Agenda for today

• Any questions on the team assignments, or what is needed next?
• Distinguish Engineering Science from Engineering Design Problems and from Technology
• Describe the 9-Step model of the Design Process
  – Start to think about the first couple of steps

Sources: RMU ENGR 1010 Notes, Hyman’s notes on "Fundamentals of Engineering Design"
A team is...

A small group of people with complementary skills who are equally committed to:

- a common purpose,
- performance objectives,
- and working approach,

for which they hold themselves mutually accountable.
What is Engineering Design?

• Engineering design is the process of **devising a system, component, or process** to meet the desired needs.

• Engineering design is a **decision-making process** in which the **basic sciences and mathematics and engineering sciences** are applied to **convert resources optimally** to meet a **stated objective**.

• Engineering design is a methodical approach to solving a particular class of large complex problems.
Donald A. Schon Cartoon

Contemplating Engineering Design

Solid Ground of Engineering Science

Design Swamp
Typical Engineering Student with Science and Mathematics Background

Solid Ground of Engineering Science

Design Swamp
Solid Ground of Engineering Science

Design Swamp

This Way
Solid Ground of Engineering Science

Design Professor

Design Swamp

Design Skills
Common Problem Features

- These problems have four common features:
  - The problem are well posed in a very compact form. i.e. the problem statement is complete.
  - The solutions to each problem are unique and compact. i.e. there is only one answer. (Analytical Problem)
  - The problems have a readily identifiable closure. i.e. you can easily recognize that the answer has been obtained.
  - The problems require application of very specialized areas of knowledge. i.e. calculus problems would require calculus concepts.

- Solving problems that have all of these four characteristics is an important part of engineering education.
Possible Logo for Engineering Design

This is meant to convey the notion that, unlike engineering science, much of engineering design does not depend on universally applicable laws of nature.
Cost of Making Changes During Different Phases of the Design Life Cycle

- preliminary design
- detailed design
- production
- consumption

cost of change, $
Heilmeier's Catechism

George Heilmeier worked on LCDs, became CTO of TI, president and CEO of Bellcore, SAIC.

When Heilmeier was the director of ARPA in the mid 1970s, he had a standard set of questions he expected every proposal for a new research program to answer. These have been called the Heilmeier Catechism.
Heilmeier's Catechism

1. What is the problem, why is it hard?
2. How is it solved today?
3. What is the new technical idea; why can we succeed now?
4. What is the impact if successful?
5. How will the program be organized?
6. How will intermediate results be generated?
7. How will you measure progress?
8. What will it cost?

Of course, if you are proposing a small effort, some of these questions should be adapted and modified (e.g., #5).
Nine Step Model of Design Process

1. Recognizing the need
2. Defining the problem
3. Planning the project
4. Gathering information
5. Conceptualizing alternatives
6. Evaluating the alternatives
7. Selecting the preferred alternative
8. Communicating the design
9. Implementing the preferred design
Step 1: Recognizing the Need

Sandra: “Jane, we need you to design a stronger bumper for our new passenger car.”

Jane: “Why do we need a stronger bumper?”

Sandra: “Well, our current bumper gets easily damaged in low-speed collisions, such as those that occur in parking lots.”

Jane: “Well, a stronger bumper may be the way to go, but there may be better approaches. For example, what about a more flexible bumper that absorbs the impact but then returns to its original shape?”

Sandra: “I never thought of that. I guess I was jumping to conclusions. Let’s restate the need as “there is too much damage to bumpers in low-speed collisions.” That should give you more flexibility in exploring alternative design approaches.”
Step 1: Recognizing the Need

- Describes a current situation that is unsatisfactory.
- Should be written in a negative tone.
- Establishes improvement in current situation as the ultimate purpose of the project.
- Market assessment

Recall: Heilmeier's Catechism

1. What is the problem, why is it hard?
2. How is it solved today?
Step 1: Recognizing the Need

Sandra: ...

Jane: ...

