authentic, original, and special to them.***

### Unsolved Problems

One problem identified in the bug list is the issue of food getting stuck in a vending machine. There is currently no solution for this problem. If you put your money in the machine, select the food that you want, and then, the food gets stuck before it can drop to where you can reach it—you are out of luck. You might try shaking or kicking the machine, but those are not designed solutions to the problem. In cases of unsolved problems, your engineering project would be to attempt to solve the problem. For this example, possible project ideas might be to design a product that can be used to remove stuck foods from vending machines or a new vending machine that makes it impossible for food to get stuck.

### Poorly Solved Problems

An example of a poorly solved problem from the bug list is the issue of cat or dog hair getting stuck on clothing. There is currently a solution to this problem—the lint brush. However, many people still complain about annoying pet hair on their clothes. Clearly, the lint brush is not the perfect solution. In cases of poorly solved problems, your engineering project would be to improve the existing solution or to replace the existing solution with something more successful. For the pet hair example, possible project ideas might be to make the lint brush more effective at removing hair from clothing or to design something better than the lint brush for the same purpose.

Whether you want to choose an unsolved problem or a poorly solved problem for your engineering project, there are plenty of problems out there! Keep in mind that the problems already exist; you just need to identify them and their users. Also, doing an engineering design project doesn't always mean inventing something brand new—it often involves bettering the projects of those before you.

## Defining the Problem

Engineers solve problems by creating new products, systems, or environments. Before creating something, it is very important to define the problem. Otherwise, you might build something only to find that it does not meet the original goal!

To define your problem, answer each of these questions:

- What is the problem or need?
- Who has the problem or need?
- Why is it important to solve?

The answers to these three questions are the what, who, and why of your problem. Your problem statement should incorporate the answers as follows:

[*Who*] need(s) [*what*] because [*why*].

In design terms, who, what, and why can be defined as:

Who = user
What = need
Why = insight

The problem statement for any good engineering design project should be able to follow the format shown. Your problem statement should always look like this:

_________ need(s)________because____________.

If you are improving an existing solution for your project, keep in mind that the improvements will be part of your problem statement. Making something better, faster, or cheaper should be part of your statement—either in the "what" portion and/or the "why" portion. For example, if you are improving a car radio, your problem statement might be:

People need cheaper and better-performing car radios, because current radios are expensive and poor at picking up weak radio signals.

# Problem Statement Examples

Here are some additional examples of engineering design problem statements:

Students need an easier way to lock their lockers at school, because combination locks are hard to unlock and often get jammed.

Dogs need a way to go to the bathroom inside homes, because dogs don't like to go outside in bad weather, and there are times when people can't take their dogs outdoors.

Teachers need a better way to erase chalkboards, because erasers are messy and don't remove all of the chalk.

Parents need a way to store lunchboxes in the refrigerator, because they often make their children's lunches the night before school.

# Evaluating Your Problem Statement

The problem that you select for your engineering design project is the cornerstone of your work. Your research and design work will all revolve around finding a solution to the problem you describe. Here are some characteristics of a good problem statement:

- The problem should be interesting enough to read about and work on for the next couple months.
- There should be at least three sources of written information on the subject, as well as similar products to analyze. You want to be able to build on the experience of others!
- The problem is specific enough to allow you to design a solution.

For an engineering project, it is important to think ahead to avoid difficulties and save you lots of unhappiness later. Imagine what you might design and make to solve your engineering problem. How does your possible solution stack up against these issues?

- Can you think of a way to measure whether your solution is better than what already exists? It is always best if you can measure your improvement numerically: cheaper in dollars, faster in time, etc.
- Can you design a solution that is safe to build, use, store, and dispose of?
- Do you have all the materials and equipment you need for your solution, or will you be able to obtain them quickly and at a very low cost?
- Do you have enough time to complete your design and make it before the due date? Allow time for doing additional research and fixing problems. It is very rare for everything to work correctly the first time.
- Does your project meet all the rules and requirements for your science fair, if you are entering one? Have you checked to see if your science fair project will require approval from the fair before you begin construction?

If you don't have good answers for the stated issues, then you probably should look for a better engineering design problem to solve.

# Mind Mapping

Mind mapping refers to a technique that designers and engineers use to express and generate ideas. All that mind mapping really is, however, is a way to get all of the ideas in your head down onto paper. There is no right or wrong way to mind map. It is simply a visual representation of the thoughts in your head, and it often looks like organized chaos.

**Why Mind Map?**

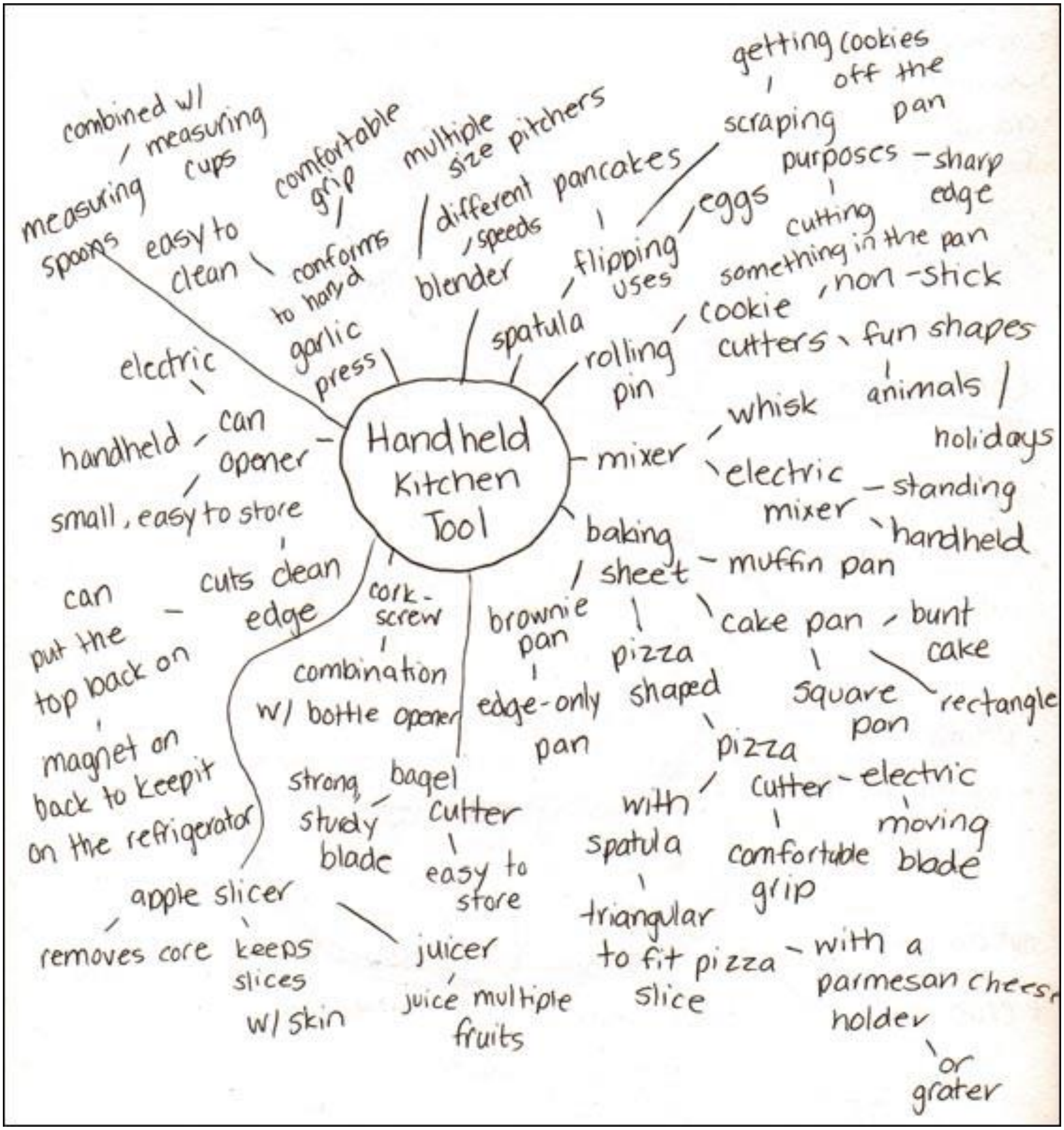
Mind mapping helps you to release all of the ideas in your head and gives you the opportunity to see those ideas visually. It is a fast and simple way to get your creative juices flowing, and the only tools you need are a pen or pencil and your design notebook.

