BEST Robotics and

The Engineering Design Process

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Setting the Stage

Why BEST?
and
Why the Engineering Design Process?

Editorial comments are provided free of charge!

- **“Learning” in the absence of context is memorization.**

- **True learning requires context – a bigger picture.**
  - **When we will ever use this?**

- **So, how do you make participation in BEST a true learning experience?**
  - **Use BEST as a context**
  - **Place BEST into context**

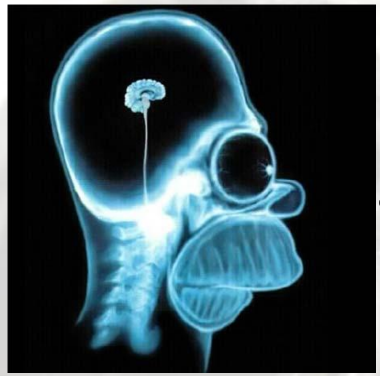
On the continuum of learning environments…

Predictable **BEST**

How do you tame the BEaST?

One idea is to focus on the process … at this stage, it’s more important than the product!

What is design?



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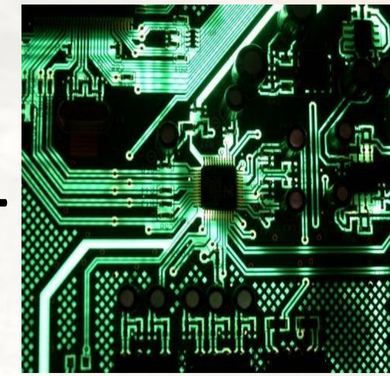
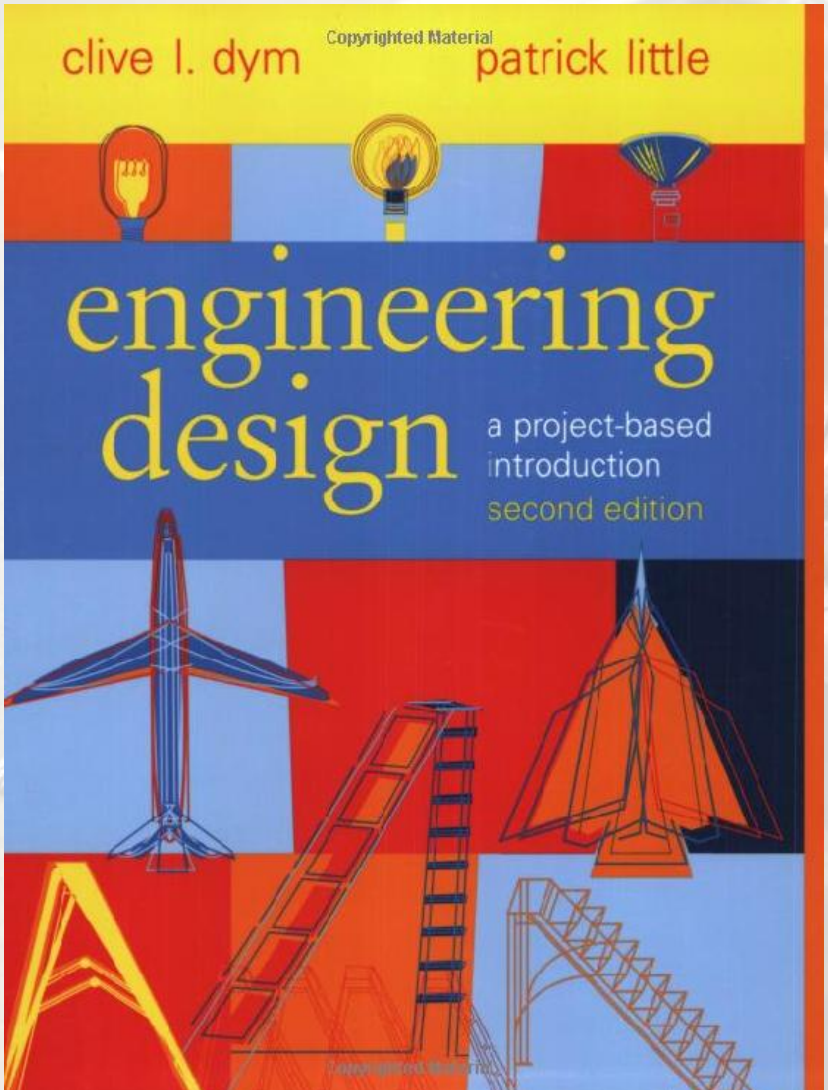


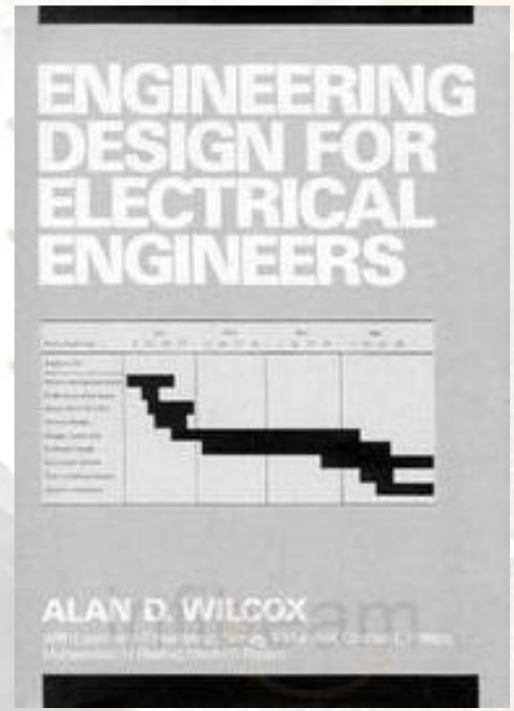
What is the Engineering Design Process?

