2.007 Design and Manufacturing I
Spring 2009

2.007 –Design and Manufacturing I

# Mechanical Design Process: A Brief Overview

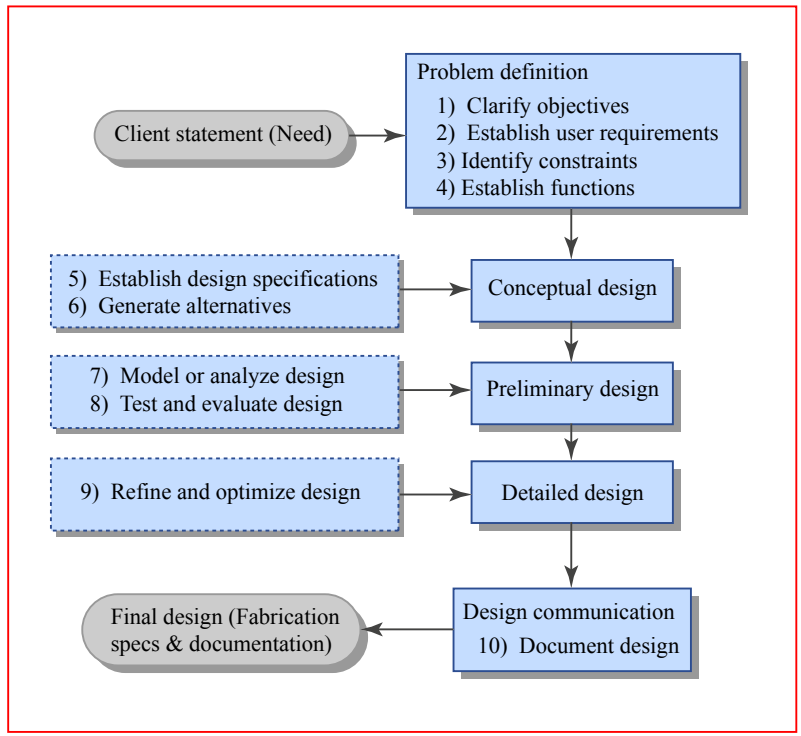
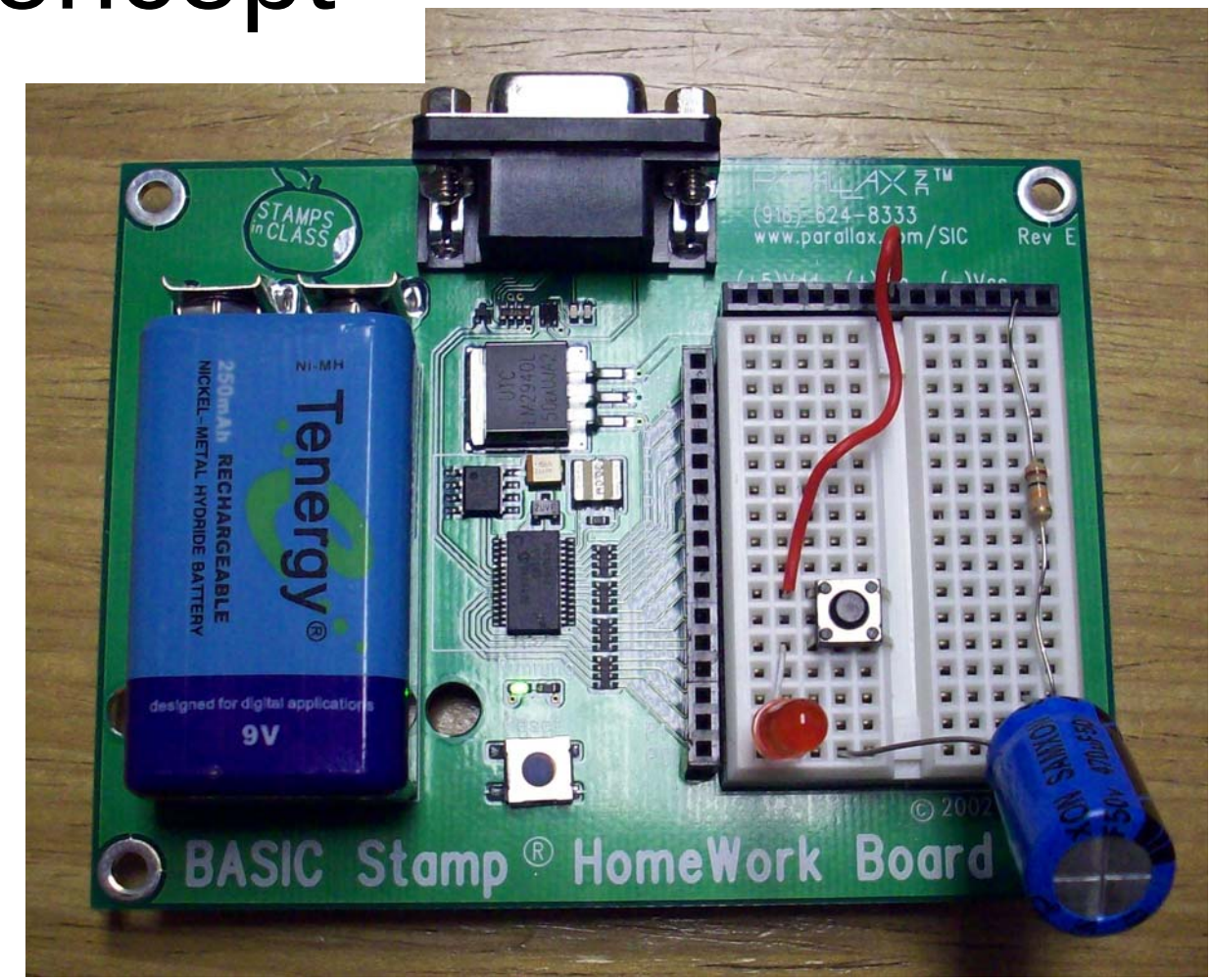



Figure by MIT OpenCourseWare.

Presented by Dan Frey on 5 FEB 2009

# A 2.670 Concept

- All these components are connected in series
- The capacitor has no potential difference across its terminals
- The switch is open (the button)
- What will happen when I push the button?




1) Nothing visibly
2)The LED will light and stay lit steadily
3) The LED will slowly become brighter
4) The LED will light and slowly dim

# A 2.670 Concept

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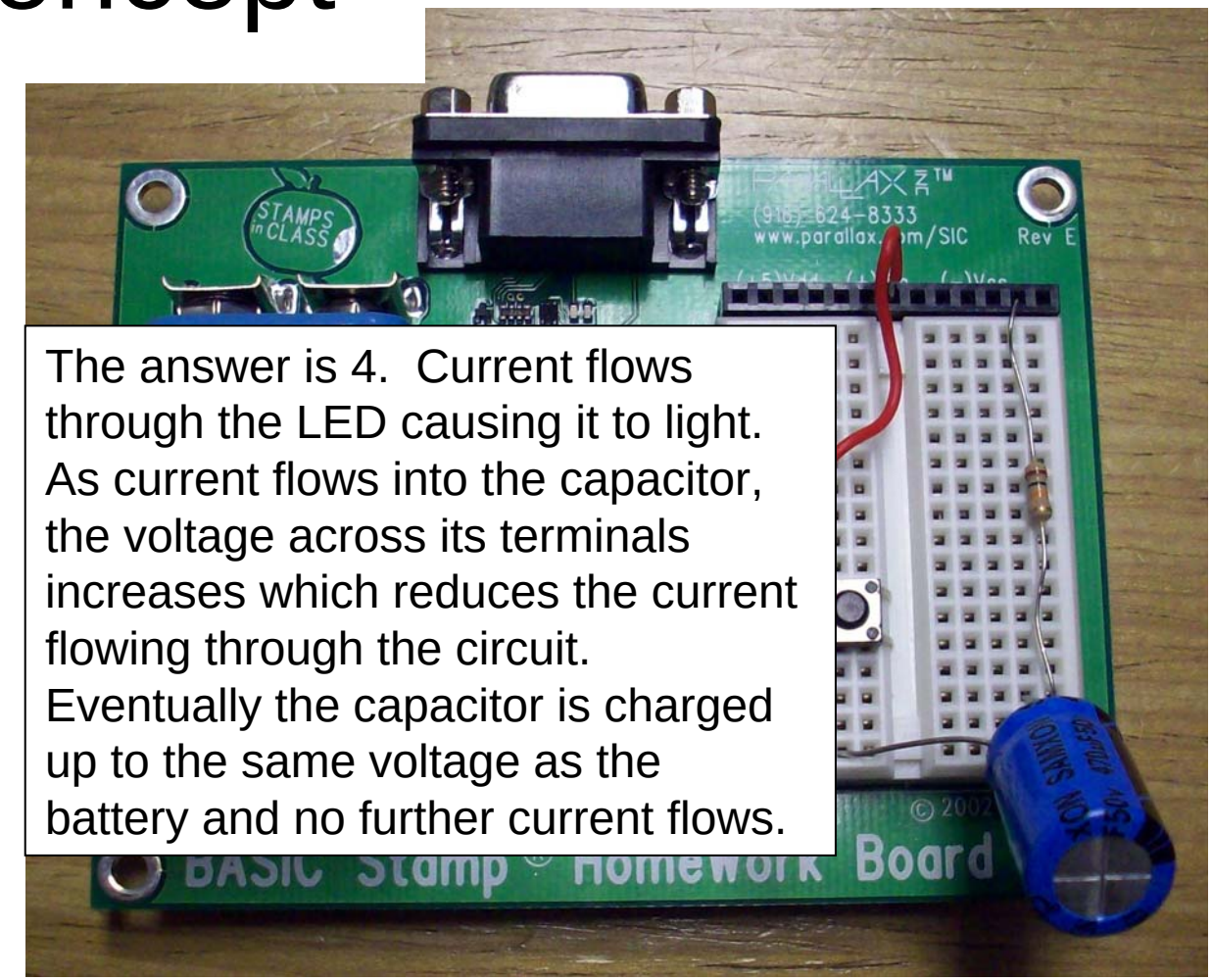



The answer is 4. Current flows through the LED causing it to light. As current flows into the capacitor, the voltage across its terminals increases which reduces the current flowing through the circuit. Eventually the capacitor is charged up to the same voltage as the battery and no further current flows.

