Lecture 10 — Engineering Design & Analysis

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November 14, 2015

Definition

Canadian Engineering Accreditation Board definition of engineering design:

> *Engineering design integrates mathematics, basic sciences, engineering sciences, and complementary studies in developing elements, systems, and processes to meet specific needs. It is a creative, iterative, and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social, or other pertinent factors.*

In other words

- You have a technical problem. You'd like to solve it.
  $\Rightarrow$ Use engineering design!

Engineering design is an open-ended process which applies technical knowledge in a creative way for some useful purpose.

Quotes on Creativity

A good scientist is a person with original ideas. A good engineer is a person who makes a design that works with as few original ideas as possible.

— Freeman Dyson, physicist with mastery of mechanical engineering

I believe that engineering is a highly creative profession. Research tells us that creativity does not spring from nothing; it is grounded in our life experiences, and hence limited by those experiences. Lacking diversity on an engineering team, we limit the set of solutions that will be considered and we may not find the best, the elegant solution.

— William W. Wulf, former president of National Academy of Engineering

Creativity

In creativity, we explore a search space for interesting points, perhaps solutions to a problem.

- Creativity is required for innovation.
- Creativity introduces the possibility of failure.
- A great engineer leverages existing design knowledge as much as possible and uses creativity only when necessary to solve a problem.

Progress

…(that) any general system of conveying passengers would …go at a velocity exceeding ten miles an hour; or thereabouts, is extremely improbable.

Thomas Treadgold, railway engineer, 1835

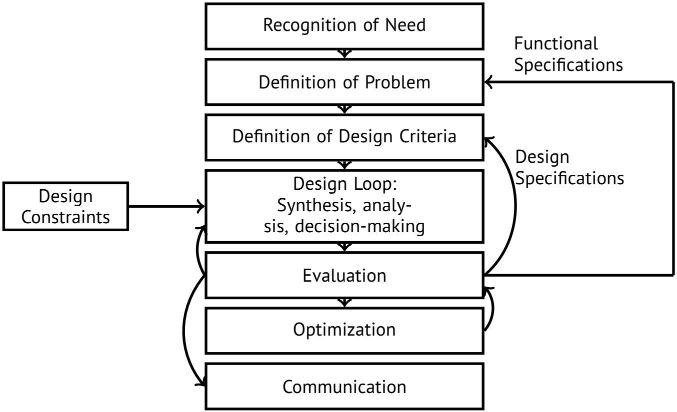
Progress has been inevitable in the past few hundred years. Engineering implements technological progress, enabling people to do the improbable.

“All parts should go together without forcing. You must remember that the parts you are reassembling were disassembled by you. Therefore, if you can’t get them together again, there must be a reason. By all means, do not use a hammer.”

IBM Maintenance Manual, 1925

One way of getting a design is by using a (metaphorical) hammer. This is not going to be a win. Good engineering design is hard.

Overview of Engineering Design Process



Previous slide: a model for classical engineering disciplines—ends with the transfer of blueprints to manufacturing and construction firms.

Software is different.

Customer Requirements

In this phase:

- trying to figure out what the customer is looking for.
- note: customers might not know what they want;
- can always give platitudes, e.g. convenient, easy-to-use, lightweight, simple.

By digging deeper, you can find a design problem among what they're saying.

Avoid getting pigeonholed by “helpful” customers giving you advice on how to solve the problem (but consider input).

Customer Requirements

Video: https://www.youtube.com/watch?v=BKorP55Aqvg

- Given a problem, you need to know *specifically* what constitutes a solution.
- Solution should, to the extent possible, meet the design criteria.
- A project that fails to meet one criterion isn't necessarily a failure.

Examples of design criteria?

Constraints are what make things interesting (as long as they're satisfiable).

- Your task: find a constraint-satisfying solution.

Design constraints may:

- apply to the design process (that is, the designer or the final design) or the manufacturing process;
- be imposed by management, the environment, or physical laws involved in the design.

What are some examples of design constraints?

We usually consider design constraints non-negotiable; solutions must satisfy all design constraints.

Four related terms:

- *design heuristic*: general (and not necessarily actionable) rule-of-thumb based on experience.

  Heuristics lead to quick design solutions that often work well but may fail in some situations.

  No substitute for understanding.

- *design guideline*: general rule based on experience and specific knowledge of the design problem that may be applied to a design solution.