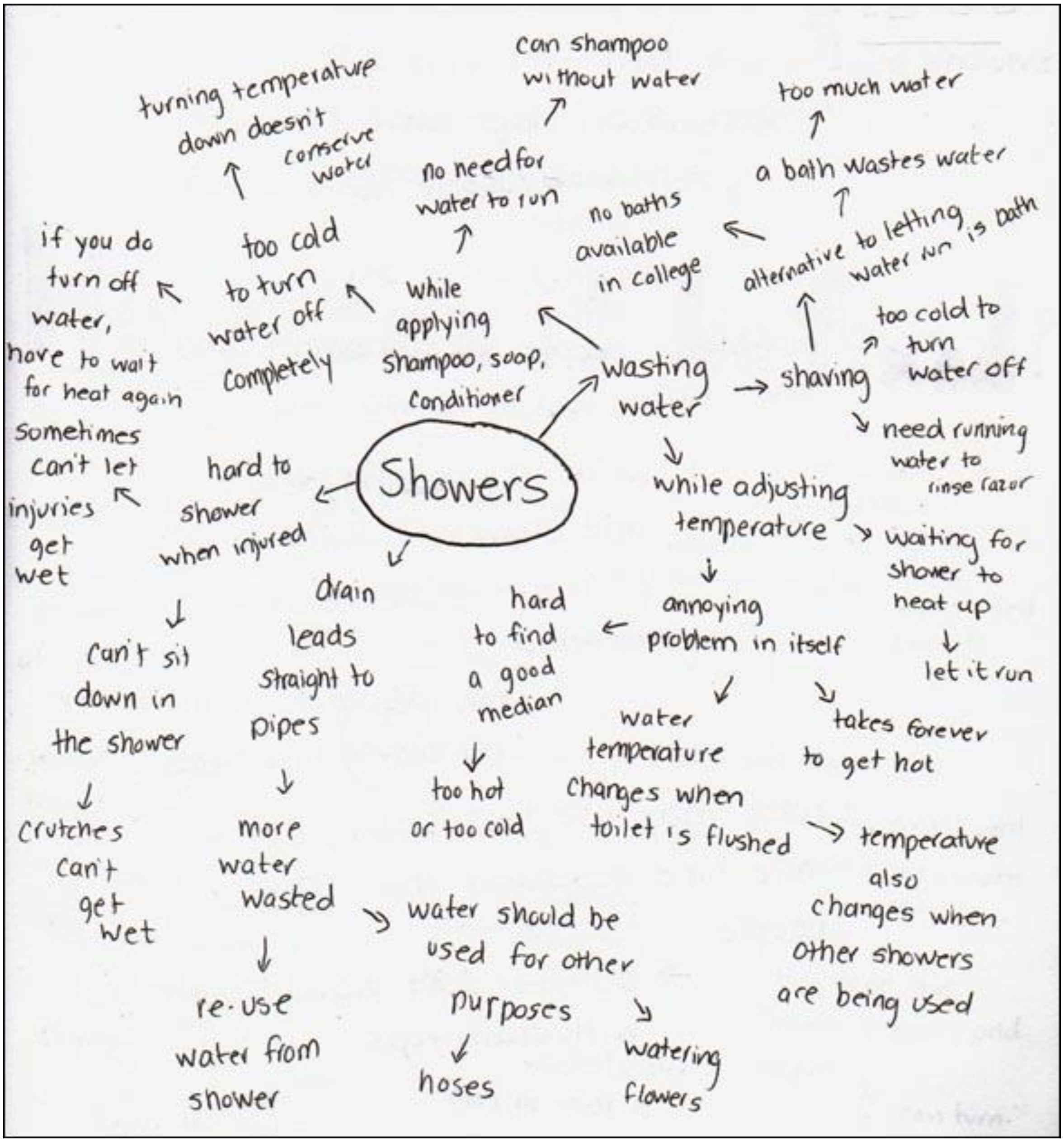
**How to Mind Map**

To start a mind map, write down one, central idea or theme in the middle of a blank page. All mind maps have this common starting point. Then, stem off of the central idea by writing down anything that comes to your mind when thinking about the idea. You can include drawings, questions, comments, solutions, problems, etc. There are no limits. Simply write down everything that relates to the central theme or anything that enters your mind.

## When and What to Mind Map

You can create a mind map at any stage in your design process and for absolutely any purpose. You can mind map at the very beginning before you have even decided what problem you are going to solve. You can also mind map to generate possible solutions to your problem or to identify different types of users for your project. Mind map whenever you feel the need to empty the thoughts in your head or whenever you feel stuck during the design process.


Handheld Kitchen Tool
combined w/ measuring cups
measuring spoons
comfortable grip
conforms to hand
easy to clean
multiple size pitchers
different pancakes
speeds
blender
garlic press
spatula
flipping
uses
eggs
scraping
getting cookies off the pan
purposes
sharp edge
cutting something in the pan
non-stick
rolling pin
cookie cutters
fun shapes
animals
holidays
whisk
mixer
electric mixer
standing
handheld
baking sheet
muffin pan
cake pan
bunt cake
square pan
rectangle
pizza shaped
pizza cutter
electric
moving blade
comfortable grip
with spatula
triangular to fit pizza slice
with a parmesan cheese holder
or grater
brownie pan
edge-only pan
cork-screw
combination w/ bottle opener
can opener
electric
handheld
small, easy to store
cuts clean edge
can put the top back on
magnet on back to keep it on the refrigerator
bagel cutter
strong sturdy blade
easy to store
apple slicer
removes core
keeps slices w/ skin
juicer
juice multiple fruits



Showers
wasting water
while applying shampoo, soap, conditioner
no need for water to run
can shampoo without water
too cold to turn water off completely
turning temperature down doesn't conserve water
if you do turn off water, have to wait for heat again
no baths available in college
alternative to letting water run is bath
a bath wastes water
too much water
shaving
too cold to turn water off
need running water to rinse razor
while adjusting temperature
waiting for shower to heat up
let it run
annoying problem in itself
hard to find a good median
too hot or too cold
water temperature changes when toilet is flushed
temperature also changes when other showers are being used
takes forever to get hot
hard to shower when injured
sometimes can't let injuries get wet
can't sit down in the shower
crutches can't get wet
drain leads straight to pipes
more water wasted
re-use water from shower
water should be used for other purposes
hoses
watering flowers

# Engineering Project Laboratory Notebook

Whether you are a research scientist, an engineer, or a first-time science fair student, you should use a lab notebook to document your science investigations, experiments, and product designs. A lab notebook is an important part of any research or engineering project. Used properly, your lab notebook contains a detailed and permanent account of every step of your project, from the initial brainstorming to the final data analysis and research report. Many science projects require a number of steps and multiple trials. By recording the steps of your procedure, your observations, and any questions that arise as you go, you create a record of the project that documents exactly what you did and when you did it. With a complete record of the project in your lab notebook, you can look back at your notes later if a question arises or if you decide to pursue a related project based on something you observed. Similarly, writing down your product design ideas, engineering challenges, and product testing data will help you keep track of all of your ideas, what you have already tried, and how well a particular design performed.

Keeping a lab notebook is easy! The most important thing to do is to "use" your lab notebook.

# Getting Started with Your Science Laboratory Notebook

Once you have selected a lab notebook, the following tips and techniques will help you get started keeping an organized, well-maintained lab notebook for your science or engineering project:

1. **Label your lab notebook.** Put your name, your teacher's name (if it applies), and some form of contact information, like an email address or phone number, in a prominent location, like the inside cover. If you accidentally leave the lab notebook behind or lose it, someone will be able to reach you if the notebook is found. If your notebook will be used for a single science or engineering project, also label the notebook with the project title and the year.
2. **Use ink.** Make your lab notebook entries in pen, not in pencil. Using a smudge-proof pen may reduce the risk of smears. If you make a mistake in your lab notebook, simply *cross out* the error and write in the necessary correction.
3. **Number the pages.** Numbering the pages of your lab notebook helps keep your notebook organized. You can use these numbers to set up an index or table of contents or to cross-reference earlier observations within your lab notebook. If the pages of your lab notebook are not already numbered, you may want to number them *before* you begin using the lab notebook.
4. **Create a table of contents.** To quickly go back and find information in your lab notebook, it helps to create a table of contents. The traditional way (used by professional scientists and engineers) is to create a Table of Contents as you go. Label the first page "Table of Contents," and then as you work on the project, enter important pages in the Table of Contents. For example, when you begin your Experimental Procedure, you might note "Trial 1, Page 10" in the Table of Contents so you can quickly find your notes at a later date.