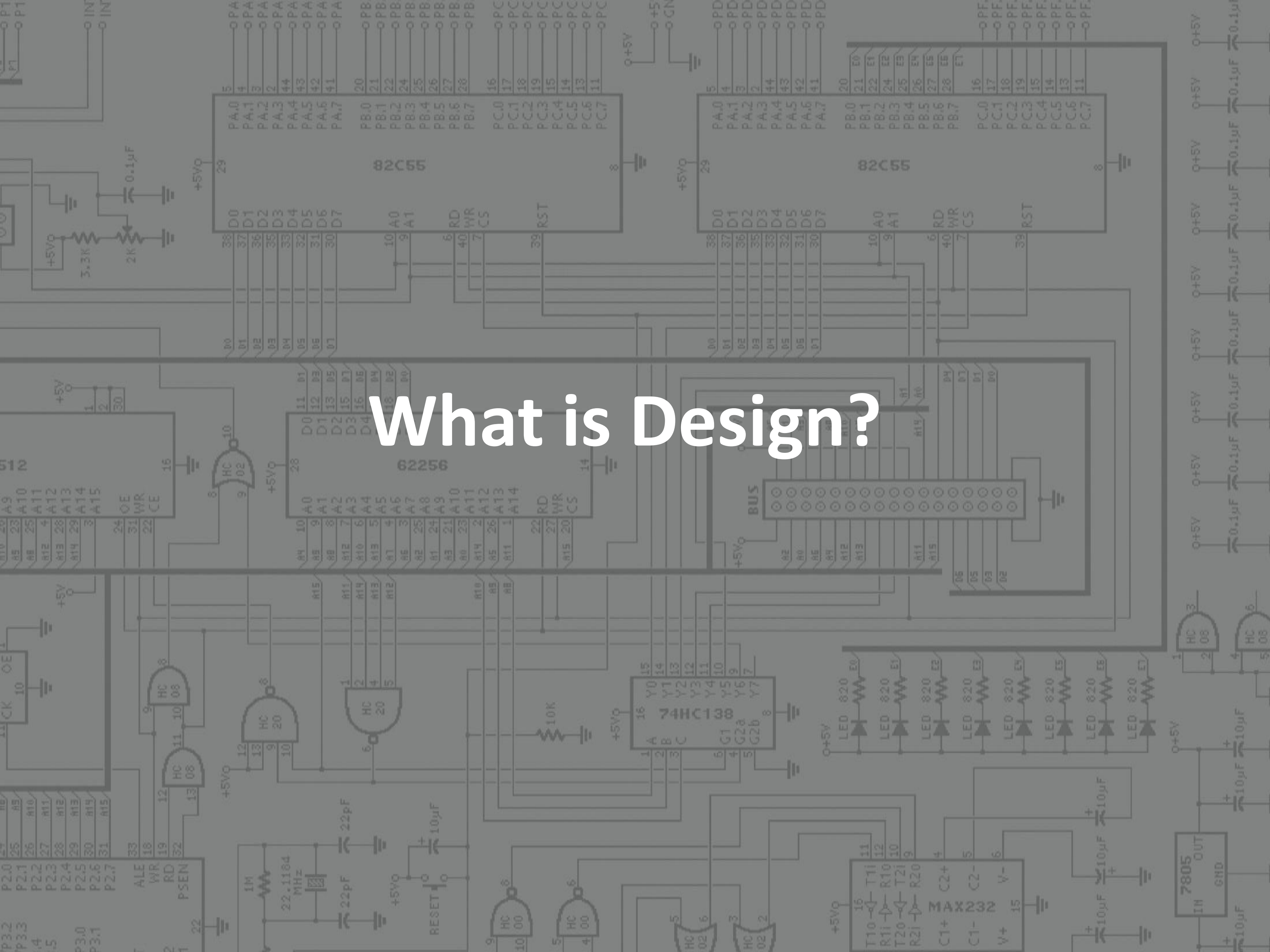
Examples help

What tools are available?

Originality can be overrated.