  More specific than heuristics.

Standards and Specifications

- *standard*: provides more direction about the acceptable solution space by stating technical requirements that must be satisfied by candidate designs.

  Do not provide a complete solution, but do dictate a set of requirements.

- *specification*: in this class, refers to a description of a solution which provides all of the details.

  Using a specification, an engineer should be able to reproduce a design exactly.

Synthesis, Analysis and Decision-Making.

You've got constraints and requirements. Time to come up with a solution. You will use the *design loop*.

- Synthesis: gather information, combine (synthesize) it, and come up with ideas or methods to solve a problem.
- Analysis: estimate the expected result from each idea or method.
- Decision-making: compare the expected results and their uncertainties; pick the best alternative.

Iteration

Expect to iterate:

- Even after you get a “best” alternative, maybe your criteria were wrong, or you didn’t satisfy all of the design constraints or meet the desired design criteria.
- When iterating, bring back less-favoured alternatives, and reconsider and revise all of the alternatives. You’ll get a better set of alternatives.

Once you have a sufficiently-good best design, exit the design loop. This design should satisfy all constraints and achieve the desired criteria.

Choose the winning design, optimize, and implement.

Innovation versus evoluation

Solutions tend to have some innovation and some evolution. It's a continuum.

- Evolutionary design solutions *build on top of* existing solutions, improving them in some way.
- Innovative design solutions invent *something new*, a completely original idea or a novel way of solving the design problem.

Modern eng. design solutions combine innovation & evolution.

(You don't want to innovate on all fronts simultaneously).

Example: Brooklyn Bagel Slider

Goal: Avoid Bagel-Related Injuries.

What is innovative about this design? What is evolutionary?

Creativity

Popular misconception: engineering is not creative.

- Good engineering uses creativity when necessary.

Know when to innovate and when to build on others' designs.

Avoid the high-risk, low-reward category: make sure there is a payoff, and analyze your proposed solution carefully to ensure that it meets all requirements and constraints.

Risks of creativity

- adds to time required to complete a design;
- adds to cost for prototyping the design;
- might not lead to a solution at all; and
- might lead to an unsatisfactory solution.

The Creative Process: Synthesis/Analysis

5 steps in a typical creative process:

1. Gather information.
2. Make a concentrated effort to understand the problem.
3. Take a break (sleep, do something else, take a shower, etc.)
4. Discover the solution to the problem (often subconscious).
5. Write down the solution and refine it.

How do you get something good?

- generate lots of alternatives.

(a.k.a. getting lots of practice developing skills[1][2])

Might not work as well:

- trying to come up with the one ideal solution.

[1] http://www.lifeclever.com/what-50-pounds-of-clay-can-teach-you-about-design/

[2] http://www.lifeclever.com/talent-isnt-everything-7-habits-of-highly-effective-junior-designers/

- Synthesis: come up with new ideas synthesizing the information; don't discount any ideas, just write them down. [The usual part of brainstorming.]
- Analysis: look at all of the ideas (to some extent) and analyze them. Determine the most promising solutions. [Also important!]

Because unusual ideas show up, and aren't immediately discounted, they can help you come up with a variety of creative solutions, some of which might be practical.

Creativity: Brainwriting

This is like brainstorming.

- Write down tentative solutions on *solution sheets*.
- Each team member picks a solution sheet to refine.
- Exchange solution sheets until members run out of ideas.

Because you're writing things down, you can avoid dropping things on the floor.

Creativity: Pitfalls to Avoid I

Roger von Oech[3] produces a lot of output about creativity.

Here are some misbeliefs, according to him:

- There is only one right answer.
- The creative process must be logical.
- They must “follow the rules” even if the rules are unwritten.
- They must be practical and therefore inhibit their fantasies.
- They must avoid ambiguity and therefore stifle their imagination.

[3] http://www.creativethink.com

Creativity: Pitfalls to Avoid II

More misbeliefs:

- They avoid new ideas for fear of making mistakes.
- Play is frivolous, and new ideas are hard work.
- They narrow their focus and miss ideas in nearby areas.
- They are not creative.
- They are afraid to look foolish by suggesting an unworkable idea.

Outline

Evaluating Designs

You have one or more candidate designs (design alternatives) and want to see how good it is/they are.

A *design review* is an independent evaluation of a design alternative:

- act as a "sanity check" on the design; and
- are often conducted by evaluation teams consisting of clients and/or managers.