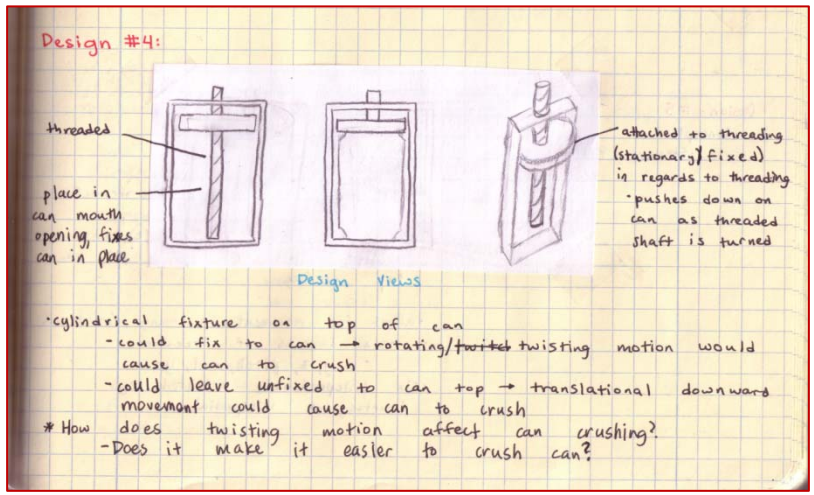
1) Nothing visibly
2)The LED will light and stay lit steadily
3) The LED will slowly become brighter
4) The LED will light and slowly dim

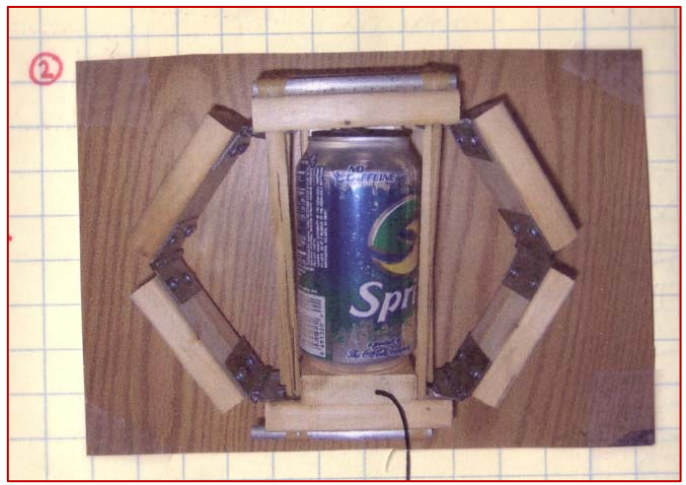
# Today's Agenda

- What is a design notebook?
- The design process
  - Clarifying objectives and constraints
  - Generating ideas
  - Evaluating design alternatives
  - Experimentation
  - Robustness
- Section assignments

# What is a Design Notebook?

- It documents your design artifact
- It documents your design process
- So, it must show <u>alternatives</u>
- And it must articulate <u>reasons</u> for your choices among alternatives



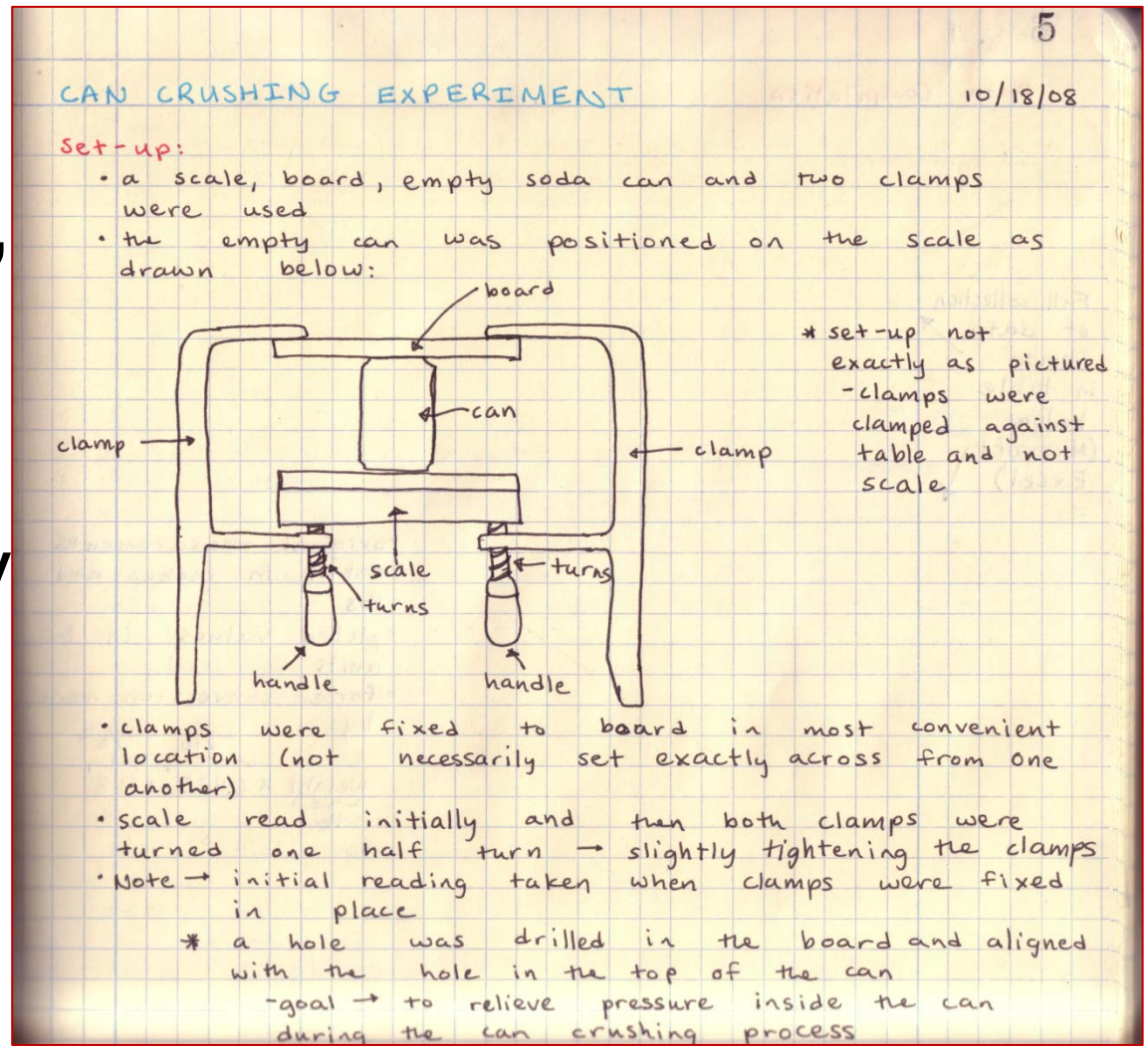




Courtesy of Katherine Smyth. Used with permission.

Smyth, K., 2008, *UROP Design Notebook*

# What is a Design Notebook?

- It has drawings, text, & photos
- It's legible
- It's reasonably organized

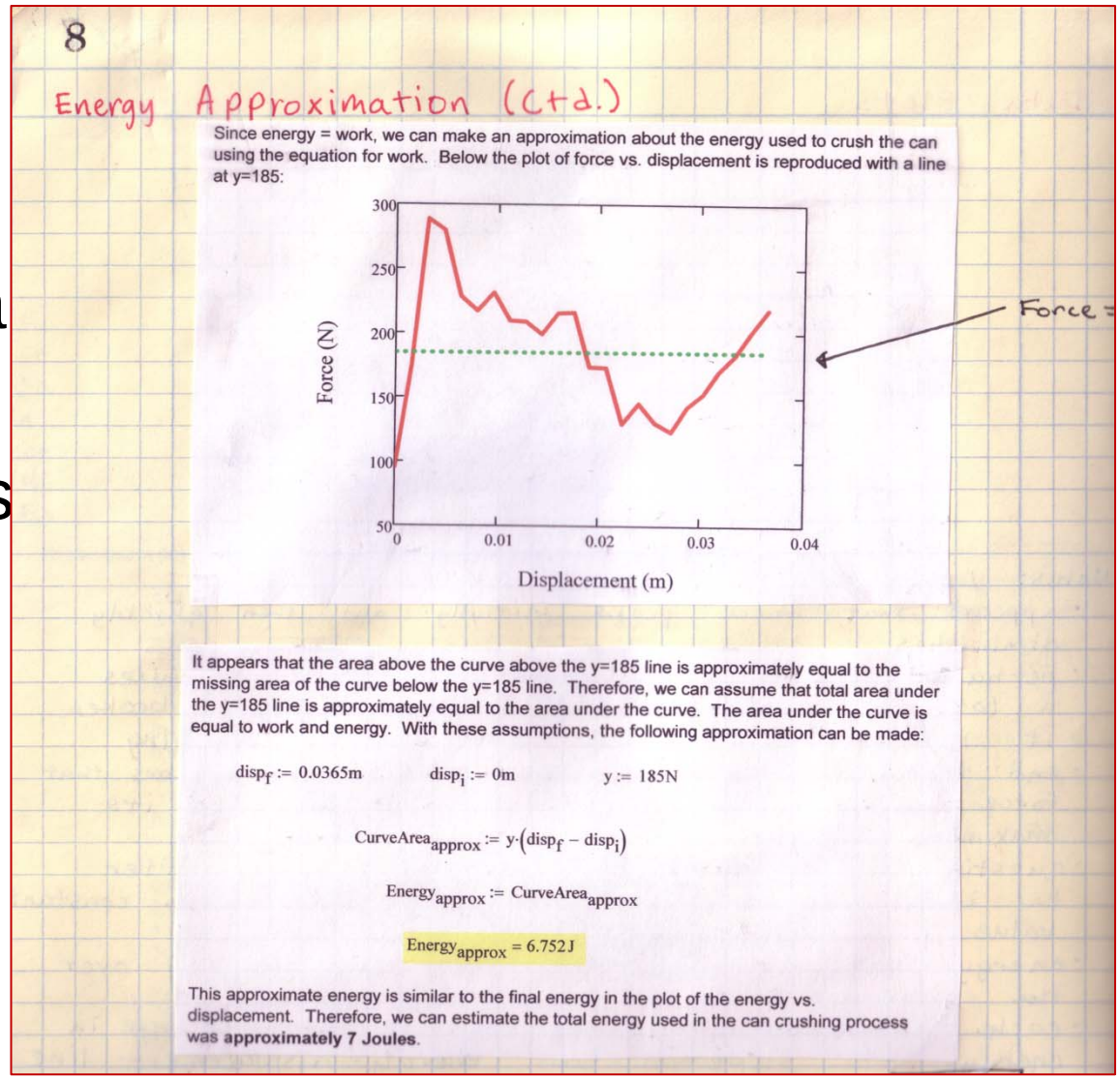



Courtesy of Katherine Smyth. Used with permission.

