Introduction

The design process is both an art and a science. The following steps may help get you on the road; they can be used as a way to track and document the design process and can give you ideas for how to proceed. “Brute force” engineering options often meet the criteria but somewhere there is a profound solution, which is simple, cheap, and beautiful. Hold out for this as long as possible. The design process is generally considered to be a combination of the following stages:

- Information gathering
- Problem definition
- Design specifications
- Idea generation
- Analysis & experimentation
- Concept evaluation
- Detail design
- Fabrication
- Testing & evaluation

The process is not a linear one, however, as it is often necessary to go back to revisit earlier stages in light of information which you discover as you proceed. Experience has shown that the more time spent on the initial stages of the design, the easier the later stages become. In this class you will learn the design process by applying it to a real technological challenge. This packet describes the design assignments for the semester.

We will move through the design process over the course of the semester, and you will report your progress in a series of design review sessions. While each project will proceed at different rates, we expect that you will have achieved the following milestones for each design review session.

SESSIONS	DESIGN REVIEW MILESTONES
Session #11	Phase 1: project background, problem definition and design specifications (aka Homeworks 10 and 11)
Session #13	Phase 2: idea generation, experimental results, concept evaluation and final concept (aka Homework 14)
Session #17	Phase 3, part 1: detail design, analysis and experimental results (aka Homework 15)
Session #20	Phase 3, part 2: Prototypes
Session #24	Practice presentations for MIT Museum D-Lab showcase

After each review session, each team should meet to discuss the feedback they received and write a one to two-page document summarizing comments and criticisms on your project. The document should contain all comments made by reviewers and should outline what your team believes to be the most pertinent criticisms and how you plan to incorporate them as you move forward. These feedback summaries should be kept on the wiki and referred to often throughout the design process.

Phase 1: Information

Information Gathering

We will begin with the information gathering and problem definition phase. As a team, you will collect information about the project, especially in terms of the following:

- Specifications for performance of the device
- The context in which it will be used
- The current state of the art
- Related technologies

Although the internet is a good source of information, it should not be your only source. Databases and reference texts such as the World Bank Development Indicators, The Economist Intelligence Unit Country Profiles and others can provide valuable background information.

The following reference materials are among those suggested by the MIT Libraries:

- Darrow Ken, and Mike Saxenian, editors. *Appropriate Technology Sourcebook*. Village Earth. http://villageearth.org/appropriate-technology/appropriate-technology-sourcebook
- CIA World Factbook - http://www.cia.gov/cia/publications/factbook/index.html
- Statistics from Food and Agricultural Organization of the United Nations (FOA) - http://www.fao.org/corp/statistics/en/

(*Note*: here's the MIT Libraries' full list of D-Lab research references, if you're at MIT or have access to an academic library. Most of these are available only with an institutional subscription.)

Most importantly, try to consult your community partners and those people who have helped to develop your challenge. These people will be familiar with the context, needs and users for whom you are designing.

Deliverable (Homework 10)

This information will be incorporated into the project background presented at the Session #11 design review. Each team member should turn in a one to two-page summary of their research findings at the review session.

Problem Framing

Now that you have a good background about the challenge, it's important to frame the problem. What aspect of the problem will you be addressing? Who are your users? Who are your customers? (they are not always the same). What do your users and/or customers actually need? It may be different than what they say they want—they may have framed the problem in a way that suggests a solution. It is important to go back to the basic requirements and build upon that. Think carefully about the stakeholders who are involved in this project, and those that you are including in your solution. Think of several different problem framings and collect more information about each so that you can choose the best one.

Deliverable

Each team should present their problem framings at the Session #11 design review and describe which one they chose and why.

Problem Statement

The problem statement should be a concise description of the design problem and its context. It should include only the functional requirements of the device and not components of the solution. The aim of problem definition is to clearly outline the problem on which the team will focus. Be sure that the problem defined is measurable and observable. Address the following questions:

- who (the user)
- what (the functionality of the device)
- where (the environment)

Don’t state the problem as a question or give a solution or cause of the problem in the statement.

Deliverable (Homework 11)

As a team, develop a concise problem description to be presented at the Session #11 review session.

Design Specifications

Now that you have an idea of the scope of your project, it is necessary to determine the user’s needs and convert them into specific design requirements. Start by generating a list of client needs. When possible, try to get information directly from the people who will be using your product. If this is not possible, then identify several people who are knowledgeable about the topic and get their input. Once you have the list of customer needs, decide upon the metrics (measurement methods) that you will use to determine whether you have met these needs. Assign acceptable and ideal values to these metrics and use this to create the design specifications for your project.

Deliverable (Homework 11)

As a team, develop a spreadsheet or other clear document that outlines all critical design specifications, metrics used and acceptable/goal values. This should be posted on the team wiki, and summarized and presented at the Session #11 design review. Each team should also print out a copy of this document and turn it in at the review session.