5. **Date your entries.** Always date your lab notebook entries. Even if your entry is very short, adding a date helps you track *when* you took certain steps or made certain observations. Your lab notebook will be a *sequential* record of your project, so the dates are important.
6. **No blank pages.** Your lab notebook entries should be entered consecutively, starting at the front of the notebook. When making entries, do not skip pages. (If you are using sections, as outlined above, do not skip pages within a section when making a new entry.) Scientists and researchers often cross out unused sections of a page so that nothing can be added later that might alter or confuse the data originally recorded.
7. **Be brief.** While some entries in your lab notebook may require in-depth notes, many of your entries will be short and concise. Full sentences are not required! Every scientist develops her own style of recordkeeping. What is important is that you record *enough* information so that you fully understand the notes you've made and so that the notes contains all important or necessary details. Looking back at an entry, even months later, it should be clear to you *exactly* what you did or documented on that day. It should also be clear to your teacher or another scientist or engineer!
8. **Keep it legible.** Your lab notebook entries should be easy to read, but do not worry if the entries are not perfectly neat or if you make a mistake.
9. **No loose papers.** Be sure to secure loose papers in your lab notebook with glue, tape, or staples. Unsecured items (including sticky notes) may fall out or be damaged. If there are digital materials you want to include in your lab notebook, you may find it helpful to print them at a reduced size and then glue or tape them into the notebook.
10. **Do not remove pages.** If something is wrong on a page, or if you discover an accidental blank page, simply put a large "x" through the area or page, signaling that it should be ignored. Do not tear pages out.
11. **Keep it with you.** You want to record every single detail of your science or engineering project in your lab notebook, so you need to make sure you have it with you at all times, especially when you are in the lab, working on your procedure, doing research, or collecting data. Do not take the chance that you will remember all of the details to record at a later date. You also do not want to make a habit or recording data on scraps of paper and entering them in the lab notebook after the fact. Loose papers are easily lost. Keep the lab notebook with you and make your entries on the spot.
12. **Do it every day.** Get in the habit of starting a new entry as soon as you go to the lab or begin working on your science project for the day, even if you are only taking a quick measurement or doing a visual check. Write down the date and then record what you do. As you get in a routine of documenting your research and experiment every day, using your lab notebook will become an important part of how you navigate a science or engineering project!

# Keeping Track of Your Engineering Project

Now that you have a lab notebook and an understanding of organizational strategies that can help you make the most of your lab notebook, it is time to start recording your science or engineering project. What should you include? **Everything!**

Your lab notebook should be used from the beginning of your project and should reflect all phases of your project (engineering method.) Someone looking at your lab notebook should be able to follow your steps through the engineering project, from beginning to end. In your lab notebook, you want to document and include the following kinds of information:

- **Project planning.** As you plan your engineering project, use your lab notebook to capture the questions you hope to investigate, your hypothesis, and your variables.
- **Research.** Record your background research, noting sources you use (including URLs or bibliographic data). Summarize articles and publications you review (or plan to review) during your background research, any interviews you conduct, and notes related to feedback, suggestions, or troubleshooting you receive from a teacher or mentor. This information will make compiling your bibliography much easier!
- **Materials.** Document the materials you use (including specific brands, quantities, and costs).
- **Experimental procedure.** Record all details related to your experimental design, setup, and procedure. As you begin your experiment, document your steps, trials, and observations. Be sure and clearly note any modifications you make and any problems you encounter, including any mistakes. Even if it seems trivial or inconsequential, you should write it down.
- **Data collection.** Your data is critical to your science project and to the conclusions you will draw at the end of the project. As you gather data, be careful to accurately enter *all* numbers, measurements, temperatures, calculations, or other data. It is best to enter **all** data **directly** in your lab notebook. If you have data logged electronically, keep a list of log dates and file names and tape or glue printed copies into your lab notebook when possible.
- **Visual records.** Diagrams and charts can be very important in helping you record your science or engineering project. When appropriate, draw a figure in your lab notebook to visually record an aspect of your project. Be sure to date and label, or annotate, the drawing.

# A Successful Laboratory Notebook

- Make entering notes about your project in your lab notebook a routine part of your science project. When it is time to put your final presentation together, you will be glad for the time you spent documenting your project in your lab notebook! An organized and well-maintained lab notebook may impress teachers and science fair judges, and if you are asked questions about specific steps of your project, you will have the information at hand!

# Two: Background Research Plan for an Engineering Design Project

## The Focus of Your Background Research

For an engineering design project, you should do background research in two major areas:

- Users or customers
- Existing solutions

### Users or Customers

- **Research your target user or customer.** Everything humans design is ultimately for the use of another human. (Think about it— even products designed for animals or plants are first purchased by another human!) Your choice of target user will sometimes have a big impact on your design requirements. For example, if you design something for a toddler, you need to make sure that there are no small parts that could be swallowed. Some customers are more sensitive to the cost than others, and so forth. You might describe your target user in any number of ways. Here are some examples:
    - Age (old, young, infant)
    - Gender
    - Occupation
    - Hobby interests
    - Amateur or professional
    - Whether users have disabilities and require accommodations
    - Size
    - First-time user or experienced user

### Existing Solutions

- **Research the products that already exist to solve the problem you defined or a problem that is 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. That would be depressing! So, you want to investigate what's already out there. Only then can you be sure that you're making something that more effectively fills a need. And keep in mind that what is "better" depends on your requirements. 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!).
- **Research how your product will work and how to make it.** When it comes time to build their solution, savvy designers also want to use their research to help them find the best

materials and way to do things, rather than starting from scratch. Background research is also important to help you understand the science or theory behind your solution. If you are entering a science fair, judges like to see that you understand why your product works the way it does and what causes it to perform better than other products.

## How to Conduct the Research

Engineers are lucky, because there are three ways to do research regarding users and existing solutions:

- Observe users first-hand, either as they use a similar product or solution or in the environment in which they encounter the problem.
- Examine and analyze similar products and solutions. Looking at similar products is super important. Other engineers spent a lot of time designing them, so you might as well learn everything you can from their work. And it is fun! You might even want to take similar products apart! (Ask first!)
- Conduct library and Internet research.

## Making a Background Research Plan: How to Know What Information to Look For

When you or your parents are driving a car, there are two ways to find your destination: drive around randomly until you finally stumble upon what you're looking for OR use a GPS or look at a map before you start. Finding information for your background research is similar. Since libraries and the Internet both contain millions of pages of information and facts, you might never find what you're looking for unless you start with a map! To avoid getting lost, you need a background research plan.

## Target Users

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

- Who needs _________?
- Who wants _________?
- Who buys _________?
- What does my target user [a child, an elderly person, etc.] need or want in a _________?
- How much would my target user be willing to pay for a _________?
- What size should I make _________ for my target user?

## Similar Products

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

- What products fill a similar need?
- What are the strengths and weaknesses of products that fill a similar need?
- What are the key, must-have features of products that fill a similar need?
- Why did the engineers that built these products design them the way they did?
- How can I measure my design's improvement over existing designs?

## How It Works and How to Make It

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

- Who invented _________?
- How does a __________ work?
- What are the different parts of a __________?
- What are the important characteristics of a __________?
- How is performance measured for a _________?
- Where does _________ get used?
- What is __________ made of?
- Why is __________ made from or using __________?
- What is the best material, component, or algorithm for building ________? (You may even ask this separately for the different parts of your device or program.)

## Talk to People with More Experience: Networking

One of the most important things you can do while working on your project is talk to other people with more experience than yourself: your parents, teachers, and advisors. This process is called networking. Some advisors or mentors may have had classes or work experience related to the science involved in your project. Others may have used or even designed products like the one you are researching. Ask them, "What science concepts should I study to better understand my project?" Better yet, be as specific as you can when asking your questions.

And by the way, networking is something many adults don't expect students to be good at, so you can probably surprise them by doing a good job at it! The best networkers, of course, enjoy the spoils of victory. In other words, they get what they want more quickly, efficiently, and smoothly.

The reality is we have all networked at some point in our lives. Remember how you "networked" with your mom to buy you that cool water gun or "networked" with your grandpa to buy you that video game you always wanted? Well, now you are "networking" for knowledge. Train yourself to become a good networker, and you might just end up with a better project (and don't forget that you'll get a little smarter too in the process). So take our advice: work hard, but network harder.