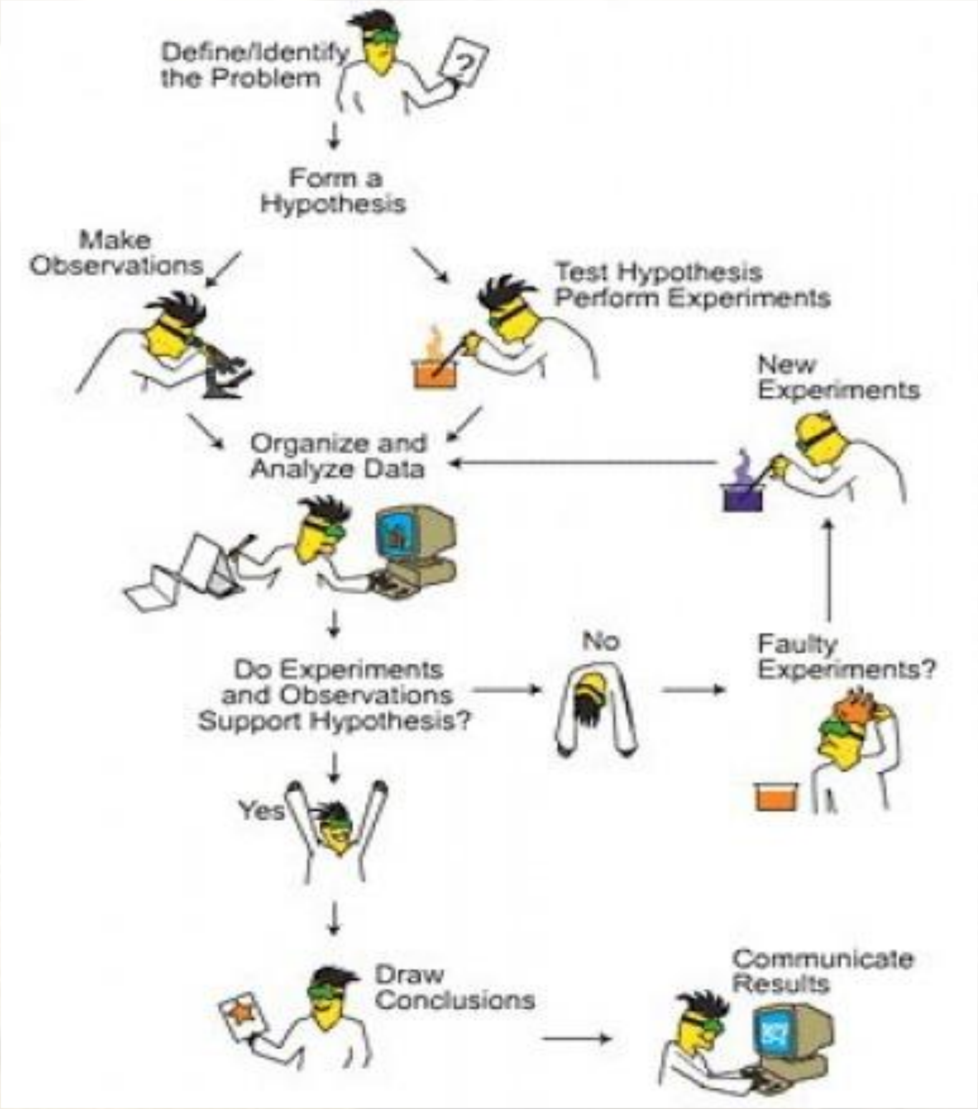


What is Design?

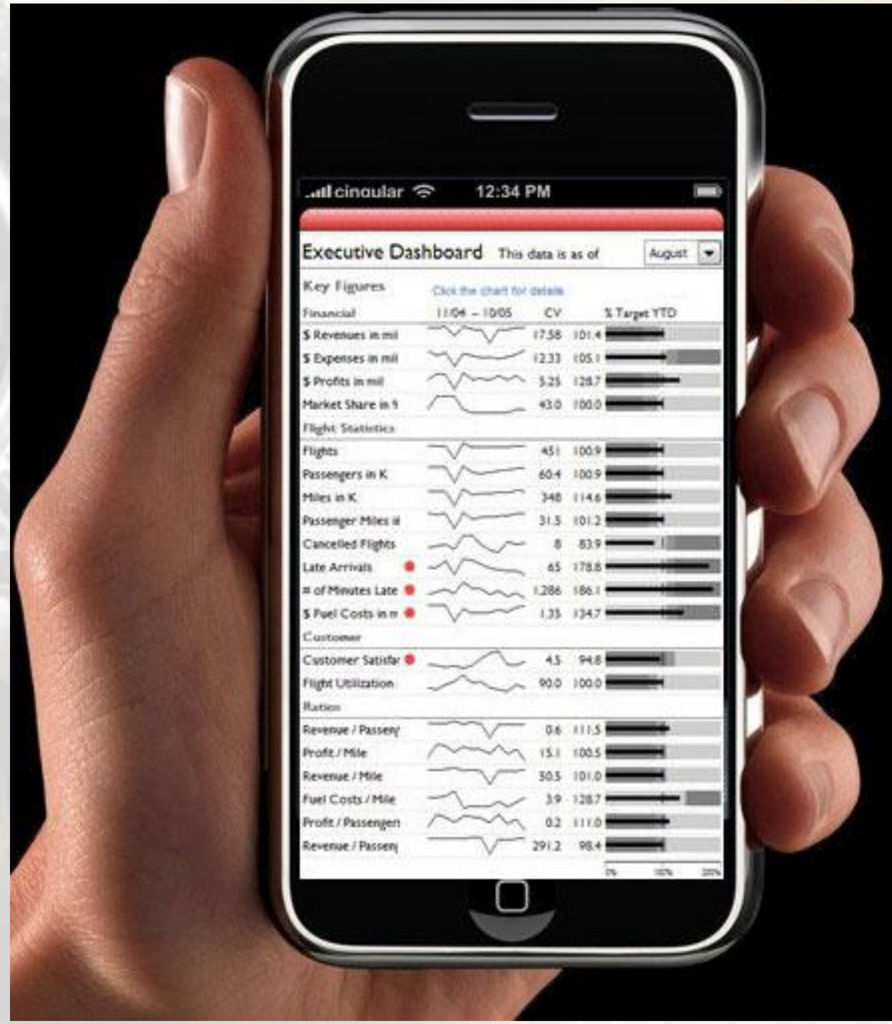
First, what it isn't…

Design isn't discovery!