Smyth, K., 2008, *UROP Design Notebook*

# What is a Design Notebook?

- It has calculations, estimates, data and graphs
- It demonstrates your ability to apply core science and math to move your design forward



8

Energy Approximation (Ctd.)

Since energy = work, we can make an approximation about the energy used to crush the can using the equation for work. Below the plot of force vs. displacement is reproduced with a line at y=185:



It appears that the area above the curve above the y=185 line is approximately equal to the missing area of the curve below the y=185 line. Therefore, we can assume that total area under the y=185 line is approximately equal to the area under the curve. The area under the curve is equal to work and energy. With these assumptions, the following approximation can be made:

$disp_f := 0.0365m$ $disp_i := 0m$ $y := 185N$

$CurveArea_{approx} := y \cdot (disp_f - disp_i)$

$Energy_{approx} := CurveArea_{approx}$

$Energy_{approx} = 6.752J$

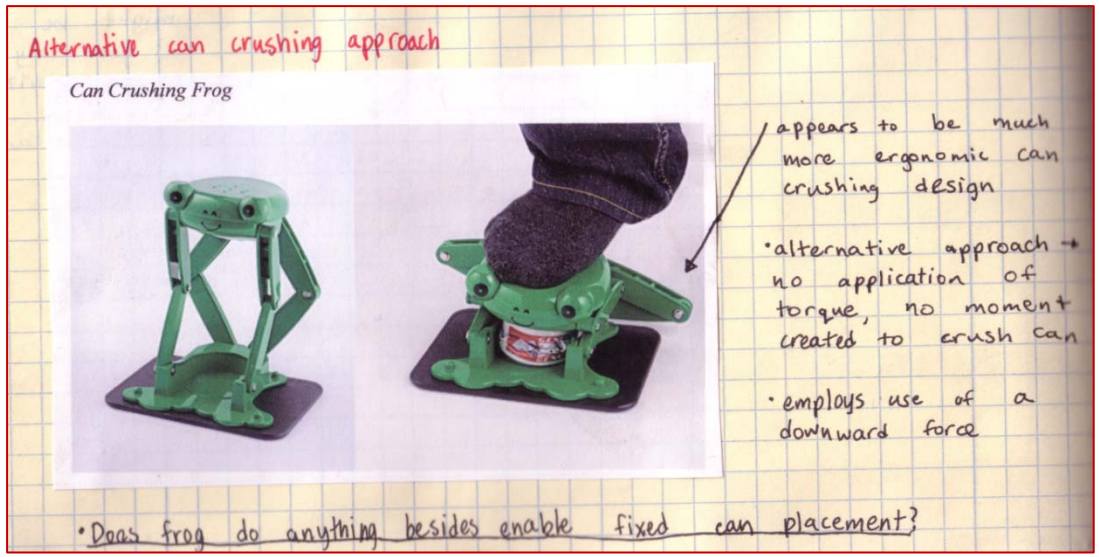
This approximate energy is similar to the final energy in the plot of the energy vs. displacement. Therefore, we can estimate the total energy used in the can crushing process was **approximately 7 Joules**.

Courtesy of Katherine Smyth. Used with permission.

Smyth, K., 2008, *UROP Design Notebook*

# What is a Design Notebook?

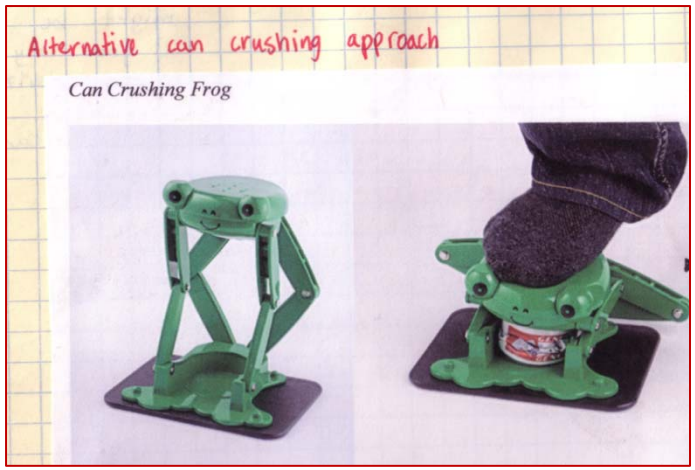
- It brings in data from a variety of sources (e.g., textbooks, commercial web sites, peers)
- It acknowledges sources of material and ideas

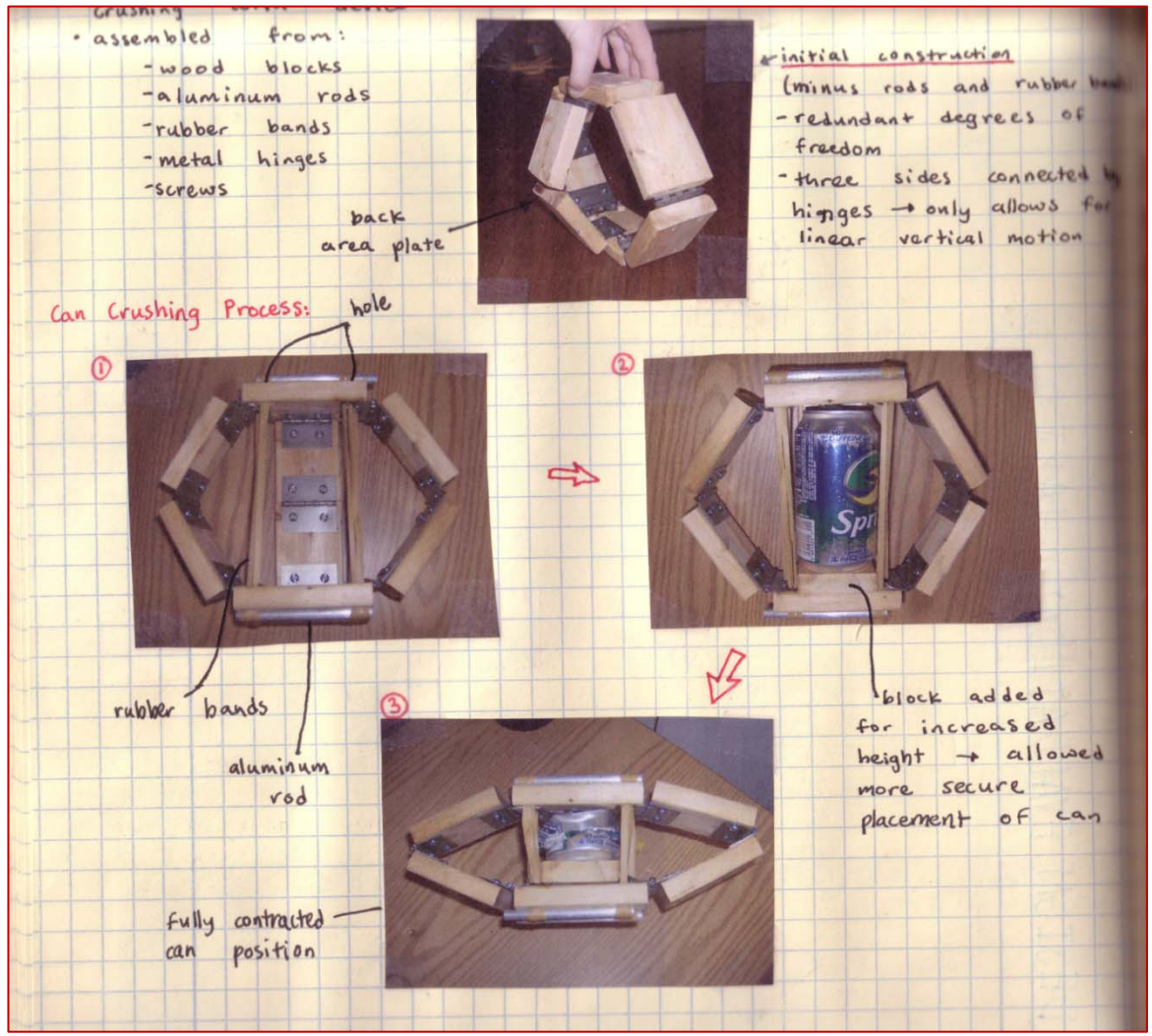



Courtesy of Katherine Smyth. Used with permission.