## Finding Information for Your Research Paper

### Key Info

- Most teachers will require you to find at least three sources of information.
- How to find information:
    - Find and read the general information contained in an encyclopedia, dictionary, or textbook for each of your keywords.
    - Use the bibliographies and sources in everything you read to find additional sources of information.
    - Search periodical indexes at your local library.
    - Search the Internet to get information from an organization, society or online database.
    - Broaden your search by adding words to your search phrases in search engines. Narrow your search by subtracting words from or simplifying your search phrases.
- When you find information, evaluate if it is **good** information:

| Good References | Bad References |
|---|---|
| Come from a credible source | Come from a source with poor credibility |
| Not too old | Out of date |
| Not biased | Not objective and fair, biased towards one point of view |
| Free of errors | Prone to errors |
| Properly cite the original source of all information | Do not cite where the information came from |
| Easy for other people to find or obtain | Difficult for others to obtain |

## Bibliography

A bibliography is a listing of the books, magazines, and Internet sources that you use in designing, carrying out, and understanding your science fair project. But, you develop a bibliography only after first preparing a background research plan — a road map of the research questions you need to answer. Before you compose your bibliography, you will need to develop your background research plan.

With your background research plan in hand, you will find sources of information that will help you with your science fair project. As you find this information it will be important for you to write down where the sources are from. You can use the Bibliography Worksheet to help you, just print out a few copies and take them with you to the library. As you find a source, write in all of the necessary information. This way, when you are typing your bibliography you won't need to go back to the library and find any missing information. The more information you write down about your source, the easier it will be for you to find if you want to read it again.

When you are writing your report, you will use the sources in your bibliography to remind you of different facts and background information you used for your science fair project. Each time you use some information from a source, you will need to cite the source that it came from. To cite a source, simply put the author's name and the date of the publication in parentheses (Author, date) in your text. If the person reading your report wants to find the information and read more about it, they can look up the reference in your bibliography for more detail about the source. That is why each source you use must be listed in a detailed bibliography with enough information for someone to go and find it by themselves.

Your bibliography should include a minimum of three written sources of information about your topic from books, encyclopedias, and periodicals. You may have additional information from the Web if appropriate.

- Make a list to keep track of ALL the books, magazines, and websites you read as you follow your background research plan. Later this list of sources will become your **bibliography**.
- Most teachers want you to have at least three written sources of information.
- Write down, photocopy, or print the following information for each source you find. You can use the Science Buddies Bibliography Worksheet to help you.

| Collect this information for each printed source: | Collect this information for each Web Site: |
| --- | --- |
| • author name<br>• title of the publication (and the title of the article if it's a magazine or encyclopedia)<br>• date of publication<br>• the place of publication of a book<br>• the publishing company of a book<br>• the volume number of a magazine or printed encyclopedia<br>• the page number(s) | • author and editor names (if available)<br>• title of the page (if available)<br>• the company or organization who posted the webpage<br>• the Web address for the page (called a URL)<br>• the last date you looked at the page |

- The bibliographic information for different types of resources are located in different places, so you may need to do some detective work to get all of the information for your bibliography. Try looking in these places:

    - the title page of a book, encyclopedia or dictionary
    - the heading of an article
    - the front, second, or editorial page of the newspaper
    - the contents page of a journal or magazine
    - the header (at the top) or footer (at the bottom) of a Web site
    - the *About* or the *Contact* page of a Web site

- When it is time to turn in your Bibliography, type all of your sources into a list. Use the examples in MLA Format Examples or APA Format Examples as a template to insure that each source is formatted correctly.

- List the sources in alphabetical order using the author's last name. If a source has more than one author, alphabetize using the first one. If an author is unknown, alphabetize that source using the title instead.

## Writing a Research Paper for Your Engineering Project

As you do your research, follow your background research plan and take notes from your sources of information. These notes will help you write a better summary.

The purpose of your **research paper** is to give you the information to understand why your experiment turns out the way it does. The research paper should include:

- The history of similar experiments or inventions
- Definitions of all important words and concepts that describe your experiment
- Answers to all your background research plan questions
- Mathematical formulas, if any, that you will need to describe the results of your experiment

For every fact or picture in your research paper you should follow it with a citation telling the reader where you found the information. A citation is just the name of the author and the date of the publication placed in parentheses like this: (Author, date). This is called a reference citation when using APA format and parenthetical reference when using the MLA format. Its purpose is to document a source briefly, clearly, and accurately.

If you copy text from one of your sources, then place it in quotation marks in addition to following it with a citation. Be sure you understand and avoid plagiarism! Do not copy another

# Specify Requirements

- **Design requirements** state the important characteristics that your design must meet in order to be successful.
- One of the best ways to identify the design requirements for your solution is to use the concrete example of a similar, existing product, noting each of its key features. Here is how to analyze:
    - A physical product
    - A software product or website
    - An environment
    - An experience

## How to Analyze a Physical Product

When you start to identify your design requirements, you already know what problem you are trying to solve. But what does "solving" your problem really mean? Your design requirements are the specific needs that must be met in order to call your design a solution.

For a physical product, your problem is likely making a task possible or easier for a user to complete. An example is a pair of crutches. The problem statement is:

*People need a way to walk while using only one foot, because they still need to be able to get around when one of their feet or legs is injured.*

1. From the problem statement, you can start asking the right questions to create a list of design requirements. Pull the major need or needs of your solution from your problem statement.

    **Example:** The major needs of a pair of crutches are that they help the user to:

    - Walk while using only one foot
    - Get around and mobilize

2. For each need, ask yourself: "What is absolutely essential to satisfy this need?" Right now, do not brainstorm. Instead, figure out what MUST happen to meet the need in your future solution. Your answers to these questions are your first design requirements. (Note: if you can remove your answer to the question and still meet the need, then your answer is not a design requirement.) The "Needs" table illustrates how to find the first design requirements for the crutches example.

| Major Needs from Step 1 | What is Essential to Meet the Need (Possible Design Requirements) |
|---|---|
| Allow the user to walk while using only one foot | ○ A way for the user to balance |
| Help the user to get around | ○ Light enough to carry<br>○ Small enough to transport |

These answers are all design requirements, because they MUST be a part of your solution in order to meet the need. When you take away "a way for the user to balance," then it is impossible to meet the need for allowing the user to walk while using only one foot.

An answer to this same question that is NOT a design requirement is "a roller blade for the hurt foot or leg." Even though putting the injured foot or leg into a roller blade might allow the user to walk using only one foot, it is not absolutely essential to make the crutches work.

3. What are the physical requirements/limits of the product you are designing? The answers to this question are your next design requirements.

   **Example:** What are the physical requirements/limits of a pair of crutches?

   - Less than 2 pounds
   - Adjustable between 4 feet and 6 feet tall
   - Able to hold up to 200 pounds of weight

4. What are the conceptual requirements/limits of the product you are designing? These are requirements that are not related to the physical nature of the product, but still must be met in order to make your solution successful. Examples often include cost and the timeline of the project.

   **Example:** What are the conceptual requirements/limits of a pair of crutches?

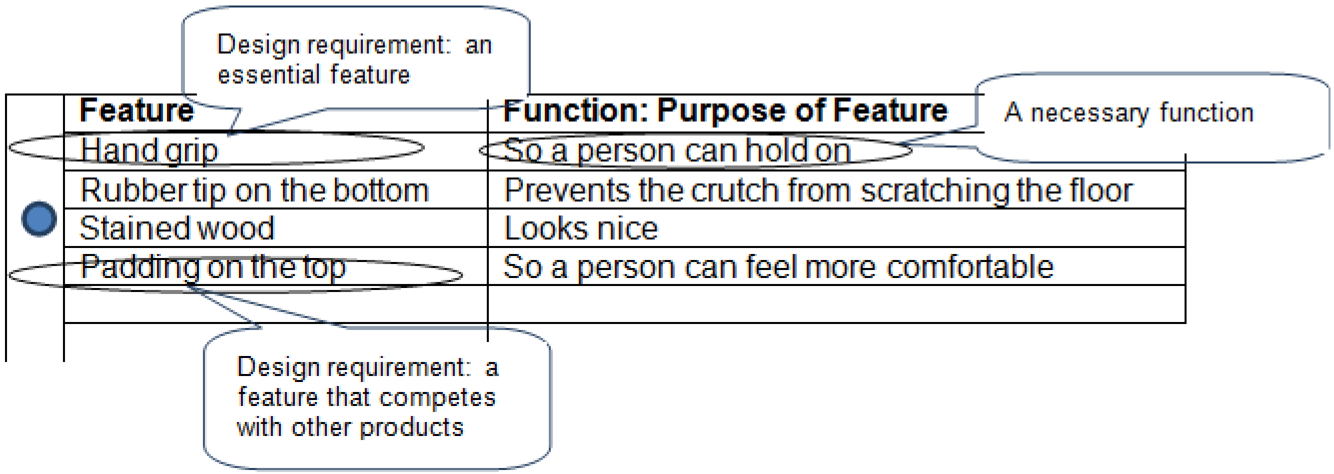
   - The crutches must cost less than $30.00.
   - The new design must be available in the next six months.