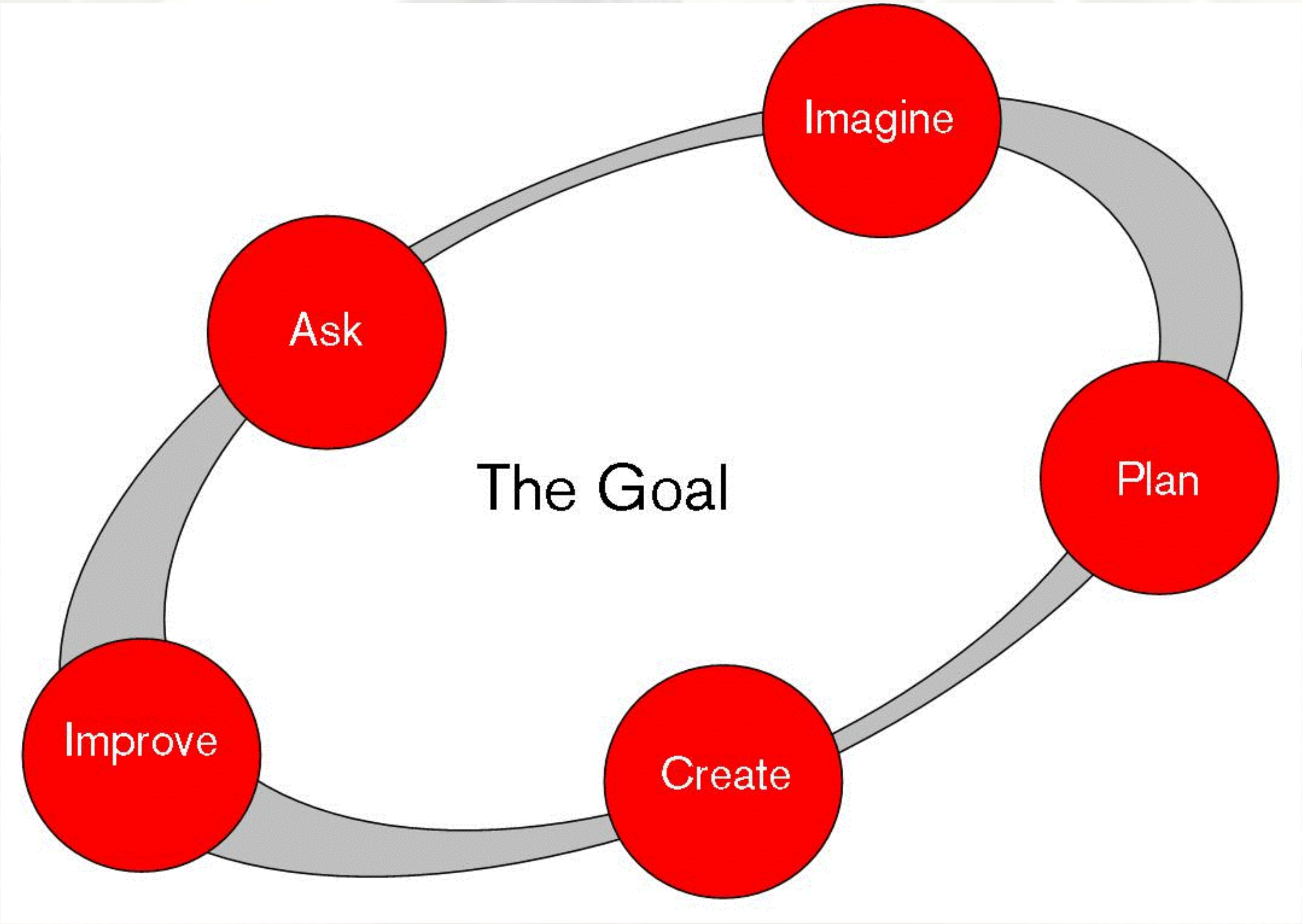
The Scientific Method is an algorithm for discovery.



Design is about **creating** – form and function achieving objectives within given constraints.