Smyth, K., 2008, *UROP Design Notebook*

# What is a Design Notebook?



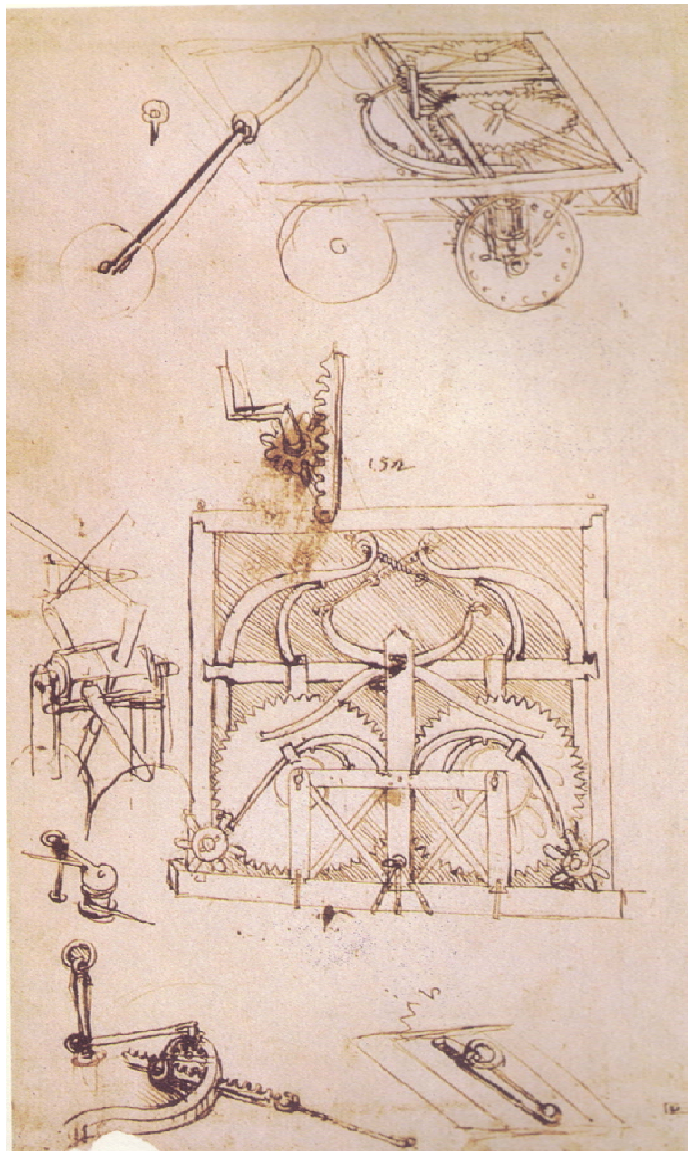




- It documents a process of evolution

Courtesy of Katherine Smyth. Used with permission.

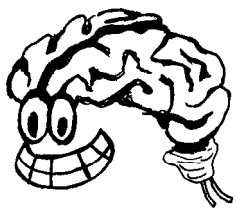
# What is a Design Notebook?

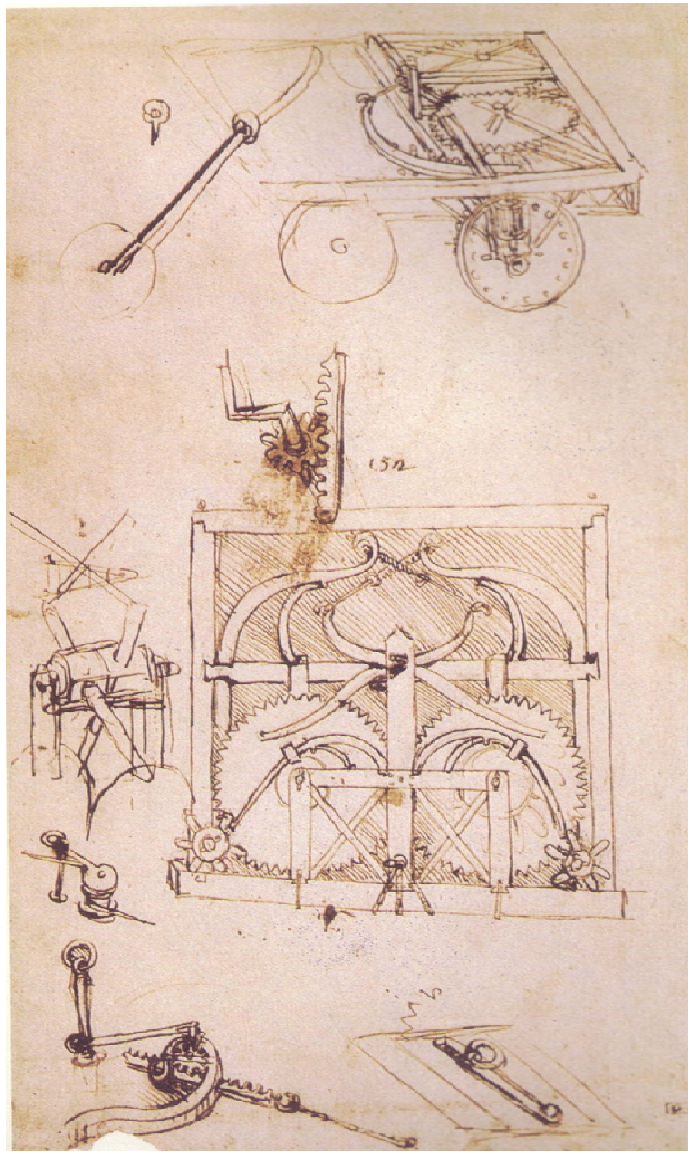
- It can be beautiful, but doesn't always have to be
- You have permission to explore the design space, work things out
- Some drawings will be iconic and/or incomplete
- Many ideas will be set aside and left undeveloped



Suh, H. Anna, 2005, *Leonardo's Notebooks,* Black Dog & Leventhal, New York.

In the margins near this drawing, da Vinci wrote: “mechanical science is the noblest and above others most useful, seeing that by means of it all animated bodies which have movement perform all their actions…”





Suh, H. Anna, 2005, *Leonardo’s Notebooks,* Black Dog & Leventhal, New York.

# What is a Design Notebook?

- It can be a legal document
  - In ink
  - Signed and dated on each page
  - Witnessed on each page
  - Notarized as a whole
- These requirements seem too burdensome for this course
- NOTE: in 2.007 web page is no longer required

# What is a Design Notebook?

- It is your notebook
- You can choose the type of notebook

Photos of notebooks removed due to copyright restrictions.

>$25

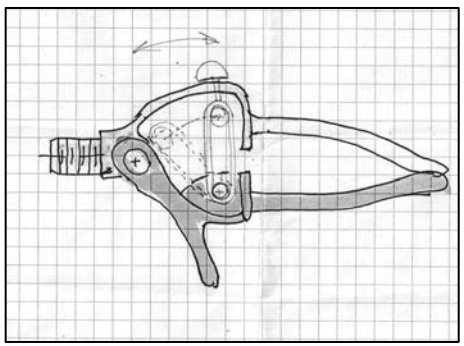
<$3

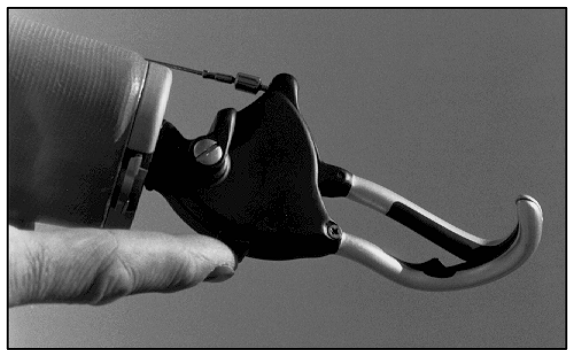
# Today's Agenda

- What is a design notebook?
- The design process
  - Clarifying objectives and constraints
  - Generating ideas
  - Evaluating design alternatives
  - Experimentation
  - Robustness
- Section assignments

# A definition of engineering design from session #1

Engineering design is a systematic process in which designers generate, evaluate, and specify devices, systems, or processes whose form and function achieve objectives while satisfying constraints.

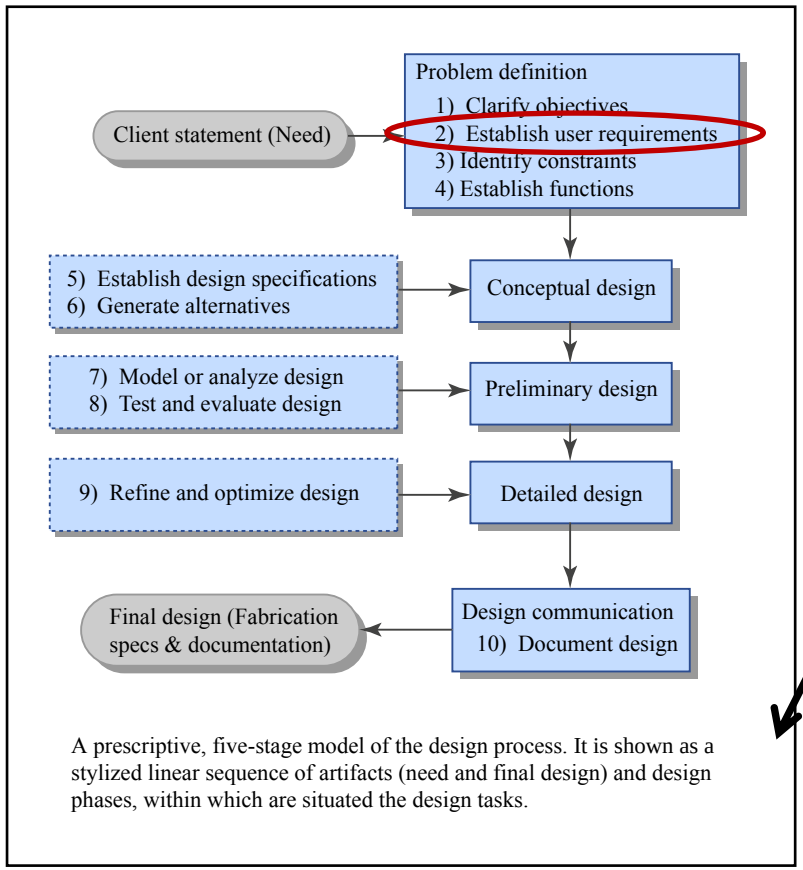


Dym, C. L., A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer, 2005, "Engineering Design Thinking, Teaching, and Learning," *ASEE Journal of Engineering Education* **94**(1):103-120.

# The Design Process: As a Flow Chart

Good idea!




A prescriptive, five-stage model of the design process. It is shown as a stylized linear sequence of artifacts (need and final design) and design phases, within which are situated the design tasks.

Figure by MIT OpenCourseWare.

Decomposition and iteration are also essential

Dym, C. L., and P. Little, 2000, *Engineering Design: A Project Based Introduction*, John Wiley & Sons, New York.

