CONCEPTS OF DESIGN
Yours truly, as a high-school senior!
Tradeoffs

• Everything interesting that you do in LIFE and in DESIGN is a tradeoff – getting what you want at the expense of something else.
• Design is a process of
  – **Understanding** the problem
  – **Creating** solutions
  – **Evaluating** solutions
    • *Crucial role of modeling and testing*
  – **Refining** and revising
  – **Detailing** the design

**DOCUMENTATION THROUGHOUT!**
Other Views of Design ...

Math, Science, Engineering Fundamentals

Practical Knowledge

Quantitative Design Analysis, Optimization

Pragmatic Design Analysis

Product

Design Spiral

payload

geometry

maintenance

sensors

control

power

sea-keeping

propulsion

design freedom

time

knowledge

“classwork”

“formal”

“modeling”

“hands-on”

“what works”

“organization”

“planning”

Massachusetts Institute of Technology, Subject 2.017
The Objectives Tree

Broad objectives…

→ **HOW ? →**

← **WHY ? ←**

… Specific objectives

- Participate, innovate, initiate
- Do assigned work
- Request lectures
- Use the shop
- Take advantage of resources
- Establish responsibilities
- Use a few design methods!
- Apply prior knowledge
- Get along
- Plan ahead
- Have fun
- Learn a lot
- Get a good grade

Have a positive experience in 2.017
### A Decision Matrix: Flettner Rotorship

What is the impact of these ENGINEERING ATTRIBUTES, relative to REQUIREMENTS?

- **A**: High rotary speed
- **B**: Large rotor diameter
- **C**: Stiff inner structure
- **D**: Number of rotors
- **E**: Height of rotor

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>Weighting</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propels the boat</td>
<td>40</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Robust to damage</td>
<td>10</td>
<td>-1</td>
<td>0</td>
<td>2</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Easy to fabricate</td>
<td>30</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>High boat stability</td>
<td>20</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>-2</td>
</tr>
</tbody>
</table>

**Weighted sums:**

- 40
- 60
- -30
- 40
- -40

- Attribute B (a large rotor diameter) is **most important** to meeting the requirements.
- Attributes C and E (stiff inner structure, tall rotors) have **negative** impact on meeting the requirements.
- The calculation helps identify and document priorities and the direction of the design.
- It suggests areas where further clarification of requirements or attributes is needed.
- Related to “House of Quality” and “Quality Function Deployment”
Knowledge vs. Confidence

- Knowledge about an idea and confidence in it are **not** the same thing!
- **Target**: a specification, criterion, requirement
- **Idea**: one possible solution
- A measure of **knowledge**: what is the probability of you getting a true/false question right about the idea?
  - *Clueless*: $K = 0.5$  
  - *Expert*: $K = 1.0$
- A measure of **confidence**: what is your certainty that the idea will meet the target?
  - *Impossible* $\rightarrow$ *Doubtful* $\rightarrow$ *Likely* $\rightarrow$ *Perfect*
  - $C = 0.0$  
  - $C = 0.3$  
  - $C = 0.7$  
  - $C = 1.0$

Confidence is subjective!
Combine Knowledge and Confidence: Belief

- A measure of belief: confidence that an idea meets the target, based on current knowledge.
- Using the above numerical values and Bayesian analysis, Ullman (2001) computes

$$\text{Belief} = 2KC - K - C + 1,$$

leading to a “belief map” →

Decisions should be based on a high level of belief – you have to have knowledge of the idea AND confidence that it meets the target.
Function Analysis

**Flow-Chart:** Algorithm design, Processes

1. Drive robot toward target
2. Range rate? 
   - No
   - Yes: Go in a straight line for one minute 
     - Turn around
     - Captured!

**Layered Functions:** A complex system having multiple functions

- Allows a person to write and edit words or images on paper
- Makes mark on paper
- Fits in hand comfortably
- Erases own marks

Autonomous underwater vehicle homing to an acoustic beacon

Similarity to objectives tree
Understanding Complexity

- Complexity is often what causes the hardest problems – and solutions that are time-consuming and expensive.
- High costs of errors once a product is out the door.
- Piecemeal vs. Holistic design.
- Fundamental rules of design – e.g. grounding & isolation, stainless steel, well-known vendors, etc.
- Basic rule: Layered Sub-functions \( \rightarrow \) Complexity.

How many functions does a car door serve?
Why does it take so long!?

Person-hours design effort can be estimated as

\[ H = A \times B \times C \]

where

\( A \) = a constant depending on communication and size of engineering group: values typically in the range 30-150 in commercial world – it may be lower or higher for students!

\( B \) = sum of products of level number and number of subfunctions at that level (1+6+9 = 16 in figure above).

\( C \) = difficulty (1 is easy – known technologies, 3 is hard – many unknown technologies)

→ Even a seemingly simple project easily runs into thousands of hours @#$%^&*

→ Role of complexity should be kept in mind when milestones are defined and set
Gantt Charts: a Graphical Schedule

Documentation
Clarify problem
Modeling
Brainstorming
First design iteration
Experiments & research
Test candidate solutions
Second design iteration
Finalize design choices
Order parts
Make machine drawings
Fabricate subsystems
Assemble system
Integrated testing
Field tests
Documentation

What are the dependencies among tasks?
What is the order of tasks?
Does the division of effort make sense?
What tasks are concurrent?
Is the time allotted for each task appropriate?

Quarter 1 2 3 4 time
A Few References…


Acoustic image of a metal box on the bottom of a barge, taken from an autonomous underwater vehicle, June 2007.