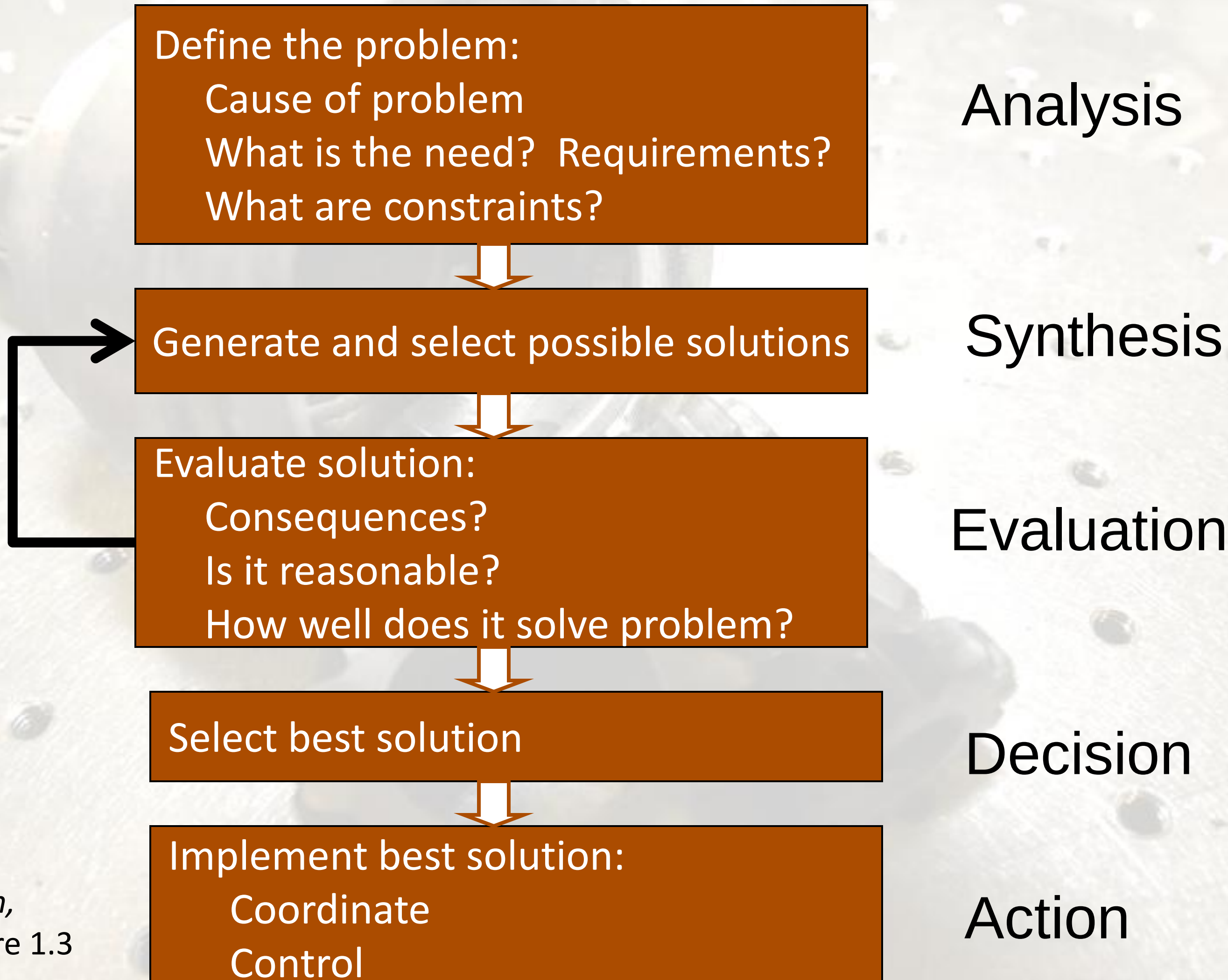


The Engineering Design Process is an algorithm for creation and invention.



What is the Engineering Design Process?

Problem-solving isn't necessarily design, but it provides a good starting point.



Engineering Design,
Alan Wilcox – Figure 1.3

The Engineering Design Process mirrors standard steps in problem-solving.

Problem Definition (Analysis)

Conceptual De

on)

Decision (Decision ☺)

Detailed Design (Action)

Documentation is crucial!

Define the problem in detail without implying a particular solution.

Problem Definition

- **Establish <u>requirements</u>**
- **Identify <u>constraints</u>**
- **Establish <u>functions</u>**
- **Establish <u>requirements</u>**

negotiable objectives
or functions

doing")

- often the result of guidelines and standards

Objectives, constraints, functions and requirements may be <u>broad-based</u>.

- **Some items are absolute – others may be negotiable**
  - **Functionality (inputs, outputs, operating modes)**
  - **Performance (speed, resolution)**
  - **Cost**
  - **Ease of use**
  - **Reliability, durability, security**
  - **Physical (size, weight, temperature)**
  - **Power (voltage levels, battery life)**
  - **Conformance to applicable standards**
  - **Compatibility with existing product(s)**

Both functional and non-functional requirements may be placed on a design.

- **Functional requirements:**
  - **support a given load**
  - **respond to voice commands**
  - **(output based on input)**
- **Non-functional requirements (usually form-focused):**
  - **size, weight, color, etc.**
  - **power consumption**
  - **reliability**
  - **durability**
  - **etc.**

Design involves creativity within boundaries. Consider *any* viable solution concept.

Conceptual Design

- **Generate design alternatives**

- **Generate design alternatives**

- must live within the design space
- let the creativity flow
- don't marry the first idea
- beware of "you/we can't…" and "you/we have to…"

Nail down enough design details that a decision can be made.

Preliminary Design

- “Flesh out” leading conceptual designs
- Model, analyze, test, and evaluate conceptual designs

- proof-of-concept
- simulation results
- mathematical models

The “optimal” design solution may or may not be obvious.

Design Decision

- **Select the <u>optimal</u> design based on the findings from the previous stage**

Time to go from idea to reality.

Detailed Design

- Refine and optimize choices made in preliminary design
- Articulate … and dime…
- Fabricate pr…type and move toward production

There is a **huge** gulf between a great idea and a working prototype!

The Engineering Design Process is generally iterative, not linear.

- Problem Definition (Analysis)
- Conceptual Design (Synthesis)
- Preliminary Design (Evaluation)
- Design Decision (Decision ☺)
- Detailed Design (Action)

How is the Engineering Design Process applied?

(Part 1 – Asking Questions)

Example #1

Designing a Ladder

engineering design: a project-based introduction, dym & little

The design process begins with some initial problem statement.

- **Initial Problem Statement**
  - **Design a “safe” ladder.**

- **Design problems are often *ill-structured* and *open-ended*.**

- **Asking questions is a great way to begin defining the problem to be addressed.**

Learning to ask good questions is a valuable tool for a successful designer.

Problem Definition

- Clarifying *objectives*
  - How is the ladder to be used?
  - How much should it cost?
- Identifying *constraints*
  - How is safety defined?
  - What is the most the client is willing to spend?
- Establishing *functions*
  - Can the ladder lean against a supporting surface?
  - Must the ladder support someone carrying something?
- Establishing *requirements*
  - Should the ladder be portable?
  - How much can it cost?

It’s best to ask as many questions as possible at the beginning of the process!