# The Design Process: As a “V”

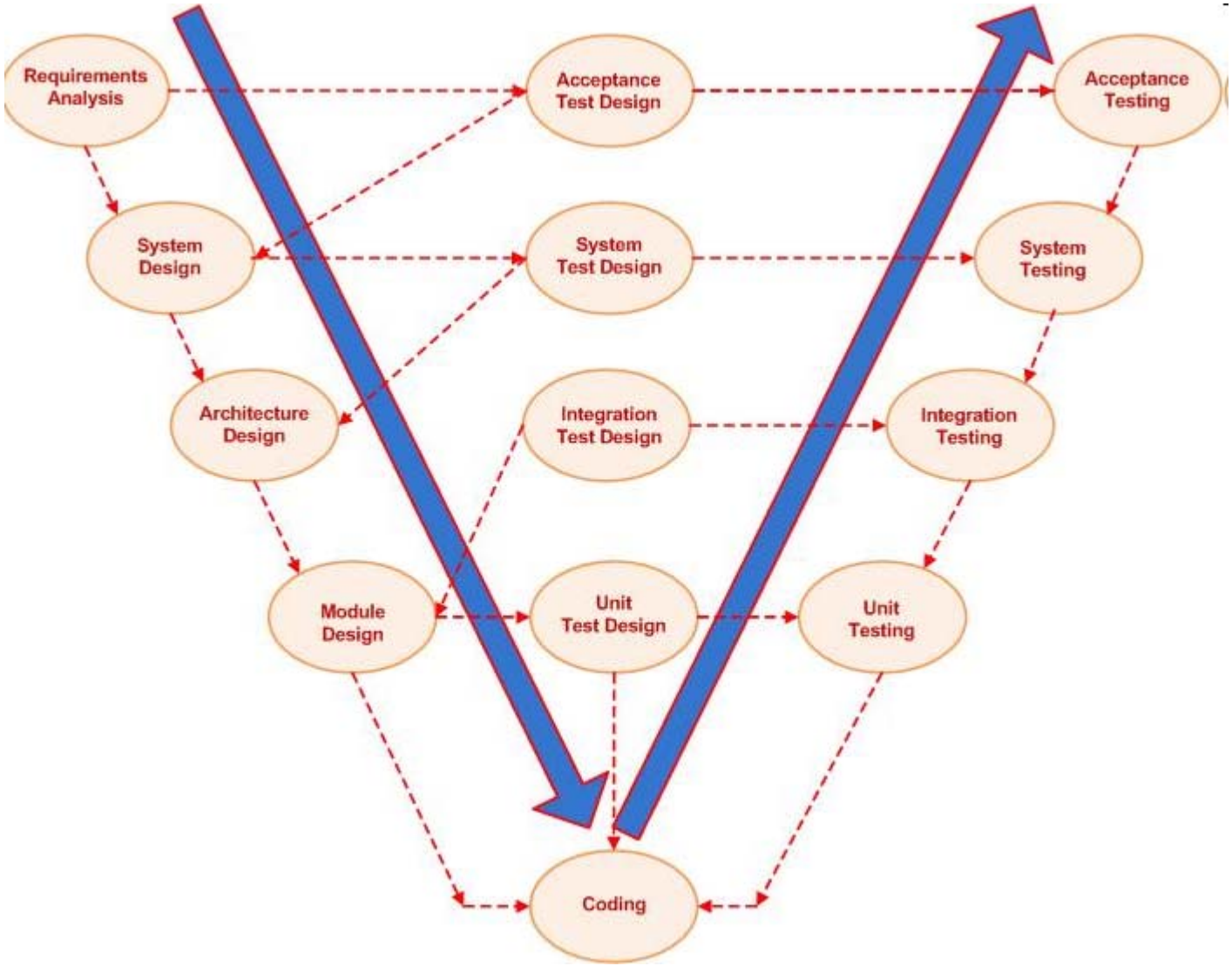



Image from Wikimedia Commons,
http://commons.wikimedia.org

# The Design Process: As a Spiral

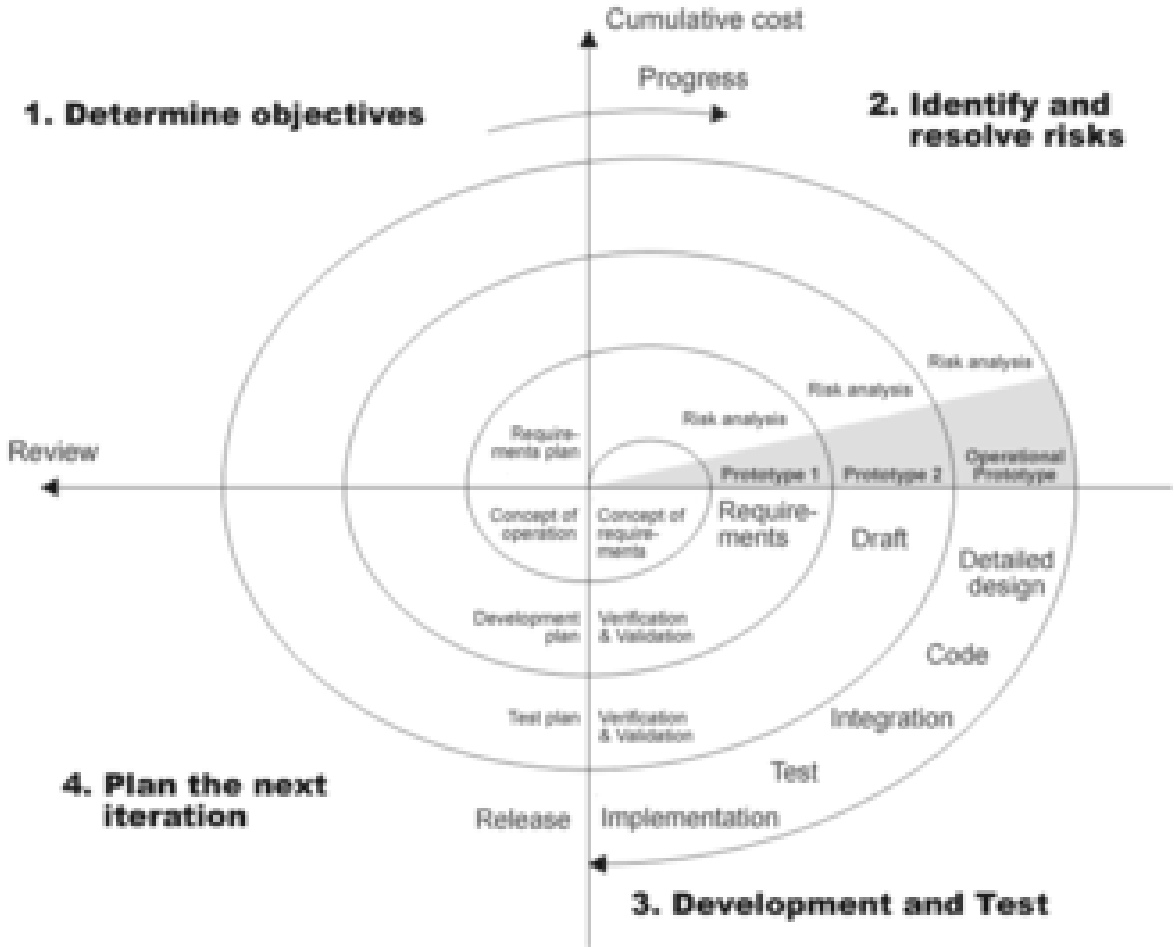
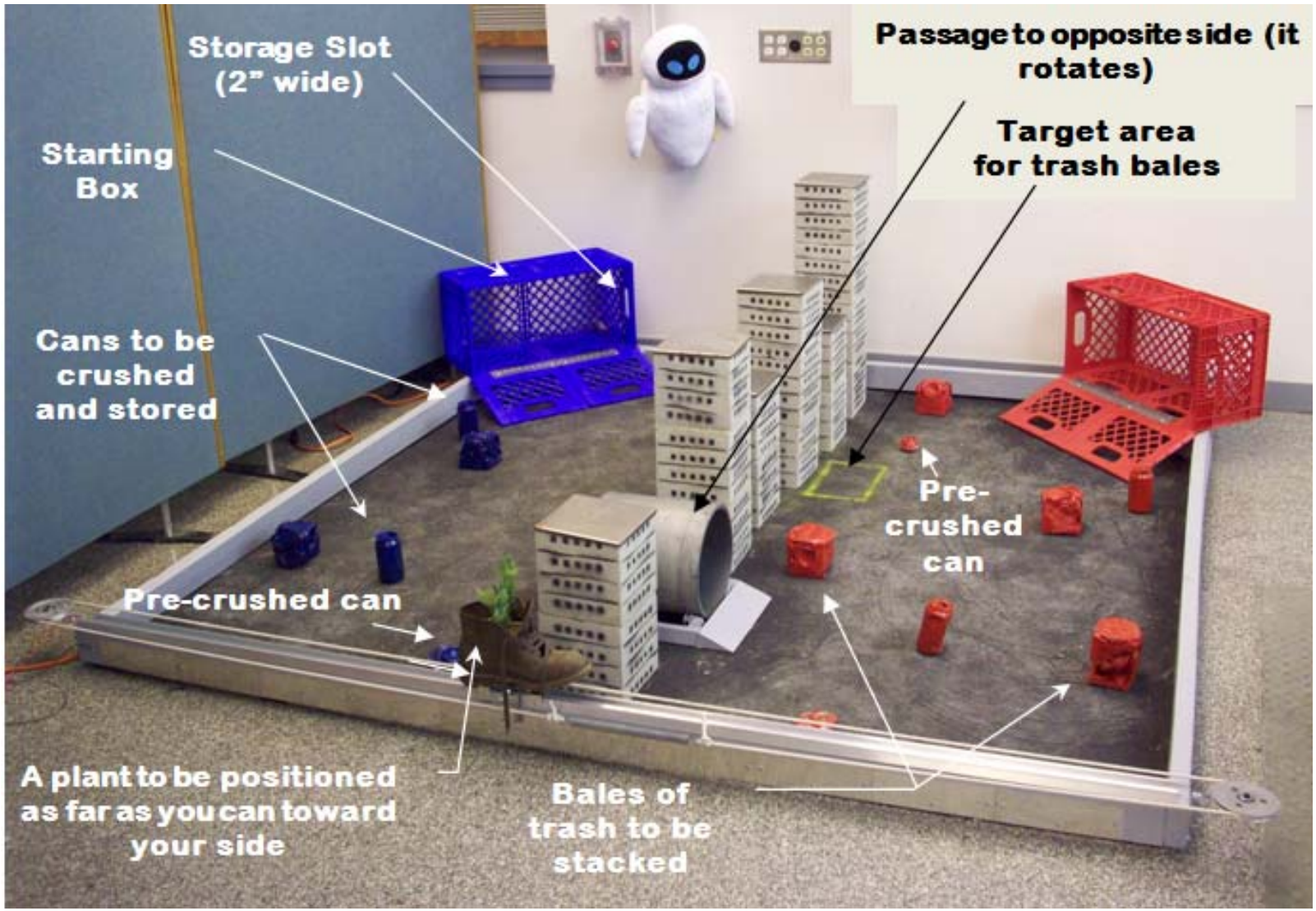



Image from Wikimedia Commons, http://commons.wikimedia.org

Boehm B, "A Spiral Model of Software Development and Enhancement", Computer IEEE, 21(5):61-72, May 1988.

