Instrument Design 101

Overview

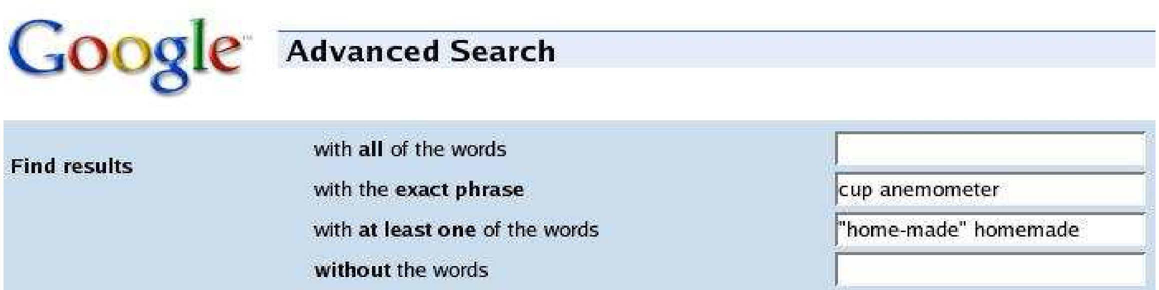
The design process is highly non-linear. That is, there is no algorithm to follow that will ensure a successful outcome. However, there is a flow to the process which is outlined here. Your actual steps and process will not follow this list exactly, but will include these activities at some time:

- Research the principle of operation of existing instruments.
- Determine which principle of operation the instrument will use.
- Investigate the major components required and itemize them.
- Sketch a basic design.
- Create a component list.
- Gather details of each purchased subcomponent.
- Gather details of each manufactured subcomponent.
- Estimate the cost and a schedule.
- Analyze the design.
- Detail the design of each non-purchased subcomponent.
- Create an assembly diagram.
- Create a final design document.

The formal "analyse the design" activity is where your design is compared against another group's design for the same instrument, but you should be analysing your design continuously as you work though the process.

Research Instrument Principles

For any one aspect of weather, there are many phenomena that exhibit many observables and hence many ways to measure it. This step itemizes some of the possibilities for instrument operation. The internet and search engines are great for this. The *Instrument Principles* document outlines only some principles and some keywords that can be used to search for them. In particular, search for instrument keywords near "homemade", "home-made", "homebrew", "home-brew", "inexpensive", "easy", "simple", "low-tech" and other similar keywords to try and limit your search to those ideas that will meet the criteria outlined in the *Instrument Criteria* document and that can be achieved by you. For example, in Google's advanced search page, enter "cup anemometer" and a keyword from the list above:



Make a short list (two or three items) of possibilities. The intent is to range widely and get as good an overview as possible of the different successful designs that are currently in existence, but then only concentrate on a coupleof them.

Determine Principle of Operation

This step serves to isolate one particular phenomenon and measurement that will be the basis for the instrument operation. From the short list of principles determined from the previous step, choose one to investigate more fully. You might choose the one that looks easiest, or the one that you have the most detailed description of, or the one that looks like it will cost the least or the one with the highest “coolness” factor; it's up to you. This may not be the final choice, i.e. you might have to start from this point again if you determine later on that your choice isn't the right one. Design is a matter of choice and constraints. How you choose and what constraints are imposed will determine the success or failure of the design.

Investigate Major Components

Once you've settled on a design to investigate, determine the major components that go into it. The important components might be mechanical, as in the anemometer and wind direction instruments, or primarily electronic in nature. Make a list of these components. Not the little ones like resistors or nuts and bolts which have a lot of design discretion, but the critical ones that are special; that you probably need to buy or make. Make sure you include all of them by taking a mental walk from one end of the instrument to the other. For an electronic instrument, the major components will be the building blocks or sub-circuits that make up the whole circuit. For a mechanical instrument, this will be the bearings, shafts, gears, and so on that comprise the “working end” of the instrument.
Check that each major component is realizable. Is it a common item? Can you buy it off the shelf? Can you make it? Are the tolerances reasonable? Does it have characteristics (like size and speed) that match other ones you can find. If not, you'll need to revisit the design or choose another design instead. For example, if one of your major components is an oscillator circuit, can you find other examples of similar circuits operating at similar frequencies and generating similar waveforms? Or if it's a mechanical design, can you identify bearings in other devices that are roughly the same size and shape? Are you pushing a limit? This is usually obvious when the values you want are not included in a table of such values because they are “off one end”, or the values you've calculated aren't reasonable because they are too large or too small.

This step will probably involve lots of calculation. Doublecheck each calculation for errors or have someone calculate the same thing separately.