Conceptual Design

- **Establishing *design specifications***
  - **How much weight should a safe ladder support?**
  - **What is the “allowable load” on a step?**
  - **How high should someone on the ladder be able to reach?**
- **Generating *design alternatives***
  - **Could the ladder be a stepladder or an extension ladder?**
  - **Could the ladder be made of wood, aluminum, or fiberglass?**

More specific questions are needed as you move through the stages of the design process.

Preliminary Design

- **Planning for *modeling and analyzing***
  - **What is the maximum stress in a step support the "design load?"**
  - **How does the bending deflection of a loaded step vary with the material of which the step is made?**
- **Planning for *testing and evaluating***
  - **Can someone on the ladder reach the specified height?**
  - **Does the ladder meet OSHA's safety specifications?**

Questions also help in the iterative nature of the design process.

Detailed Design

- ***Refining and optimizing*** **the design**
  - **Is there a more economic design?**
  - **Is there a more efficient design (e.g. less material)?**

Example #2

Designing a High School Engineering Program

Remember, ill-structured and open-ended.

- **Initial Problem “Statement”**
  - **“How would you feel about a four-year engineering program?”**
  - **“Great! Go figure out what it looks like.”**

Knowing *who* to ask is sometimes more important than knowing *what* to ask.

Problem Definition

- **Clarifying *objectives***
  - **Who is the target audience?**
  - **What personnel resources are available?**
- **Identifying *constraints***
  - **What budget will be available?**
  - **How many sections are permitted?**
  - **What academic infrastructure exists?**
  - **Where does this live relative to the SDE?**
- **Establishing *functions***
  - **What should graduates be prepared for?**
  - **Will the program encompass only electives or will it include core courses?**
- **Establishing *requirements***
  - **What are appropriate pre-requisites, if any?**
  - **Can students skip electives?**

- Establishing *design specifications*
  - Can/should the engineering electives have a weighted GPA?
  - Is a minimum GPA required to stay in the program?
- Generating *design alternatives*
  - Could the program be curricular? Extracurricular? Both?
  - Are we required to use an existing curriculum?
  - Will dedicated computer resources be available?

- Planning for *modeling and analyzing*
  - What high school engineering curricula are already available?
  - What schools are implementing the various models?
  - Is data available from these schools?
  - Are site visits a possibility?
- Planning for *testing and evaluating*
  - How do we know if the program is successful during start-up?
  - How do we measure success relative to our stated objective(s)?

- ***Refining and optimizing* the design**
  - **From the teachers' perspectives, what is definitely working and what isn't?**
  - **From the students' perspectives, what is definitely working and what isn't?**
  - **What needs modifying before we know?**
  - **What software/hardware is considered state-of-the-art?**
  - **What feedback are we getting from graduates once they enter college?**

What tools are available to aid in the Engineering Design Process?

How is the Engineering Design Process applied?

(Part 2 – Some Tools to Guide the Process)

Some simple tools can help organize the design process.

Problem Definition	• Attributes List • Pairwise Comparison Chart •Objectives/Constraints Tree
Conceptual Design	•Design Specifications
Preliminary Design	• Function-Means Tree • 6-3-5 Method • Gallery Method

An Attributes List contains a list of objectives, constraints, functions, and requirements.

Problem Definition

- **Partial attributes list for "safe ladder" design**
  - **Used outdoors on level ground**
  - **Used indoors on floors or other smooth surfaces**
  - **Could be a stepladder or short extension ladder**
  - **Step deflections should be less than 0.05 inches**
  - **Should allow a person of medium height to reach/work at levels up to 11 feet**
  - **Must support weight of an average worker**
  - **Must be safe**
  - **Must meet OSHA requirements**
  - **Must be portable between job sites**
  - **Should be relatively inexpensive**
  - **Must not conduct electricity**
  - **Should be light**