# This Year's Contest



# Clarifying a Constraint

- David: “…the rules say no control signals may be sent in the first 10 seconds, but will the radios still be powered on?  I only ask because my code has an auto-calibrator built in…”
- Dan: “Yes, you can keep your radio on during the first 10 seconds.  You just can't touch the radio.  That will actually help the audience to understand what's happening.”

# Clarifying a Constraint

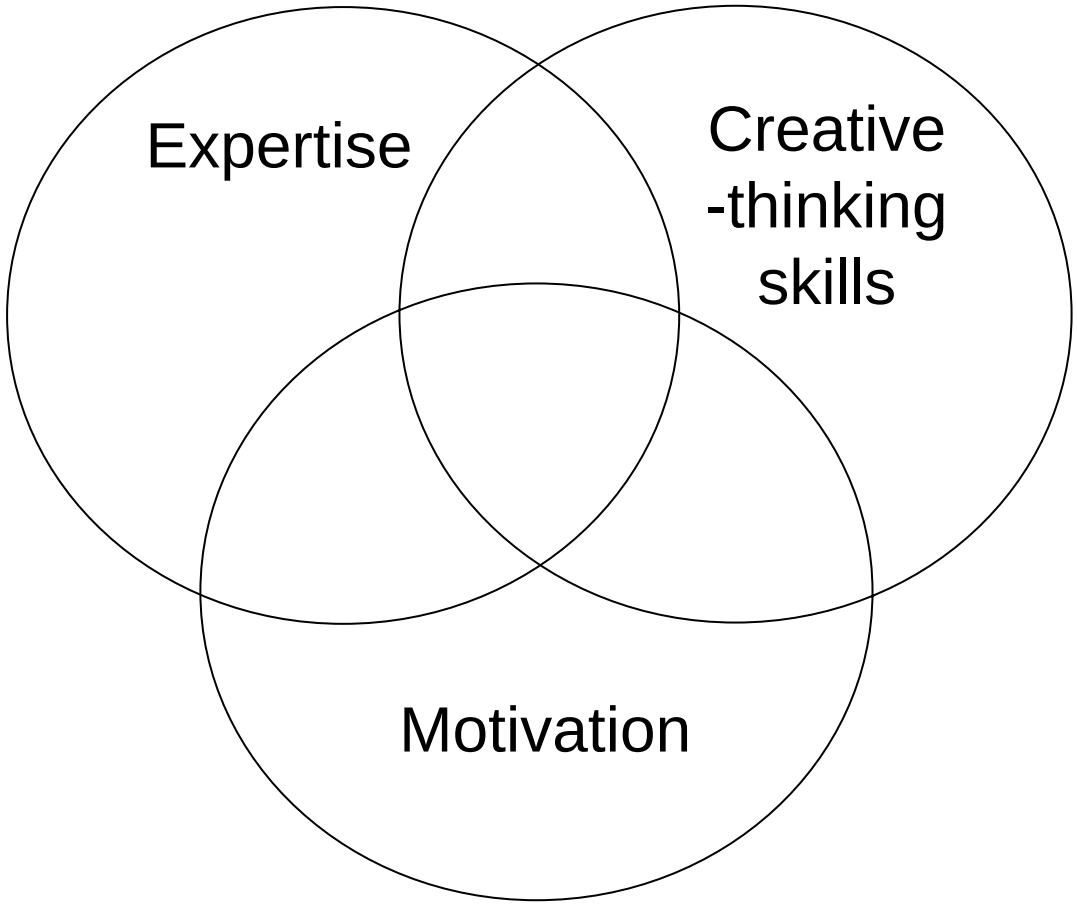
- The rules state – “Energy may be stored in batteries, compressed air, and elastic strain.  Total stored energy may not exceed 20kJ.  This limit will be enforced by the section instructors based on calculations in the lab notebooks.”
- Let’s estimate the energy in
  - The battery pack that came with the radios
  - A 2 liter bottle at 60 psi gauge pressure

# Killing Creativity is Ubiquitous

- “When I consider all the organizations I have studied and worked with over the past 22 years, there can be no doubt: creativity gets killed more often than it gets supported… Creativity is undermined unintentionally in work environments that were established … to maximize coordination, productivity, and control.”

Amabile, 1998, “How to Kill Creativity”, *HBR*.

# Three Components of Creativity



# Intrinsic and Extrinsic Motivation

- Intrinsic motivation – enjoyment of the work itself
- Extrinsic motivation – bonuses, promotions, praise
- Extrinsic can displace intrinsic motivation

> Three studies were conducted … The primary hypothesis was that explicitly contracting to do an activity in order to receive a reward will have negative effects on creativity... All three studies provided support for this hypothesis. Moreover, this support appears to be strong and generalizable across different subject populations, reward types, reward presentations, and creativity tasks…

Amabile, T.M., Hennessey, B.A., & Grossman, B. (1986). Social influences on creativity: The effects of contracted-for reward. *Journal of Personality and Social Psychology,* 50, 14-23.

# Intrinsic and Extrinsic Motivation

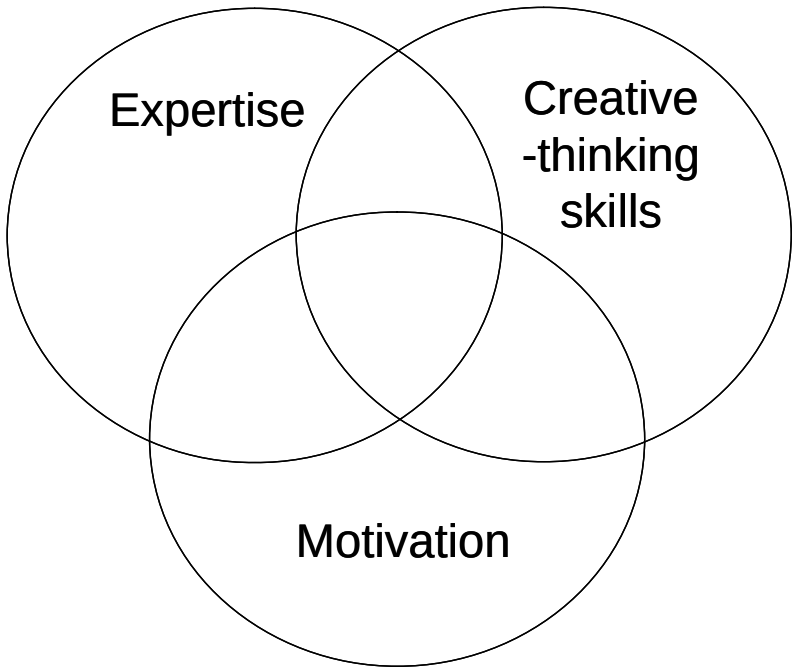
- Intrinsic motivation – enjoyment of the work itself
- Extrinsic motivation – bonuses, promotions, praise
- But it doesn't have to

> Two studies were conducted … The primary hypothesis of the present research was that the usual overjustification effect would be counteracted by directed discussion sessions focused on intrinsic reasons for working in school and explicitly dealing with ways to cognitively distance oneself from the reward contingency. Both studies provide partial support for this hypothesis. In fact, children receiving the intrinsic motivation training seemed to later treat reward as an actual augmentation of intrinsic motivation…

Hennessey, B.A., Amabile, T.M., & Martinage, M. (1989). Immunizing children against the negative effects of reward. *Contemporary Educational Psychology,* 14, 212-227.

# Assignments

- “Of all the things managers can do to stimulate creativity, perhaps the most efficacious is the deceptively simple task of matching people with the right assignments.”




Amabile, 1998, “How to Kill Creativity”, *HBR*.

# Freedom

- Interview study of 120 R&D scientists
- The most frequently mentioned environmental feature surrounding the high creativity events was freedom
- How to do one’s work
- A sense of control over one’s own work and ideas
- But not always choice of the challenge

# IDEO Brainstorming

- A group problem solving technique that involves spontaneous contribution of ideas from all members of the group

# The Five Rules of the Brainstorm

- Defer judgment
- Build upon the ideas of others
- One conversation at a time
- Stay focuses on the topic
- Encourage wild ideas

What did Pugh say about this?

# Concept Evaluation / Generation

- Experience gained over many projects both in industry and associated with industry has led to the conclusion that matrices in general are probably the best way structuring and representing an evaluation procedure…


Pugh, 1990, *Total Design*

# Controlled Convergence

e.g., QFD

specification

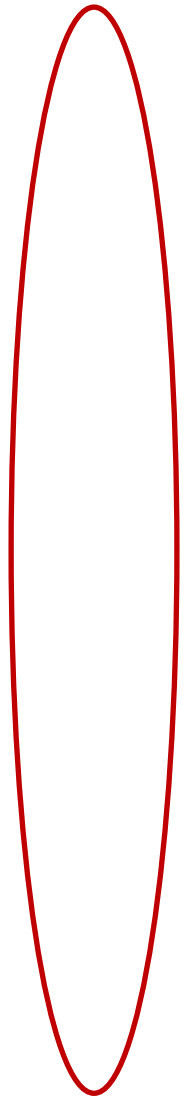
e.g., TRIZ

- This is Pugh's vision of the conceptual phase of design
- Takes us from a specification to a concept
- Convergent and divergent thinking equally important

Image removed due to copyright restrictions.
Please see Fig. 4.1 in Pugh, Stuart. *Total Design*.
Reading, MA: Addison-Wesley, 1991.