5. What other products exist that serve a similar function to solving your problem?

   **Example:** Products similar to crutches:

   - Other crutches on the market
   - Wheel chairs
   - Leg braces

Examine these products. If possible, obtain the products themselves and take them apart. Otherwise, research everything you can about the products. Identify every individual piece of the product in addition to any features of the product. In your design notebook, draw a vertical line down the middle of the page. On the left, write down all of the component parts and features that you see. On the right, write down the purpose for each component or feature. Why is it present? See Figure 1 for an example related to crutches.




| Feature | Function: Purpose of Feature |
|---|---|
| Hand grip | So a person can hold on |
| Rubber tip on the bottom | Prevents the crutch from scratching the floor |
| Stained wood | Looks nice |
| Padding on the top | So a person can feel more comfortable |
| | |

**Figure 1:** This table shows an example of how to analyze a pair of crutches.

6. Look at the right side of your table from Step 6. Which functions listed here will your product need to fulfill? Circle these functions, and look at the feature on the left for each. Is the feature absolutely essential in meeting the need on the right? If it is, then this is a design requirement, and you should circle it. If it is not, it is a possibility that could contribute to your design, but not a requirement.
7. Is the product that you are designing going to have to compete with the other products you listed in Step 5? If the answer is "yes," look more closely at the features on the left side of your table. If you feel that your design needs to include the feature in order to keep up with current products, then that feature becomes another design requirement.
8. Will you include any features that are not present in the competing product? What are they? If they are features that you consider to be "must haves" in order to make your design successful, then they can be considered your final, additional design requirements.

- To complete the requirements step of the design process, you should write a **design brief**; a document that holds all of the key information for solving your problem in one place. Here is a Design Brief Worksheet to help you develop your own.

## How to Analyze a Software Product or Website

When you start to identify your design requirements, you already know what problem you are trying to solve. But what does "solving" your problem really mean? Your design requirements are the specific needs that must be met in order to call your design a "solution."

For a software product or a website, your problem is likely related to completing a task on a computer in the easiest and most efficient way possible. An example is a website for ordering flowers. The problem statement is:

People need an easy way to buy and deliver flowers online, because they want to see what they are buying, but going to the florist is time-consuming.

From the problem statement, you can start asking the right questions to create a list of design requirements. Pull the major need or needs of your solution from your problem statement.

**Example:** A flower website needs to:

Sell flowers

Allow users to arrange for delivery of the flowers

Be easy to use

For each need, ask yourself: "What is absolutely essential to satisfy this need?" Right now, do not brainstorm. Instead figure out what MUST happen to meet the need in your future solution. Your answers to these questions are your first design requirements. (Note: if you can remove your answer to the question and still meet the need, then your answer is not a design requirement.) The "Needs" table illustrates how to find the first design requirements for the flower website example.

| Major Needs from Step 1 | What is Essential to Meet the Need (Possible Design Requirements) |
|---|---|

| Major Needs from Step 1 | What is Essential to Meet the Need (Possible Design Requirements) |
|---|---|
| Sell flowers | Flowers available for purchase<br>A way to pay on the computer |
| Allow users to arrange for the delivery of flowers | • Somewhere to enter a delivery address |
| Be easy to use | • Minimal number of steps |

These answers are all design requirements because they **must** be a part of your solution in order to meet the need. When you take away "a way to pay on the computer," then it is impossible to meet the need for users to be able to buy flowers.

An answer to this same question that is **not** a design requirement is "a picture of a shopping cart filled with flowers." Even though a picture like this might be nice to have, it is not absolutely necessary to allow users to buy flowers on the site.

3. What other software products or websites exist that serve a similar function in solving your problem?

**Example:** If you are designing a website for buying and delivering flowers online, you might consider looking at:

- Other flower-buying websites
- Food delivery websites
- Other various online shopping websites

4. Visit these websites. Look at every screen. Identify every feature present, right down to the copyright statement on the "about" screen. In your design notebook, draw a vertical line down the middle of the page. On the left, write down all of the features that you see. On the right, write down the purpose of each feature. Why is it present?
5. Look at the right side of your table from Step 4. Which functions listed here will your website or software product need to fulfill? Circle these functions, and look at the feature on the left for each. Is the feature absolutely essential in meeting the need on the right? If it is, then this is a design requirement, and you should circle it. If it is not, it is a possibility that could contribute to your design, but not a requirement.

6. Is the website or software product that you are designing going to have to compete with the other products you listed in Step 3? If the answer is "yes," look more closely at the features on the left side of your table. If you feel that your design needs to include the feature in order to keep up with current products, then that feature becomes another design requirement.
7. Will you include any features that are not present in the competing product? What are they? If they are features that you consider to be "must haves" in order to make your design successful, then they can be considered your final, additional design requirements.

## How to Analyze an Environment

When you start to identify your design requirements, you already know what problem you are trying to solve. But what does "solving" your problem really mean? Your design requirements are the specific needs that must be met in order to call your design a "solution."

For designing an environment, your problem is likely related to how to use a space in a way that is successful to its users. An example is a school cafeteria. The problem statement is:

Students need a better place to eat their lunch, socialize, and relax during the school day, because the current cafeteria is overcrowded, stressful, and noisy.

1. From the problem statement, you can start asking the right questions to create a list of design requirements. Pull the major need or needs of your solution from your problem statement.

   **Example:** The major needs of the new cafeteria design are to provide a place to:

   - Eat lunch
   - Socialize
   - Relax
2. For each need, ask yourself: "What is absolutely essential to satisfy this need?" Right now, do not brainstorm. Instead, figure out what **must** happen to meet the need in your future solution. Your answers to these questions are your first design requirements. (Note: if you can remove your answer to the question and still meet the need, then your answer is not a design requirement.) The "Needs" table illustrates how to find the first design requirements for the cafeteria example.

These answers are all design requirements because they **must** be a part of your solution in order to meet the need. When you take away "space for groups to gather," then it is impossible to meet the need for socializing. Socializing means interacting with others. You cannot interact with others if there is no space to gather with those other people.

An answer to this same question that is **not** a design requirement is "a DJ at lunch." Even though a DJ playing music would allow for socializing, you can take away this answer and still meet the need. You don't **have** to have a DJ at lunch to be able to socialize.

3. What are the physical requirements/limits of the specific space you are designing? The answers to this question are your next design requirements.

   **Example:** What are the physical requirements/limits of designing cafeteria?

   - Space for 200 students at a time
   - Indoors
   - Floors, seating, and eating surfaces that can be cleaned easily
   - An entrance and an exit for traffic flow between classes
4. What are the conceptual requirements/limits of the specific space you are designing? These are requirements that are not related to the physical nature of the space, but still must be met in order to make your solution successful. Examples will often include cost and the timeline of the project.

   **Example:** What are the conceptual requirements/limits of designing cafeteria redesign?

   - The renovation must cost less than $5,000.
   - The new design must be ready by the start of next school year.
   - The renovation must be completed by 25 project volunteers.
5. What other spaces currently exist that serve a similar purpose to your design project? Make a list of these spaces.

   **Example:** If designing a school cafeteria, other spaces to consider would include:

   - Work cafeterias
   - Hospital cafeterias
   - Restaurants
   - Faculty rooms (where your teachers eat lunch)
   - Hotel dining rooms
6. Go out and observe these spaces first-hand. Take your design notebook with you, and write down everything that you see. Answer the following questions while you are observing each of the spaces:
   a. Who is using this space? What type of people are they, and why are they here?
   b. What objects are in the space? What purpose does each of the objects serve?
   c. Are there any objects in the space that are not being used?
7. Analyze your answers to the questions in Step 5. In part a, you wrote down **why** the people in the space are there. What objects that you wrote down in part b are directly related to helping the people in the space do what they want to do? If these objects in part b are must-haves for your users as well, then they are design requirements.
8. Think back to your problem statement. Is the environment that you are designing going to have to compete with the other spaces that you listed in Step 5? If the answer is "yes," look at the features that you listed in part c of Step 6. If you feel that your design needs to include the feature in order to keep up with these other spaces, then the feature becomes a design requirement. Otherwise, the objects and features you have listed in part c are NOT design requirements.