A Pairwise Comparison Chart allows the designer to order/rank the objectives

Problem Definition

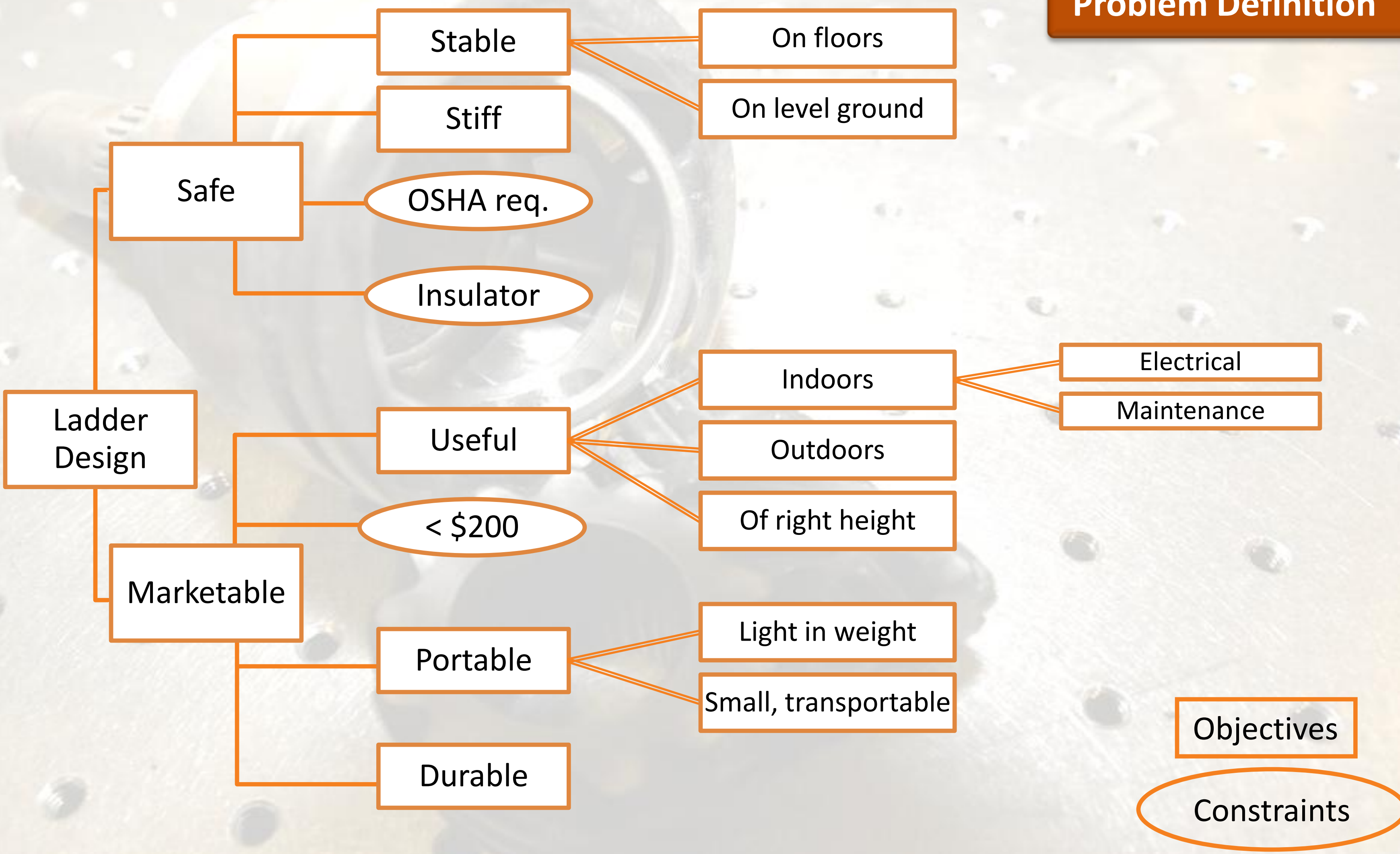
- “0” if column objective > row objective
- “1” if row objective > column objective
- Higher score = more important

Pairwise comparison chart (PCC) for a ladder design

Goals	Cost	Portability	Usefulness	Durability	Score
Cost	••••	0	0	1	1
Portability	1	••••	1	1	3
Usefulness	1	0	••••	1	2
Durability	0	0	0	••••	0

An Objectives/Constraints Tree provides a hierarchical view of key attributes.

Problem Definition



Sample Design Specifications for the Ladder project.

Conceptual Design

- **Extended length of 8 feet**
- **Unextended length of 5 feet**
- **Support 350 pounds with a deflection of < 0.1 inches**
- **Total weight not to exceed 20 pounds**
- **Outside width of 20 inches**
- **Inside width of at least 16 inches**

A Function-Means Tree shows means for achieving primary functions…and the fallout.

Preliminary Design

The 6-3-5 Method is one way to begin generating design alternatives.

- **6 team members**
- **3 ideas each (described in words or pictures)**
- **5 other team members review each design idea**

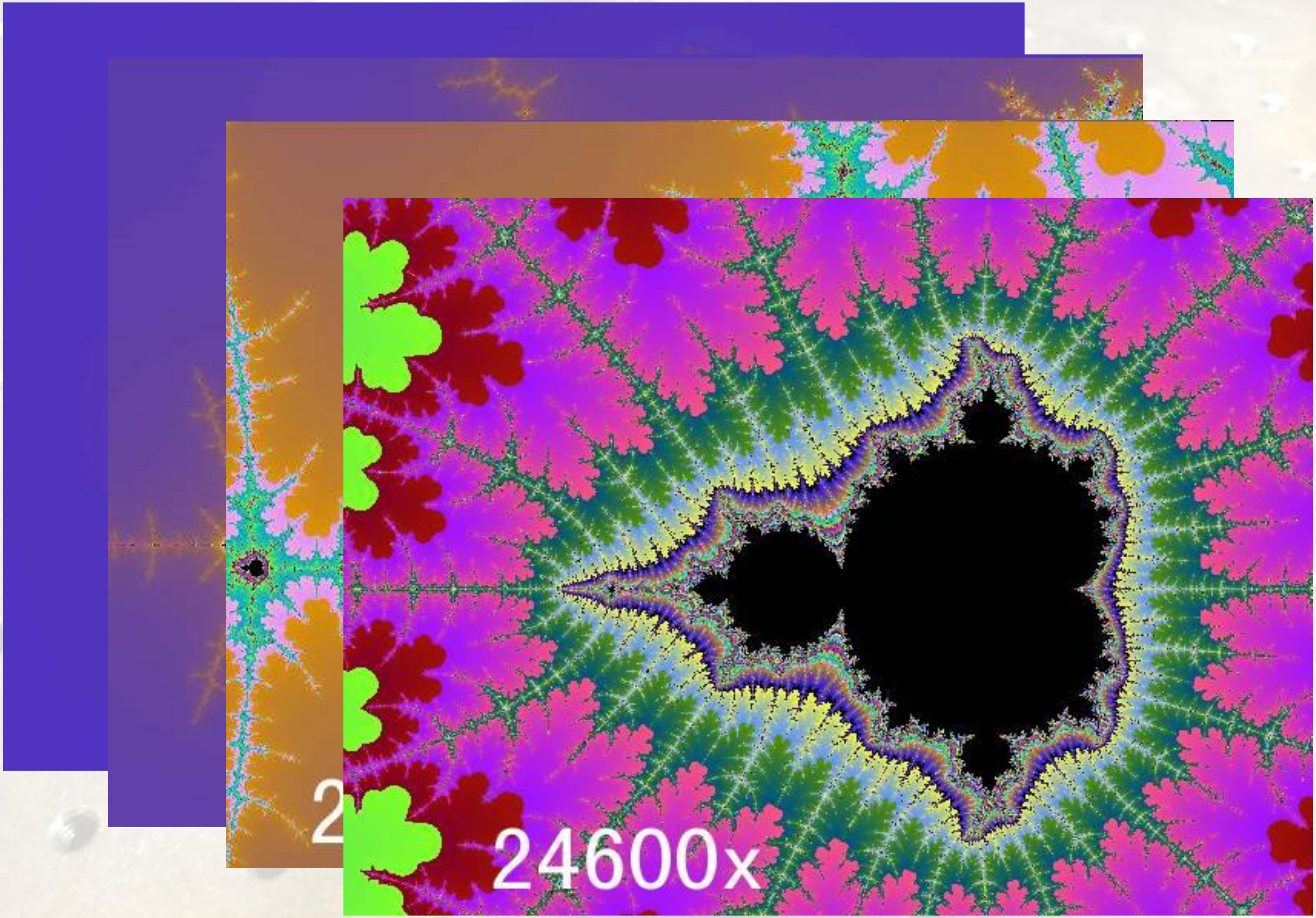
- **No discussions allowed during the process**
- **Can be modified to *N–3–(N-1)***