# Evaluation Matrix

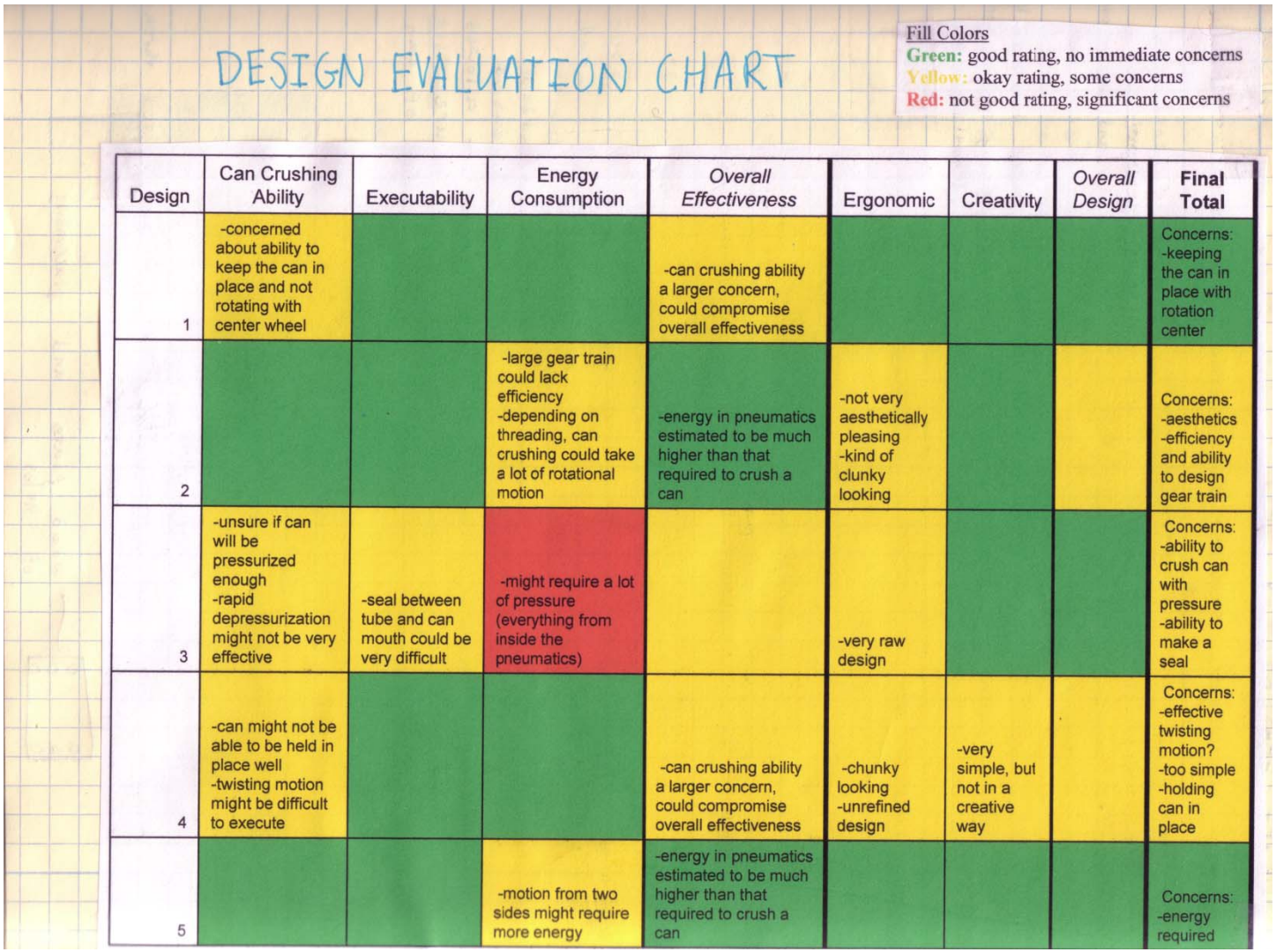
Image removed due to copyright restrictions.
Please see Fig. 4.2 in Pugh, Stuart. *Total Design*.
Reading, MA: Addison-Wesley, 1991.



# Using a Pugh Matrix

- Generate multiple solutions to same problem spec.
- Depict the solutions (sketches)
- Form the matrix
- Choose criteria (and clarify them)
- Choose datum (pick one of the ‘best’ solutions)
- Insert comparisons (+, S, -), form sums thereof
- Look at strongest concepts, try to reverse negatives (combine with complementary concepts)
- Look at weaker concepts, try to improve them
- Eliminate the weakest remaining concepts

# Departures from the Pugh Method are acceptable in 2.007, but…



DESIGN EVALUATION CHART

Fill Colors
Green: good rating, no immediate concerns
Yellow: okay rating, some concerns
Red: not good rating, significant concerns

| Design | Can Crushing Ability | Executability | Energy Consumption | *Overall Effectiveness* | Ergonomic | Creativity | *Overall Design* | **Final Total** |
|---|---|---|---|---|---|---|---|---|
| 1 | -concerned about ability to keep the can in place and not rotating with center wheel | | | -can crushing ability a larger concern, could compromise overall effectiveness | | | | Concerns: -keeping the can in place with rotation center |
| 2 | | | -large gear train could lack efficiency -depending on threading, can crushing could take a lot of rotational motion | -energy in pneumatics estimated to be much higher than that required to crush a can | -not very aesthetically pleasing -kind of clunky looking | | | Concerns: -aesthetics -efficiency and ability to design gear train |
| 3 | -unsure if can will be pressurized enough -rapid depressurization might not be very effective | -seal between tube and can mouth could be very difficult | -might require a lot of pressure (everything from inside the pneumatics) | | -very raw design | | | Concerns: -ability to crush can with pressure -ability to make a seal |
| 4 | -can might not be able to be held in place well -twisting motion might be difficult to execute | | | -can crushing ability a larger concern, could compromise overall effectiveness | -chunky looking -unrefined design | -very simple, but not in a creative way | | Concerns: -effective twisting motion? -too simple -holding can in place |
| 5 | | | -motion from two sides might require more energy | -energy in pneumatics estimated to be much higher than that required to crush a can | | | | Concerns: -energy required |

Courtesy of Katherine Smyth. Used with permission.

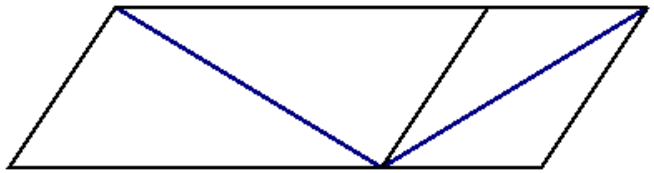
Smyth, K., 2008, *UROP Design Notebook*

# Hypothesis

- Facts about the brain provide some insight into problems in engineering design
- Cognitive sciences and psychology also provide insights into the remedies

# Visual Cognition and Perception

- “The mind has to be built of specialized parts because it has to solve specialized problems…Each of our mental modules solves its unsolvable problem by a leap of faith about how the world works, by making assumptions that are indispensible but indefensable – the only defense being that the assumptions worked well enough in the world of our ancestors.”



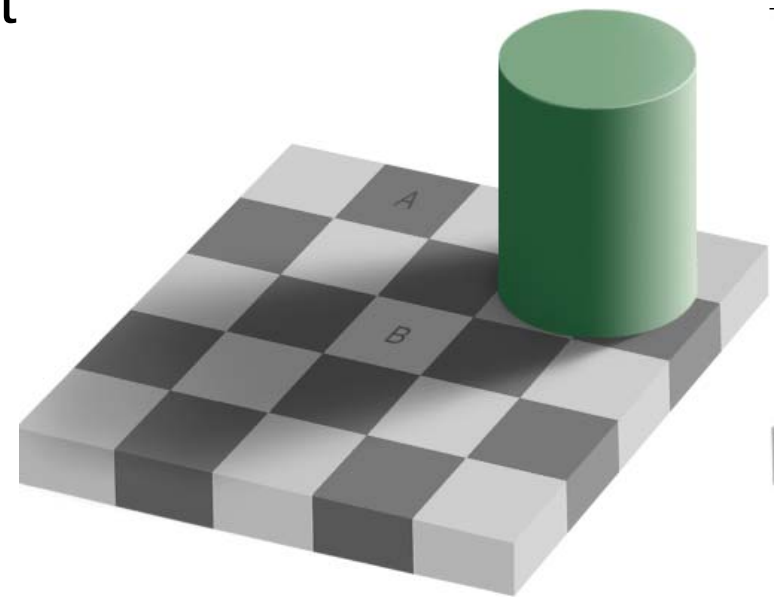



Image courtesy Edward H. Adelson.

**Pinker, Steven, 1997, *How the Mind Works*, Norton & Co, New York.**

# An Exercise in Evaluation

- Rate selected squares on a scale of 1 to 10
- 1 is the white background of this side
- 10 is the black color of these letters

A=

B=

Left of A=

Left of B=

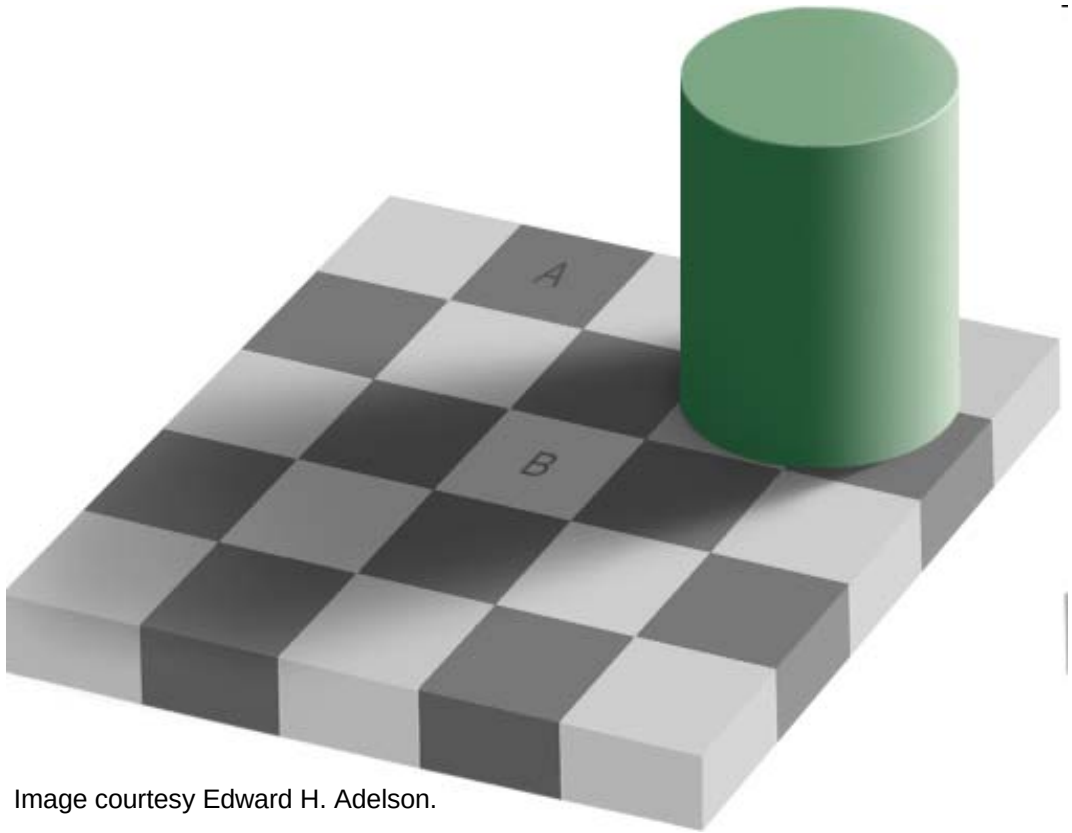



Image courtesy Edward H. Adelson.