Phase 2: Ideas

Idea Generation

Now that your design problem has been clearly defined and the specifications have been set out, it is time to concentrate on thinking of solutions. When there is an existing solution to your problem or a similar one there are three basic types of design ideas that you may generate: scaled designs, evolutionary designs or revolutionary designs. A *scaled design* can be derived from an existing design that does the job well, and just needs to be scaled for your application. An *evolutionary design* can be created when an existing design is pretty good, but fundamental improvements can be made. A *revolutionary design* is a totally new approach used to achieve the same function as an existing design, but with better performance. All three approaches can have successful results. In fact, your final design will probably be a combination of all of them.

Begin by generating ideas on your own (you may have already done a little of this while you were doing research into the problem definition). Try to think of as many different ways as possible to solve the problem. Be sure that you do not focus on a single approach. Use sketches and notes in your design notebook to record your ideas. Be sure to use large, well-labeled sketches so that others will be able to understand them. Some ideas will be at the system level and others at a more detailed level. Keep track of them all. Think of at least *ten ideas* for your project and record them in your design notebook. They may be ideas for the overall system or for the sub-systems. Use these ideas as a starting point in your group idea generation session.

As a team, you will have a group brainstorming session, chose one or two people to record information. Before you start, be sure that you agree on the problem, and state it clearly. Each person should have a packet of sticky notes, and as you come up with new ideas, write them down and add them to the work surface (wall, table, floor, or whatever is comfortable for you). This allows you to capture your ideas as they come in without interrupting others. You should start by giving each team member the opportunity to share an idea from their individual list. Build off each idea as it is presented, and see where that goes. New ideas will emerge, don't pass judgment at this point, and encourage all new ideas. You will evaluate and critique ideas at a later stage. In order to ensure a productive brainstorming session, keep it under one hour, and follow the *Rules of Brainstorming* (it is highly recommended that you put them up on one of the walls where you are meeting or on a whiteboard):

- Defer judgment (don't dismiss or criticize any ideas)
- Build on the ideas of others (no "buts", only "ands")
- Encourage wild ideas (think naively, keeping all engineering knowledge of what is feasible to the side. Embrace the most out-of-the-box notions because they can be key to solutions)
- Go for quantity (aim for as many ideas as possible: in a good session, up to 100 ideas are generated in 60 minutes)
- Be visual (use color markers to write on big Post-its that are put on the work surface)
- Stay focused on the topic
- One conversation at a time (no interrupting, no dismissing, no disrespect, no rudeness
- Be optimistic

Once you feel like have exhausted your ideas, try to generate more. One way to do this is through a process called bisociation. In this approach, you choose a topic that may seem unrelated to your topic, and then think of ideas that bring these two ideas together. For example, you may be generating ideas for the charcoal project, and choose the bisociation topic of shoes. Then you might think of how you could use shoes as a material to make the press, how a shoe could operate the press, how the shape of the shoe could be incorporated into the press design, how shoe manufacturing methods could be adapted to make charcoal, how charcoal could be used in making shoes, or how it might be used to absorb odors in shoes. And then you might decide to follow up on one of the more promising ideas. How charcoal might absorb odors, or perhaps other contaminants, perhaps chemicals in water, perhaps removing pesticides from ground water, and perhaps the charcoal could be formed into a briquettes in a way that you could regulate the pore size, and then it could filter bacteria from the water as well. Which leaves you with the idea of making charcoal water filters for removing chemical and bacterial contaminants. Which might actually be a good idea (let's go make one and try it out!!!). You may choose to do bisociation with additional topics if you don't get fruitful results from the first.

There are many strategies for creative idea generation, brainstorming and bisociation are just a couple.

At the end of your session, group your ideas together into similar approaches and write up a brief summary of each approach. As a team, choose five to ten approaches that you think are worth following up on.

Deliverable (Homework 14)

The results of your idea generation sessions should be summarized and presented at the Session #13 design review.

Analysis & Experimentation

Now that you have sorted through your ideas, you will need to start the process of choosing the best approach. It is often necessary to investigate the approach further in order to make that decision. Go through each approach and think of the key things that you would need to know in order to effectively evaluate the approach. Think of simple experiments that you could do to find out this information if it is not possible to get the information through additional research or through analysis. Devise an experimental procedure, and perform the tests to get the information you need. At this stage, you need to go fast, build mock-ups quickly and cheaply that will provide you with the results you need. Don't waste time on complicated concepts at this stage, and don't sweat the details.

Deliverable (Homework 14)

Each team should present the results of the research, analysis and experiments for each approach at the Session #13 design review.

Concept Evaluation

Your next task is to choose which of your many ideas you will concentrate on in your design solution. It is often difficult to do this as ideas tend to take on a life of their own and you will find that you each have favorites. It is important to judge as objectively as possible. You will need to consolidate your various ideas into designs that you can compare. You might consider group together ideas that are similar and combine them into a single solution. Try to narrow it down to three to five different concepts, each of which may be a marriage between several of your original ideas.

Pugh Chart Analysis

A Pugh chart is a tool that helps evaluate ideas by setting up a list of characteristics and judging each idea in terms of the individual criteria. This helps to create a more objective and structured selection process.