## How to Analyze an Experience

When you start to identify your design requirements, you already know what problem you are trying to solve. But what does "solving" your problem really mean? Your design requirements are the specific needs that must be met in order to call your design a "solution."

For an experience, your problem is likely related to an event, an interaction, or a particular portion of time that you are trying to improve for a user or a group of users. An example is going to summer overnight camp for the first time. The problem statement is:

Kids who are going to overnight camp for the first time need to feel safe and at home, because being away from their parents can make them homesick and sad.

1. From the problem statement, we can start asking ourselves the right questions to create a list of design requirements. Pull the major need or needs of your solution from your problem statement.

**Example:** The major needs of the overnight camp experience are to make the campers feel:

- Safe
- Like they are at home

2. For each need, ask yourself: "What is absolutely essential to satisfy this need?" Right now, do not brainstorm. Instead, figure out what **must** happen to meet the need in your future solution. Your answers to these questions are your first design requirements. (Note: if you can remove your answer to the question and still meet the need, then your answer is not a design requirement.) The "Needs" table illustrates how to find the first design requirements for the camp experience example.

These answers are all design requirements because they **must** be a part of your solution in order to meet the need. When you take away "protection from danger," then it is impossible to meet the need for the campers to feel safe.

An answer to this same question that is **not** a design requirement is "steel locks on all of the windows and doors." Even though having steel locks at the camp might make the campers feel safe, you can take away this answer and still find a different way to make the campers feel safe. That is just one possible solution to the need, not a requirement of your design.

3. What are the time and place requirements/limits of the specific experience you are designing? The answers to this question are your next design requirements.

**Example:** What are the time and place requirements/limits of the overnight camp experience?

- The experience must occur at the summer camp location.
- The experience must take place during the first week of camp.

4. What other experiences exist that are similar to the experience that you are designing?

**Example:** Experiences similar to attending your first overnight camp include:

- Leaving for college
- Starting the first day at a new school
- Going on vacation with a friend's family

5. Go through each of these other experiences one at a time. If possible, talk to people who have been through these experiences in the past. Ask the people you are interviewing (or yourself if you don't know anyone to interview) the following questions:

    - What negative things happen during these experiences that are similar to the things you are trying to protect your user from?
    - What objects, people, or activities exist that protect people from the negative effects of the experience?
    - What positive things happen that are similar to the things you are trying to create for your user?
    - What are some objects, people, or activities that aid in creating the positive effects of the experience?

6. Analyze your answers to the questions in Step 5. Look at your answers to part b and part d. If the objects, people, or activities must also exist in the experience you are designing (either to protect your user from something negative or to aid in creating a positive portion of the experience), then they are design requirements.

# The Design Brief

To complete the requirements step of the design process, you should write a design brief. A design brief gathers all the key information for solving your problem in one place. It should contain:

- A description of your target user.
- A definition of the problem you intend to solve. [*Who*] need(s) [*what*] because [*why*].
- A description of how existing products are used and why they fail to address the problem.
- A list of all the requirements for your design.

## Brainstorm Multiple Solutions

- #1 Rule when creating alternative solutions: **DON'T SETTLE FOR YOUR FIRST IDEA!**

- Good designers try to generate as many possible solutions as they can before choosing one that they feel is the best. This creative process of developing ideas is called **ideation**.
- Methods of ideation include:
    - Examining existing solutions
    - Creating and using analogies
    - Conducting brainstorming sessions
    - Sketching and doodling

## Why Create Multiple Solutions?

When solving a design problem, there are always many possible good solutions. If you focus on just one before looking at the alternatives, it is almost certain that you are overlooking a better solution. Good designers try to generate as many possible solutions as they can before choosing one that they feel is the best. Even "wild and crazy" design ideas that you end up rejecting might have some pieces that can make other designs better.

## Ideation

Ideation, also known as idea generation, is the creative process of developing ideas. Start ideation after you have settled on a design problem that you want to solve and have done your background research, including the analysis of existing solutions. If you have not researched existing solutions, be sure to do so before starting ideation. Existing solutions are a great place to begin the ideation phase of your process because they give you a starting platform for ideas.

Generating lots of ideas is important to solving your design problem, so follow these key rules! One key rule for successful ideation is no limits. Start huge. Don't confine yourself to only one or two great ideas, and don't be afraid to think outside the box. No solutions are impossible during the ideation phase, so consider even the craziest of ideas. There will come a time later on when you will weigh your ideas against one another based on how easy they are to implement, but not yet. Ideation is the perfect time to put aside all judgment, and see how many design solutions you can come up with!

#1 Rule when Ideating: ***Don't settle for your first idea!***

If you think you have a great solution to your problem right from the beginning, you might be tempted to stick with that original idea. Even if it's the most perfect, without-a-doubt, best possible way to solve your problem -- don't stop here! Fixating on your first idea is a terrible mistake, because it stops your creative process before it even has the chance to get going. You never know what new ideas could branch off of your original idea or what new ideas might come to you over time, so you have to give the process (and yourself) a chance.

The list are many creative techniques to help you come up with design ideas.

## Existing Solutions

Existing solutions to your problem (or similar problems) are one of the best sources for creating design alternatives. Studying these designs will give you creative ideas of your own. Can the best features of existing solutions be combined in new ways? Can two entire solutions be combined to form one, better solution? Are there pieces missing from existing designs that if added, might make the designs more successful? Ask yourself these questions and see what new ideas you can come up with.

## Analogies

By comparing your design problem to an entirely different situation, you may notice solutions that never would have come to mind otherwise. Try to create analogies between your design problem and random objects and people. For example, ask yourself:

- How is my design problem like [random object or problem]?
- How would I solve my problem using a [random object]?
- How would [random person, company, or group] solve my problem?

Choose random objects and people to create these analogies. Even though they may seem unrelated, the analogy will force your mind to come up with ideas to fit the specific cases of the random objects and people.

**Example:** Imagine you are designing a better lunchbox for students. Try these analogies to spark new and interesting design ideas...

**Analogy:** How is designing a lunchbox like designing a hotel?

**Answer:** When designing a hotel, you need to design for the people who will be staying in it. Think about the furniture, the decorations, the size of the rooms, etc. Try applying these to your lunchbox. What about the size of the lunchbox? Are there any components you could add to your lunchbox to serve as furniture-like features? Does the food in the lunchbox need furniture to sit on? You may never have considered these ideas without comparing a lunchbox to a hotel.

**Analogy:** How would I design a lunchbox using a skateboard?

**Answer:** You might create a lunchbox that has wheels, or a lunchbox that could be attached to a skateboard, or a skateboard that has a compartment to store food, or a lunchbox that could strap to the bottom of someone's feet. All of these are lunchbox designs that you might never have considered!

**Analogy:** How would Facebook design a lunchbox?

**Answer:** Facebook might design a lunchbox that you can take pictures with, or a lunchbox that has a computer screen on the inside. All of these are lunchbox designs you may never have thought about!

### Brainstorming

Group brainstorming is a great way to generate lots and lots of ideas. Ask your friends, parents, and relatives if they would be willing to help you brainstorm ideas to your design problem. Gather a few of these people together for 30 minutes to an hour and tell them about your design problem. Then, leave the rest to discussion! Keep in mind:

- Fewer than five or six people per brainstorming session are best.
- No judgment! No ideas are bad ideas during ideation.
- Post-it notes are a great way for the people to show their ideas to the group.
- You should write down all of the ideas mentioned in your design notebook.

## Sketching and Doodling

You can come up with great ideas by using all of the techniques listed, but ideation really isn't complete without sketching and doodling. Drawing is an ideal way to express your ideas and to visually connect multiple ideas to one another. Draw everything on your mind! Even if the idea is not fully developed, try to draw it and see what it looks like. Sketch all of the ideas that you have already come up with using other ideation techniques. By sketching, you will see new aspects of those ideas and be able to come up with even more.

## "Sleep on It!"

Ideation isn't a one-day activity. In fact, it should be the longest phase of your entire design process. So don't feel like you need to come up with your perfect solution in one sitting. Ideate until you feel like you've run out of ideas. Then, sleep on it and return to ideation the next day or a few days after that. You will be surprised at how many more ideas you are able to come up with!

# Choose the Best Solution

- First, look at whether each possible solution met your design requirements. Consider solutions that did a much better job than others, and reject those that did not meet the requirements.
- Some criteria apply to virtually every design. Good designers consider these **universal design criteria** when choosing which possible solution to implement:
    - Elegance
    - Robustness
    - Aesthetics
    - Cost
    - Resources
    - Time
    - Skill required
    - Safety
- It helps to compare solutions in a **decision matrix**—a chart with the requirements and criteria on one axis and the different solutions on the other. Use the Decision Matrix Worksheet to help you choose a design.
- If your requirements and solutions are relatively simple, you can sometimes just list the **pros** and **cons** for each solution. Pros are good things about a solution and cons are bad things.