1. So we are Identifying the client
2. Working from the Client’s perception of the need
   Asking: Why is this a need?
   Trying to: Identify the reason for the need
## Step 2: Defining the Problem

<table>
<thead>
<tr>
<th>Goal Statement</th>
<th>Idealized and scope still poorly delineated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives</td>
<td>Each is unambiguous and measurable</td>
</tr>
<tr>
<td>Constraints</td>
<td>Each is unambiguous and measureable, clearly satisfied or violated. Hard requirements; cut down the feasible set</td>
</tr>
<tr>
<td>Design Criteria</td>
<td>Compact descriptor: useful for first-pass analysis of alternative approaches</td>
</tr>
</tbody>
</table>
Step 2: Defining the Problem: Goal

- Now we try to produce a Goal Statement
- Sets out to answer the question “How are we going to address this Need?”
- Brief, general, and ideal response to the Need.
- At this stage: Is so ideal that it might never be achieved, or so general that we cannot determine when it is achieved.
  - Its selection establishes the general direction of the design effort.
  - Don’t yet have readily identifiable closure.
Step 2: Defining the Problem: Goal
Step 2: Defining the Problem: Goal

- Goal Statement scope is often not clear initially.
- Statement needs to be understood by the client.

Example:

**Need:** *Childproof pill bottles are too difficult for people with arthritis to open.*

**Possible goal statements:** *Design a –*

- Childproof pill bottle that is easier to open
- Childproof pill container that is easier to open
- Childproof system for dispensing pills
- Childproof system for dispensing medication
Step 2: Defining the Problem: Objectives

- Quantifiable expectations of performance.
- Establish operating environment.
- Indicators of progress toward achieving Goal.
- Define the performance characteristics of the design that are of most interest to the client.
- Facilitate determination of which alternative designs best meets expectations.
Step 2: Defining the Problem: Objectives

Examples from the bumper problem:

• inexpensive
• no significant damage to bumper
• no significant damage to other parts
• easily recyclable
• operative

Revised Need: *There is too much damage to cars in low-speed collisions*

Revised Goal: *Design an improved front bumper*
## Step 2: Defining the Problem: Objectives

<table>
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<tr>
<th>Objective</th>
<th>Measurement Basis</th>
<th>Units</th>
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<tbody>
<tr>
<td>Inexpensive</td>
<td>Unit manufacturing cost for a production run of 50,000</td>
<td>dollars</td>
</tr>
<tr>
<td>No significant damage to bumper</td>
<td>Distance bumper is pushed into body</td>
<td>inches</td>
</tr>
<tr>
<td>No significant damage to other parts</td>
<td>Repair cost</td>
<td>dollars</td>
</tr>
<tr>
<td>Easily recyclable</td>
<td>Amount of aluminum</td>
<td>lb</td>
</tr>
<tr>
<td>Retain maneuverability</td>
<td>Turning radius</td>
<td>ft</td>
</tr>
<tr>
<td>Retain braking capability</td>
<td>Braking distance</td>
<td>ft</td>
</tr>
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</table>
Step 2: Objective and Constraint Duality

Restating the problem in a slightly different way can result in some objectives becoming constraints and vice-versa.

- The **objective** “not causing significant damage” can be reworded as a **constraint** “not costing more than $200 to repair”.
- It may be desirable to include both in the problem statement.
  - Or at least think about which is the better form.
  - Think: landscape gradient vs. bounds.
Step 2: Defining the Problem: Criteria

Objectives ➔ Quantifiable expectations of performance
Criteria ➔ Value-free descriptor of objective

*Same units; same basis for measurement*

**Example:**
Design objective: should be lightweight
Associated criterion: weight

Criteria are compact descriptors of performance associated with objectives.
Criteria can be developed from approaches. They allow you to think about common and unique features.
**Step 2: Defining the Problem: Criteria**

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Goal Statement

Objectives

Constraints

Design Criteria
Nine Step Model of Design Process

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Gathering Information

• There are vast amounts of information available on any subject.

• It is always better to base your design on existing information rather than relying exclusively on your own ideas.