One idea is chosen as the datum, or the idea to which all others will be compared. It is a good approach to choose a fairly simple idea as the datum, as it will be easier to do the comparisons than if you choose one of your more complicated ideas. Revisit your problem statement and your list of design specifications to determine the criteria and characteristics that you will use to judge your potential solutions. For each of the criteria, decide if the option you are evaluating is the same (0), better (+) or worse (-) than your datum. Tally the results for each option and determine which idea is the best. You may want to weight some of the criteria more heavily (for example, safety might be deemed more important than portability when evaluating your idea, and therefore you may choose to double the weight of that criterion). You may also find that when you make your final selection, you will choose characteristics from several of your options and combine them to form the final design; however you should be careful not to make your project too complex.

Deliverable (Homework 14)

Each team should present the results of their concept evaluation at the Session #13 design review.

Phase 3: Implementation

Analysis & Experimentation

Now that you have chosen the final concept, it is necessary to establish that critical subsystems will perform as required. In many cases, performance can be predicted by calculations using data obtained during the research phase. In others, experimentation will be required. The experimental setup may closely resemble the contemplated prototype (in which case it's sometimes called a "breadboard" after the practice, in the early days of radio, of building the circuit up on a wooden board used for cutting bread). Or, it might be much simpler, simply containing the functional element to be tested. For example, a phase-change incubator will require testing to determine the optimal geometry and quantity of phase change material. It might be enclosed in plastic spheres of the intended size and number, or it might simply be contained in a laboratory beaker. The choice would depend on the information needed and the resources available. Another example might be a mechanical linkage. If linkage dynamics are important, an accurate breadboard would be necessary. If only kinematics are required, a Lego model, or even cardboard model might be sufficient.

Deliverable (Homework 15)

Each team member should choose a critical subsystem of your chosen concept and perform the necessary analyses and experiments to ensure that it can work according to specifications. Ideally, each person on the team should choose a different component or subsystem, but if there aren't enough, independent work on the same component is acceptable. Present a summary of this work at the Session #17 design review.

Detail Design

Once the performance potential of the critical subsystems is established, it is necessary to work out all the details that will make a workable prototype. This will vary greatly from project to project but includes aspects such as: dimensions and tolerances, material selection, kinematics of assemblies and sub-assemblies, and calculations of energy and power requirements. Every component of your project should be designed to best fulfill its purpose. Your first layout will not be your final one; continual refinement is possible until you run out of time, but the difference in quality from the first layout to the last can be enormous.

Keeping all these considerations in mind, start the process of producing technical drawings of your proposed design. Make sure to have all critical custom-made components drawn up either by hand or using computer programs such as SolidWorks, Pro/Engineer or AutoCAD (we don't need drawings of screws, nuts, off-the shelf parts or banana leaves!). Also, with each drawing make a list of materials that you will need in order to fabricate the parts you have designed, a list of processes needed to fabricate each part and denote where they will be made (a small-scale machine shop, a large plastics factory, etc.).

Deliverable (Homework 15)

Each member of the team should choose a different component of the design and turn in the detail drawing and materials list for that part. Even though each team member turns in just one part, this process should be done for all parts of the design. Present this information at the Session #17 design review.

Fabrication

Now it is time to turn your ideas into reality—generally one begins by building a proof of concept prototype. In this case, the parts are typically fabricated on an individual basis and may not be made in the same way, or of the same material, as the final product. A careful planning of this phase will save you valuable time, unnecessary waiting times for your raw materials or components, and stressful last-minute hard-work.

Deliverable

As a group, make a plan that outlines how you propose to complete your prototype during the next three weeks. Sketch out the main steps in a Gantt chart or timeline, including milestones. List all the materials you will need in the fabrication of your prototype, and make a preliminary budget detailing where you plan to obtain all your materials. Present this plan and the progress you have made to date at the Session #17 design review.

Testing and Evaluation

Once you have built a prototype, it is necessary to test it and see if it does what it is supposed to do. Now is the time to go back to the design specifications outlined in the early stages of the design process and verify that the device works according to the given specifications. Devise techniques for measuring the performance of your device for each of your design specifications. As part of this exercise, think of how your device could be improved. Are there ways you can make it cheaper, faster, better? Try to lower the part count or remove material. Is it as simple as possible (but not simpler? Not only should the technical performance of the device be tested, but also the human factors; test for usability and ergonomics. Have people try your device and get their feedback. Whenever possible, have the actual users try the device, if this is not feasible, try to find people with as close to the same background as possible. Have users try your device without as little instruction or guidance as possible, and analyze their interactions. You can observe how intuitive, easy and/or safe the device is to use.

Use all the information gathered at this stage to inform the next iteration of the design process. Consider revising the design specifications and the original ideal and desired values. Identify the subcomponents that need to be revisited or redesigned, and outline the goals for how to move the project forward.

Deliverable

Summarize the results of your tests and present them at the Session #20 design review. Videos of people using the machine are an especially effective presentation technique. Include recommendations for moving forward with the project.

EC.720J / 2.722J D-Lab II: Design
Spring 2010