## Defining "Best"

- Once you have created a number of possible solutions to your design problem, you need to choose which one is best.
- First, look at whether each possible solution met your design requirements. Consider solutions that did a much better job than others, and reject those that did not meet the requirements.
- In addition to your design requirements, you probably have some features that would be "nice to have" in your solution. These are things that are not quite as important as your design requirements; they are desirable, but not mandatory. Some of your possible solutions might include more of these nice-to-have features than others, and that is a possible reason they might be better.

### Universal Design Criteria

- Some criteria apply to virtually every design. Good designers consider them in every solution that they choose to implement.

- **Elegance.** An elegant design solution is simple, clever, or ingenious. It might have fewer parts to wear out or fail. It might combine solutions from different areas in an inventive way not seen before. All good designers strive for elegance in their designs.
- **Robustness.** A robust design is unlikely to fail, even when used in conditions more severe than it was designed for. It is sturdy or resilient, perhaps bending, but not breaking in hard use.
- **Aesthetics.** If everything else is equal, people prefer a solution that is tasteful and pleasing to look at.
- **Cost.** What will it cost? Can the target user afford the solution? Do you have enough money to build your prototype?
- **Resources.** Do you have all the materials and equipment you need for your engineering project, or will you be able to obtain them quickly and at a very low cost?
- **Time.** Do you have enough time to complete your design and make it before the due date? Allow time for doing additional research and fixing problems. It is very rare for everything to work correctly the first time.
- **Skill Required.** Do you have the skills to build and implement your solution, or can you learn them in the time available?
- **Safety.** Is your solution safe to build, use, store, and dispose of?

**The Decision Matrix**

- As you compare potential solutions to your design brief and the universal criteria for a good design, it may be obvious which solution is the best. More often than not it helps to compare the solutions in a decision matrix. A decision matrix is a chart with your requirements and criteria on one axis and the different solutions on the other. Use a simple numeric evaluation scale to rate each solution against each of the criteria (2 = totally meets the criteria, 1 = somewhat meets the criteria, 0 = does not meet the criteria). Total up the columns to see which solution is best.
- Alternatively, if you have colored stickers or pens, you can rate projects with a color scale (green = totally meets the criteria, yellow = somewhat meets the criteria, and red = does not meet the criteria). Using colors gives a highly visual indication of which solution is best (the more green the better!).
- In our example, we lump together nice-to-have, desirable features and the universal design criteria into the "Other criteria" row of the decision matrix. That way these criteria serve as a tiebreaker, but they do not out-weigh "must-have" design requirements. You can make the design matrix with as many requirement rows and solution columns as you need, as shown in the examples.

| • Requirements and Criteria | Solution #1 | Solution #2 | Solution #3 | Solution #4 |
|---|---|---|---|---|

| • Requirements and Criteria | Solution #1 | Solution #2 | Solution #3 | Solution #4 |
|---|---|---|---|---|
| Your requirement #1 | 1 | 2 | 2 | 1 |
| Your requirement #2 | 1 | 1 | 2 | 1 |
| Your requirement #3 | 2 | 2 | 2 | 2 |
| Other criteria (nice-to-have and universal criteria) | 1 | 1 | 2 | 1 |
| | | | | |
| Total Points | 5 | 6 | 8 | 5 |

## Pros and Cons

If your requirements and solutions are relatively simple, you can sometimes just list the pros and cons for each solution, as shown in the examples. Pros are good things about a solution and cons are bad things. (The terms pro and con come from the Latin phrase *pro et contra*, for and against, and they have been used for centuries.)

| Solutions | Pros | Cons | Comments |
|---|---|---|---|
| Solution Idea #1 | | | |
| Solution Idea #2 | | | |
| Solution Idea #3 | | | |
| Solution Idea #4 | | | |

# Four: Implement a solution

## Development Work

- **Development** involves the refinement and improvement of a solution.
- The goals of development work are to:
  - Make it work!
  - Reduce risk.
  - Optimize success.
- **Methods** of development work include:
  - Drawings
  - Modeling
  - Prototyping
  - Storyboards
  - Analysis

Development involves the refinement and improvement of a solution. Some development work might be needed very early in the design process in order to evaluate different potential solutions. For example, it might not be possible to compare the cost of early design concepts without doing some development work to estimate what the cost of an alternative would actually be.

Development work continues throughout the design process, often even after a product ships to customers.

Goals of Development Work

### Make It Work!

Of course, the primary goal of development work is to make a workable solution to your problem. This goal is true of all development efforts.

### Risk Reduction

In any complicated development effort, for example, building a robot for a competition, you will be uncertain about how well certain elements of your design solution will work. In a situation like this, it is very important to eliminate the uncertainty as soon as possible. This is called risk reduction. The longer you wait to eliminate the risk, the more likely that you will waste time on a solution that will fail. It is much better to find out that a potential solution will not work early in the design process before choosing your final solution for development. Fail fast, fail early!

To do risk reduction, use an appropriate method of development. For example, one strategy is to prototype just a small part of the potential solution, the risky part, to make sure that it will work.

## Optimization

Almost any design problem has multiple requirements. In many cases, requirements might conflict with each other, at least somewhat. For example, if you try to maximize almost any characteristic of a solution (speed, appearance, etc.), the cost will go up. Optimization is the process of finding the best trade-off between your different requirements, and it is an important part of almost every development effort.

# Methods of Development

## Drawings

Designers use drawings to record ideas so that they are not forgotten, to communicate ideas to others, and to study how different parts of a design work together during development.

There are several types of drawings. **Sketches** are rough freehand drawings done very quickly and usually showing just the outlines of an object. **Pictorial drawings** portray a photo-like view of objects. **Technical drawing** is an accurate way of drawing that shows an object's true size and shape. It is often done with CAD (computer-aided design) software and is used in **plans** and **blueprints** that show how to construct an object. Technical drawings show in detail how the pieces of something relate to each other.

## Modeling

Models can be physical objects, such as a **scale model** of a solution that shows all the parts in correct proportion to each other. Generally, scale models do not actually work. Designers use them to visualize the solution and see how it looks.

A completely different kind of model is a mathematical or **computer model**. Designers use these models to predict how a solution will work. For complex problems, this can be extremely valuable, because the computer model is often much less expensive than building the solution itself, and it can assist the designer in making trade-offs among different requirements.

## Prototyping

A **prototype** is an operating version of a solution. Often a designer makes a prototype with different materials than the final version, and generally it is not as polished. Prototypes are a key step in the development of a final solution, allowing the designer to test how the solution will work and even show the solution to users for feedback.

Occasionally, designers will prototype pieces of the final solution very early in the design process. Sometimes designers will make several prototypes during the development of a solution.

### Storyboards

Storyboards are a series of graphic illustrations or images for the purpose of visualizing a video, website, software program, environment, user experience (like a theme park ride), or the like. Storyboards show how the solution appears as the user interacts with it over time, highlighting any problems in the flow of the experience.

### Analysis, Running the Numbers

Sometimes development work can be as simple as adding up the weight of all the components of a solution to see if the total weight meets the requirements. Similarly, you might add up the cost of all the parts to get a total cost or predict the speed of a vehicle by looking at the power of the engine. Analysis of this type is an important part of the development of many solutions, and it is often called running the numbers.

## Prototyping

- A prototype is an operating version of a solution. It is often made with different materials (cheaper and easier to work with) than the final version.
- Prototypes allow you to test how your solution will work and even show the solution to users for feedback.
- Creating prototypes may involve using readily available materials, construction kits, storyboards, or other techniques that help you to create your solution quickly and with little cost. Keep in mind that these are mockups of your final solution, not the real thing!
- Prototypes are a key step in the development of a final solution, allowing the designer to test how the solution will work and even show the solution to users for feedback. Occasionally, designers will prototype pieces of the final solution very early in the design process. Sometimes designers will make several prototypes during the development of a solution.
- Prototypes can help you to develop the structure, function, and appearance of your solution.

## Prototyping Physical Structures, Objects, and Mechanical Designs

### Readily Available Materials

- Cardboard, paper, poster board, mat board, and Foam-core™ are excellent modeling materials for prototypes. You can cut them easily with the proper knife, and you can assemble them with a variety of tapes and glues. You can find these materials at an art supply store. Plastic sheet and wood are also good modeling materials.
- Found objects like plastic bottles, straws, aluminum cans, and other things lying around the house can often fill a need in your prototyping.