• Sources
  – Technical (Library, Papers, Internet)
  – Creative (Brainstorming)
  – Acquisition (Catalogs)
  – Economic (Market forecasts, etc.)
Gathering Information: Stages

• Identify the kind of information required.
• Physically or electronically gather the information.
• Determine how reliable and credible the information is.
• Decide when to stop looking.
Team work

Personality Characteristics

- Myer-Briggs Type Indicator is designed to classify individuals according to four basic preferences
  1. extraversion versus introversion
  2. sensing versus intuitive
  3. thinking versus feeling
  4. judgment versus perception
- Given the time frame of the project, it is best to accept rather than try to change people’s personalities

Leaders and Followers

- “Born Leaders” myth -- no scientific evidence
- Different leaders may emerge depending on the situation at hand
Roles within the group

Generators
 – People who have lots of ideas

Integrators
 – Good at integrating other people’s ideas into credible proposals

Developers
 – Advance the idea stage into a product or process

Perfector
 – Improves the product or process
What does a leader do?

**Task oriented function**

– Organize the group, help define goals, monitor progress, make adjustments to meet the goal

**Relationship oriented function**

– Responsive and considerate to the needs of each group member
Group Tasks

Group project activities operate in a cycle:

– Group meets
– Tasks are assigned to individuals
– Individuals go off and accomplish tasks
– At next meeting, individuals report to group
– Group discusses and evaluates progress
– New tasks are assigned
– Cycle repeats
Group Tasks

Figure 3-2. XP lifecycle
Elements of Project Planning

• Divide project into tasks, tasks into subtasks, subtasks into ...

• Estimate duration of each task, subtask, ...

• Estimate resource requirements for each task, subtask, ...(budget, personnel, facilities)

• Identify precedence relations among tasks
Benefits of Project Planning

• Communications tool
  – Clients and coworkers

• Resource allocation
  – funds, personnel, facilities, equipment

• Benchmarking
  – progress monitoring
  – required adjustments
Project Planning Tools

• Gantt Chart

• Critical Path Method (CPM)

• Program Evaluation and Review Technique (PERT)

Variations and combinations of the above

Many available software packages contain these tools
Gantt Chart

Durations explicitly listed on the left

The critical path is in red

The slack is the black lines connected to non-critical activities

Diamonds used to mark milestones

Can mark progress along the bars by highlighting fraction complete  
\textit{e.g.}, cross-hatching
Critical Path Method (CPM)

• Uses a network flow diagram to depict the precedence relations among activities (tasks)

• Elements of diagram are directed line segments and nodes

• Facilitates identification of activities whose timely completion are “critical” to timely completion of the project
• An activity is an ongoing effort on a project task (directed line segment). Consecutive activities connected by events.

• Every activity has an initiating event and a closing event (nodes). Events consume no time.

- A precedes D
- A and B precede E
- B and C precede F
Critical Path Method (CPM)

• The critical path is the path of activities from the start event to the finish event for which delay in any activity along that path will delay the project finish.

• For projects with a small number of alternative paths, the critical path can be most efficiently identified by finding the longest of the alternative paths.
Program Evaluation and Review Technique

• Based on Critical Path Method
• Replaces single estimate of activity duration by a probability distribution
• Allows estimate of probability of completing project by a specified time
• First developed by the United States Navy in the 1950s
Program Evaluation and Review Technique

The beta distribution can be used to model events which are constrained to take place within an interval defined by a minimum and maximum value.

• $t_o$-optimistic estimate; the shortest time within which this activity can be completed assuming everything goes right. This is the left terminus of the pdf.

• $t_m$-the most likely time required to complete the activity. This is the mode of the pdf.

• $t_p$- pessimistic estimate; the longest time it will take this activity to be completed assuming everything goes wrong. This is the right terminus of the pdf.
Get distribution over the graph by summing $t_e$ over the paths.

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

$$\sigma^2 = \left(\frac{t_p - t_o}{6}\right)^2$$
Oral Communication

• Never underestimate the importance of an oral presentation
• Many decisions are made based on the basis of a presentation

Presentation Design:

1. Tell them what you are going to say.
2. Say it.
3. Tell them what you just said.
Oral Communication: Delivery

• Speak clearly and slowly
• Maintain eye contact
  – But do not fixate on a single person
• As a guideline allow one minute per slide
  – Figure out your “style”
• Presentation Zen, Guy Kawasaki
  – Good video: Authors@Google: Garr Reynolds
• Watch TED talks