# Advantage of Pairwise Comparison

- Pugh method uses only "discrimination", never "magnitude estimation"
- Smith et al. [1984] demonstrated a 2X advantage in accuracy

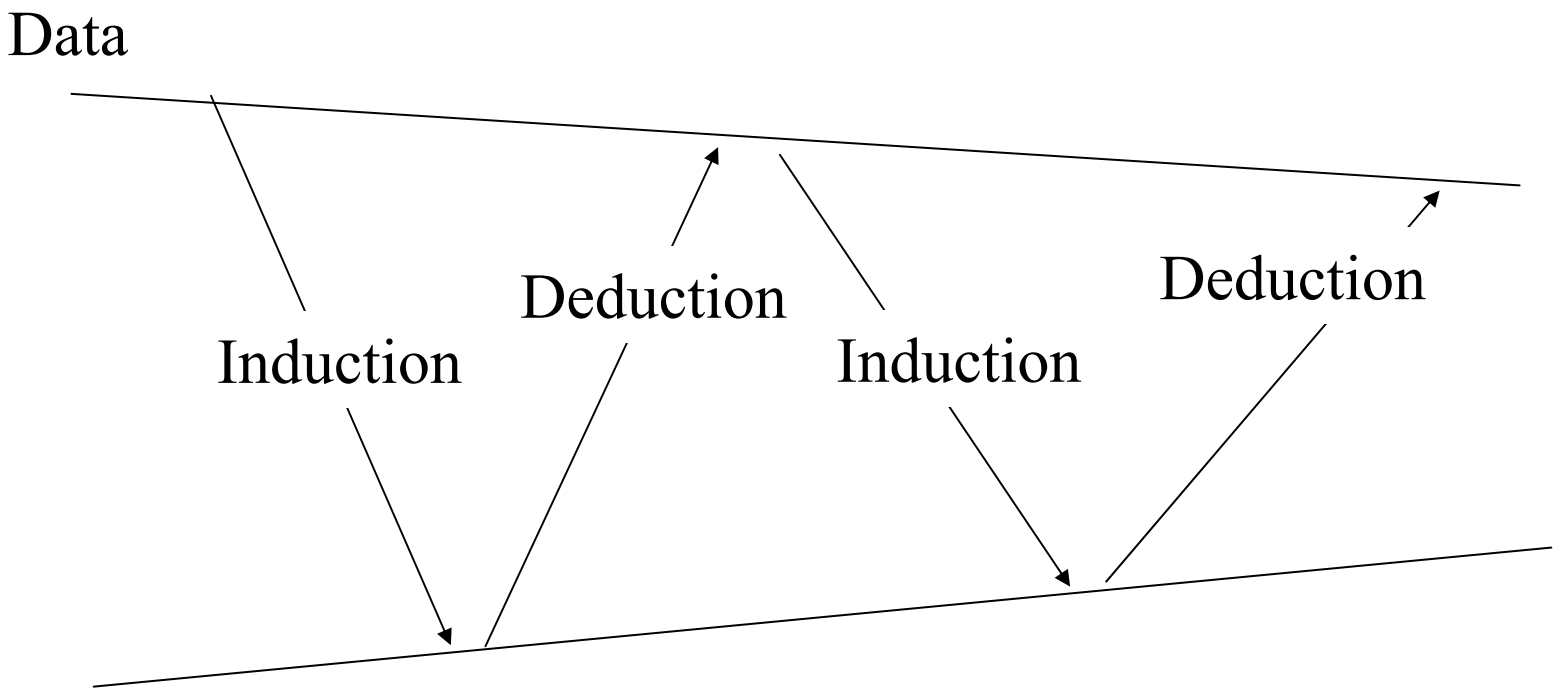
Image removed due to copyright restrictions. Please see Fig. 1 in Smith, J., H. Kaufman, and J. Baldasre. "Direct Estimation Considered within a Comparative Judgment Framework." *American Journal of Psychology* 97 (1984): 343-58.

Smith, J, H. Kaufman, and J. Baldasre, 1984, "Direct Estimation Considered within a Comparative Judgment Framework, *American Journal of Psychology* 97(3)343-58.

# Experiments in Engineering Design

- Promote understanding
- Calibrate our models
- Promote innovation
- Refine the product
- Certify the product

# The Iterative Learning Process



# What is this Prototype For?

Image removed due to copyright restrictions. Please see Exhibit 12-5 in Ulrich, Karl T., and Steven D. Eppinger. *Product Design and Development.* Boston, MA: McGraw-Hill, 2008.

Ball supported at varying locations to determine effect on “feel”.

From Ulrich and Eppinger, *Product Design and Development*.

# What is This Prototype For?

Actuator arm on switches

No arm on switches

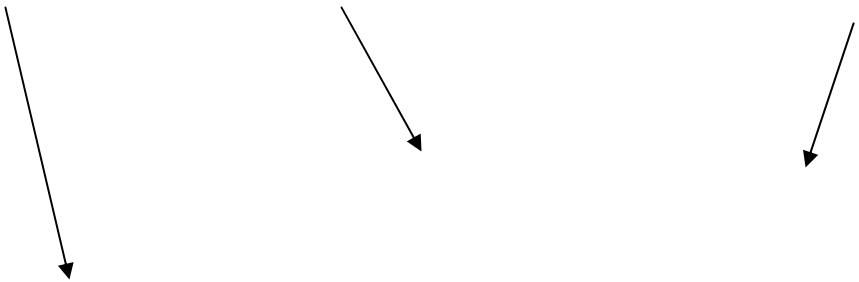


Image removed due to copyright restrictions. Please see Exhibit 12-6 in Ulrich, Karl T., and Steven D. Eppinger. *Product Design and Development.* Boston, MA: McGraw-Hill, 2008.

From Ulrich and Eppinger, *Product Design and Development*.

# 3D Computer Modeling

- Easy visualization of 3D form
- Automatically calculate
  physical properties
- Detect interferences in assy
- Communication!
- Sometimes used in milestones

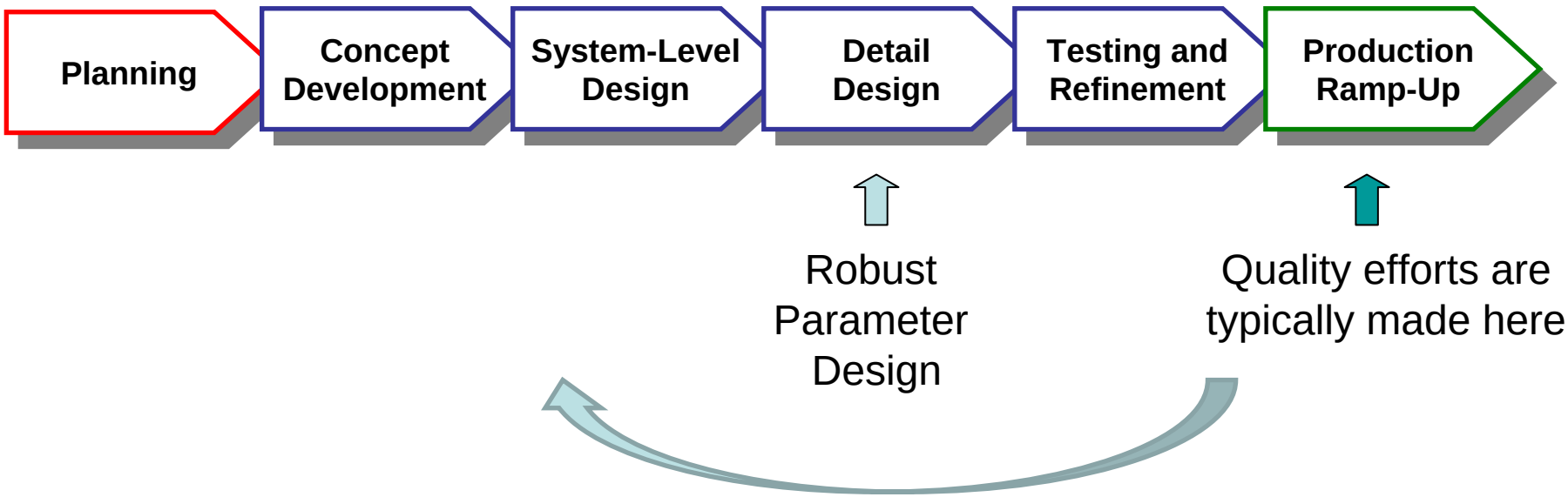
# Robust Designs

A robust product or process performs correctly, even in the presence of noise factors.

Noise factors may include:

- operating conditions / environment
- operator variation
- manufacturing variations
- changes with time (wear)
- your opponent's strategies?

# Robustness in the Design Process



# Next Steps

- No lab sessions this week
- The are lab sessions next week
- Come to lab with a lab notebook
- BEFORE your lab, prepare 4-6 pages describing kit and contest exploration
- Next “lecture” session is Tuesday 10 FEB right here in 10-250