You might need some brainstorming here. Follow a thought trail on the internet with a search engine, or take a walk though a hardware store.

Check that each identified component isn't really two or more components that could be broken down into separate pieces, or conversely that you aren't dealing with pieces that should really be only one component.

Only when you are comfortable with each of the major components and you have a complete list of them should you go on.

Sketch a Basic Design

Once the major components have been identified, you can put them together into a comprehensive picture. It doesn't have to be a formal diagram, but it should be roughly to scale, showing each of the major components and how they interoperate.

This is the really creative part of the process, where you actually need to think about what it is you are trying to measure and how the idea that you have will accomplish that goal. You may do this step many, many times.

A sketch or diagram is used to activate the right hemisphere of your brain; to get the creative, holistic, intuitive and symbolic side thinking and to suppress the linear, critical and logical side. Try to switch back and forth between modes. Visualize the instrument in your mind and draw a sketch of it. After the initial sketch is made switch to the analytical side. Now is the time to figure out how the pieces go together. For an electronic project, are the voltages and currents compatible between the subcircuits? For the mechanical design (and every instrument will have *some* mechanical design), what's holding that piece in place? Does it fit? How big is it? Does that part interfere with the movement of that one?

You should be able to pass the result of this phase to an independent person and have them give you an assesment. Ask your teacher or an engineer if this design should work. Know in advance the questions that will be asked and have answers ready or written down for each of them.

The sketch is your working document. Keep it up to date. Start with a large sheet of paper and put detailed drawings of important parts in the corners and relevant points in the margins. Don't be afraid to redraw it if necessary. A clear picture of the *entire* instrument is the necessary outcome from this step. If it isn't absolutely clear in your mind, go back to a previous step.

Create a Component List

From your diagram, make a complete parts list. This time, include all the little niggly bits that will be needed. Imaging yourself on a dessert island with just a toolbox and figure out what you will need. Everything.

For each component, identify whether you will *make* or *buy* it.

For each part you identify, see if you can label it on your drawing (write small if necessary or draw a detailed view in the corner), and if it isn't on your drawing, add it.

Gather Details of Purchased Components

For purchased components, identify the supplier (what store) and availability (is it in stock or will you need to order it) and roughly how much it costs. Get cost estimates from catalogues, the web (make sure the prices are all in Canadian dollars), or by going to the store. If you can't find a price, estimate it from the cost of other similar items. Estimate the time it will take to acquire parts that need to be ordered.

The component list will now have several columns from this step. You might want to use a spreadsheet with these column names:

- Component Name

- Quantity
- Unit Cost
- Cost
- Make/Buy
- Supplier
- Availability

Gather Details of Manufactured Components

For manufactured components, figure out how to build it, what quantities of raw materials are required, their availability and cost and also estimate a time to manufacture the component (your labour is assumed to be free but you only have so much time). You will need to take into account that materials may only be sold in certain sizes that are more than you need, for example threaded rod is sold as a meter long item, but you may only need 20cm.
For each manufactured component you will need several columns similar to the one for purchased components, so you might want to use a similar spreadsheet, for each component, with these column names:

- Raw Material
- Quantity Needed
- Stock Size
- Stock Cost (ea.)
- Cost
- Supplier
- Availability

Estimate the Cost and a Schedule.

Add up the costs associated with all your components. This may be pretty easy with a spreadsheet. Figure out who in your group will do what when, and draft a preliminary schedule. Take into account things like other commitments, holidays, when the purchased parts will become available and the order in which the components need to be built. Only proceed on to the next step if you're pretty sure you can build the instrument in the allotted time and within budget because if you get the *design win* you *will* have to build it. If it is too expensive or you can't manufacture the instrument in the alloted time, go back to a previous step and try again.

Analyze the Design

In this phase your design will be compared with another design from another group and only one will be chosen to be built. The evaluation is done pairwise, using the *Instrument Criteria*.

Detail the Design of Non-purchased Components

Draw separate, more detailed, diagrams of non-purchased subcomponent so you can split up the tasks between members of your group and still have the components fit together. If the components need some special outside machining, a drawing is absolutely required. If you change the design while you are building it, the drawing should be changed to reflect the *as built* dimensions and configuration.

Create an Assembly Diagram

This step just makes an electronic version of your design sketch so that it can be included in your design document.

Create the Final Design Document

In this step you bring all your notes together into a document that can be submitted for a mark. The write-up should cover why you made the design decisions that you did, and the contraints that came into play as you were designing it. Examine every piece of paper or note you've made over the course of the design and ensure that it is reflected somehow in the document.