### Test and Redesign

The design process involves multiple loops and circles around your final solution. You will likely test your solution—find problems and make changes—test your new solution—find new problems and make changes—and so on, before settling on a final design.

At this point, you have created prototypes of your alternative solutions, tested those prototypes, and chosen your final design. So you're probably thinking that your project is finished! But in fact, you have yet to complete the final and most important phase of the engineering design process—test and redesign.

Test and redesign requires you to go out and test your final design with your users. Based on their feedback and their interaction with your solution, you will redesign your solution to make it better. Repeat this process of testing, determining issues, fixing the issues, and then retesting multiple times until your solution is as successful as possible. Keep in mind that minor changes this late in the design process could make or break your solution, so be sure to be thorough in your testing!

## User Test

The first step in user testing is to get in contact with the users of your solution. Go back to your problem statement, and remember your potential users. You will want to test your solution on this group of people. For example, if you are designing a website for kindergarten students, you will want to test your final solution with kindergarteners.

When it comes to testing, there is no such thing as too many testers! The more people that you are able to test with the more you will find out. So try to find as many users as you can who are willing to help you. A good goal to reach for is three to five users for each round of testing.

The second step, after you have located three to five users, is to present your solution to these users while the users are in the **problem environment**. The problem environment is the situation or atmosphere in which the problem you are trying to solve happens.

- If your solution is a product, give the product to the users in the environment where they would use it. For example, if you designed a pair of sunglasses, you would give your sunglasses to the users outside while the weather is sunny. You wouldn't ask them to try the sunglasses at night or indoors, because those aren't situations where they would be using sunglasses.
- If your solution is a website or software product, ask users to test it on computers. You wouldn't want to just show them pictures or explain the website, because how they interact with the computer itself is also important.
- If your solution is an environment or experience, place your user in that environment or experience, and see how they react. For example, if you designed an after-school program for students, invite users to attend this program or a mock version of it. However, in many cases, having your users actually visit your designed environment or go through your designed experience will not be possible. An example is a student who designed a new school bus but obviously does not have an actual bus to use for testing. In a case like this, use a storyboard to present your solution to the users.

The third and final step of user testing is observing the interaction between the user and your solution. Record your observations in your design notebook. Watch closely as people use your product, navigate your website, or go through your designed environment or experience. Listen to what they say, but also watch what they do, see how they react, note where or when they get confused, and write down everything that happens during their interaction with the solution. Below are three questions to ask during testing. The answers will be helpful when you move onto the redesign phase of test and redesign.

1. Are your users able to overcome the problem by using or interacting with your solution?
    - If yes, why are they successful?
    - If no, what problems do they encounter that prevent them from being successful?
2. Do the users ever need to ask you any questions when using or interacting with your solution?
    - If yes, what questions do they ask? During what part of their interaction do they ask these questions?
3. Do the users interact with your solution exactly the way that you intended for them to?
    - If no, what do they do differently?
4. If you have measurable targets for your solution, did you meet them?

## Redesign

After you have tested your design, you will use your findings to complete a redesign of your solution. Use the findings from testing to:

- Fix any problems that occurred, and
- Further polish aspects of the design that were even more successful than you originally thought.

To make these changes, look at the answers to the three major questions you asked during testing:

1. Is your user able to overcome the problem by using or interacting with your solution?

    If the answer is "yes," focus on why the user was successful. What specific aspects of your design helped the user to achieve success? Should those aspects become larger parts of your design? Should you make these features more prominent or more obvious to the user? Consider emphasizing these aspects of your design. Then, in the next round of testing, see if the user is able to achieve success even more quickly and easily.

If the answer is "no," focus on the problems that users encountered during testing. What prevented them from achieving success? What changes to your design would eliminate these issues? Make these changes.

2. Does the user ever need to ask you any questions when using or interacting with your solution?

   If the answer is "yes," focus on the questions that the users asked you. Why did they need to ask you a question? Were they confused? What part of the solution wasn't self-explanatory? You normally wouldn't be there to answer questions, so how can you make sure that the next users won't need to ask the same questions? Make changes that will eliminate these questions.

3. Does the user interact with your solution exactly the way that you intended for them to?

   If the answer is "no," focus on what the users did that you hadn't intended to happen. Did their unexpected actions make your design more successful or less successful? If less successful, what changes could you make to your design to prevent these unexpected actions? What issues are causing the users to interact differently than intended, and how can you fix those issues? Make these changes.

4. If you have measurable targets for your solution, did you meet them?

   If your design requirements call for your solution to be better, faster, or cheaper, you should measure the improvement that you made. If you met your targets, great! If not, how can you redesign your solution to improve its performance?

Once you have made changes to your design, go back and test again with your users. See if the improvements and changes you made negatively or positively affected your solution. Ask yourself the same three questions again, and then repeat the redesign again. Repeat this test and redesign process as many times as necessary to make your final solution as successful as possible. It may seem like you are doing the same thing over and over again, but with each test and redesign, you are greatly improving your project!

Works cited: Information collected from Sciencebuddies.org

# Display Boards Specifications:

**Display boards most be typed! Font type should be consistent. Students will have the opportunity to type and print from school.**

**Maximum Size of Project**
**Depth** (front to back): 30 inches or 76 centimeters
**Width** (side to side): 48 inches or 122 centimeters
**Height** (floor to top): 108 inches or 274 centimeters

- All project materials and support mechanisms must t within the project dimensions.

- All demonstrations must be done within the confines of the finalist booth. When not being demonstrated, the component must be returned to project and must t within allowable dimensions.

Any photograph/visual image/chart/table and/or graph is allowed if:

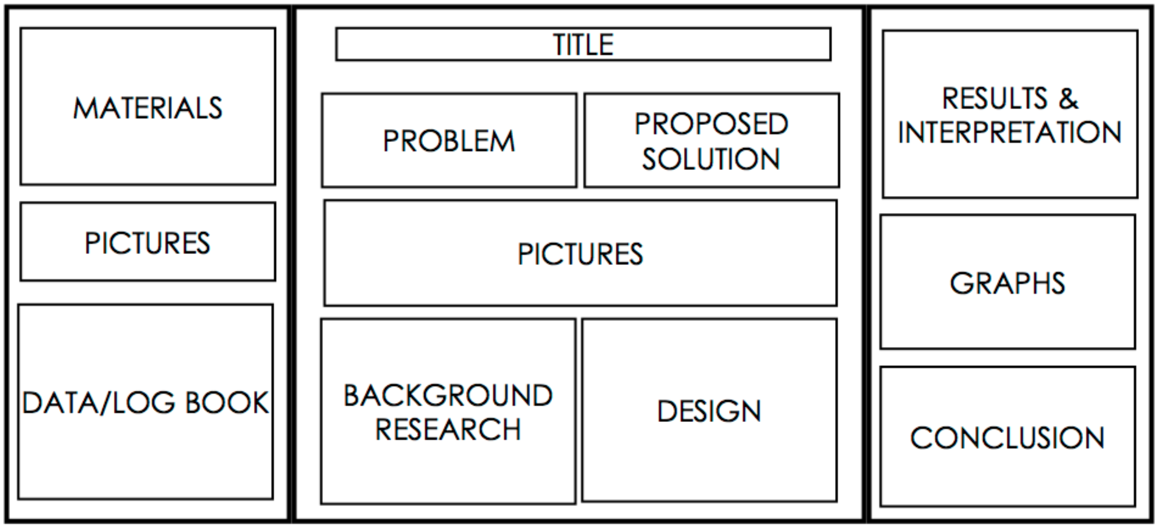
- It has a credit line of origin ("Photograph taken by..."or "Image taken from..." or "Graph/Chart/Table taken from..."). (If all images, etc. being displayed were taken or created by the finalist or are from the same source, one credit line prominently and vertically displayed on the backboard/ poster or tabletop is sufficient.)

- It is from the Internet, magazine, newspaper, journal, etc., and a credit line is attached. (If all photographs, etc. are from the same source, one credit prominently and vertically displayed is sufficient.)

- It is a photograph or visual depiction of the finalist.

- It is a photograph or visual depiction for which a signed consent form is at the project or in the booth.

# Engineering Projects




- Engineering projects follow the Engineering Process, found in our Student Handbook. Your board should be a visual representation of this process.
- Be sure to organize your board how best fits your project - the above is a simple example

Image taken from: http://www.sacstemfair.org/assets/how-to-design-your-board.pdf