If all alternatives are bad (failed design reviews), the client might terminate the project.

Questions for Evaluating Designs and Teams

- Does the design team have a thorough understanding of the purpose and goals of the design?
- Have all of the relevant requirements, criteria, and constraints been identified?
- Is the overall design plausible for meeting the design objectives?
- Does the overall design appear to meet the criteria specified?
- Is the (anticipated) performance of the design adequate?
- Are there any flaws in the analysis of the design?

Consider presenting more than one alternative at a design review[4].

- Life is often unclear.
- Alternatives: customer has a choice,
- rather than saying “I don’t like that!”

Trying to push bad designs forward can help you understand why those designs are bad.

[4] `http://www.microsoft.com/design/article.aspx?type=stories&key=design`

On Communication

Communication is the final phase in traditional engineering disciplines.

(Not so in software!)

- You haven't done anything if you don't (successfully) tell anyone about it.
- Communication is also important en-route.

Who To Communicate With?

- Between Stakeholders: Designers/implementers, managers, and clients.

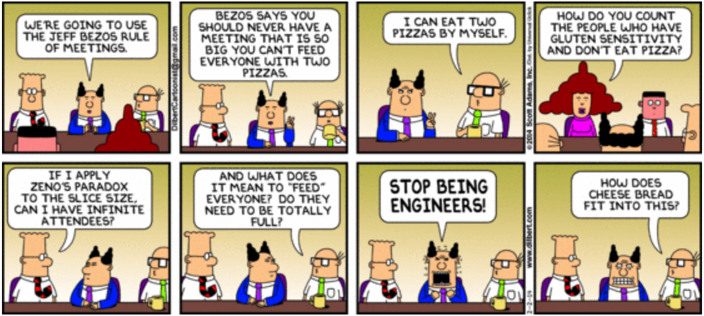
  Default assumption: things are going well.
  May lead to unhappiness.

- Intra-Team Communication.
  - Small team: helps with continuity; allows you continue the project even if an engineer leaves the company.
  - Large team: mandatory for making sure that all parts integrate and for tracking the schedule.

Outline

Tips on Organizing Design Teams

- Keep teams small, e.g. “two-bit” teams.
  Larger teams have too much coordination overhead.
- Think about dividing responsibility.
- No useless work.
- Open communication; track progress. (Don’t pester!)
- Encourage creativity when necessary, but make sure team members aren’t going overboard.


WE'RE GOING TO USE THE JEFF BEZOS RULE OF MEETINGS.
BEZOS SAYS YOU SHOULD NEVER HAVE A MEETING THAT IS SO BIG YOU CAN'T FEED EVERYONE WITH TWO PIZZAS.
I CAN EAT TWO PIZZAS BY MYSELF.
HOW DO YOU COUNT THE PEOPLE WHO HAVE GLUTEN SENSITIVITY AND DON'T EAT PIZZA?
IF I APPLY ZENO'S PARADOX TO THE SLICE SIZE, CAN I HAVE INFINITE ATTENDEES?
AND WHAT DOES IT MEAN TO "FEED" EVERYONE? DO THEY NEED TO BE TOTALLY FULL?
STOP BEING ENGINEERS!
HOW DOES CHEESE BREAD FIT INTO THIS?
DilbertCartoonist@gmail.com
www.dilbert.com

Potential Dysfunctions

Per Steve McConnell, *Rapid Development*, pp. 156–168, Microsoft Press, 1996.

- Lack of common vision
- Lack of identity
- Lack of recognition
- Productivity roadblocks
- Ineffective communication
- Lack of trust
- Problem personnel

Typical Set of Design Groups

- Development Group: tests the feasibility of new technologies and ideas.
- Design Group: refines a design to ensure manufacturability, reliability, safety, and efficient operation.
- Manufacturing Group: refines a design based on the results of the manufacturing process and the performance of test batches.
- Quality Control Group: monitors the quality of products in wide use.
- Customer Service Group: tracks the performance of products and ongoing maintenance performed for customers.

Comments on Design Groups

Design groups work concurrently and synchronize with each other.

Groups have different goals and deadlines—consensus and cooperation may be difficult to achieve.

(Organizational inertia generally makes cooperation difficult, even without different goals and deadlines.)

Project management: get everyone working together.

Time management is particularly key.