The Gallery Method can be used in small or large groups to develop design alternatives.

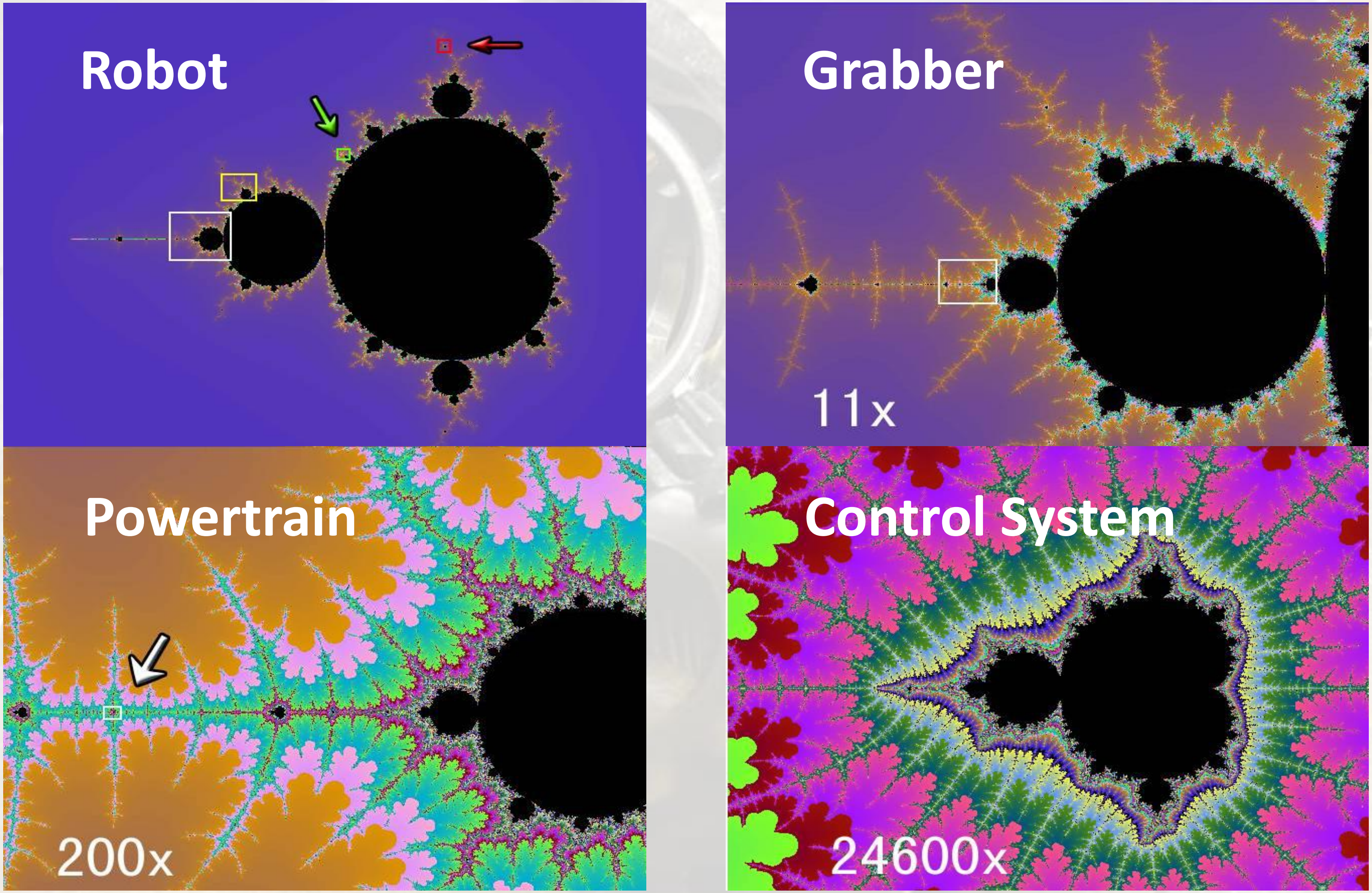
Preliminary Design

- **Each individual sketches a design idea**
- **All sketches are posted**
- **Every member can comment on any idea**

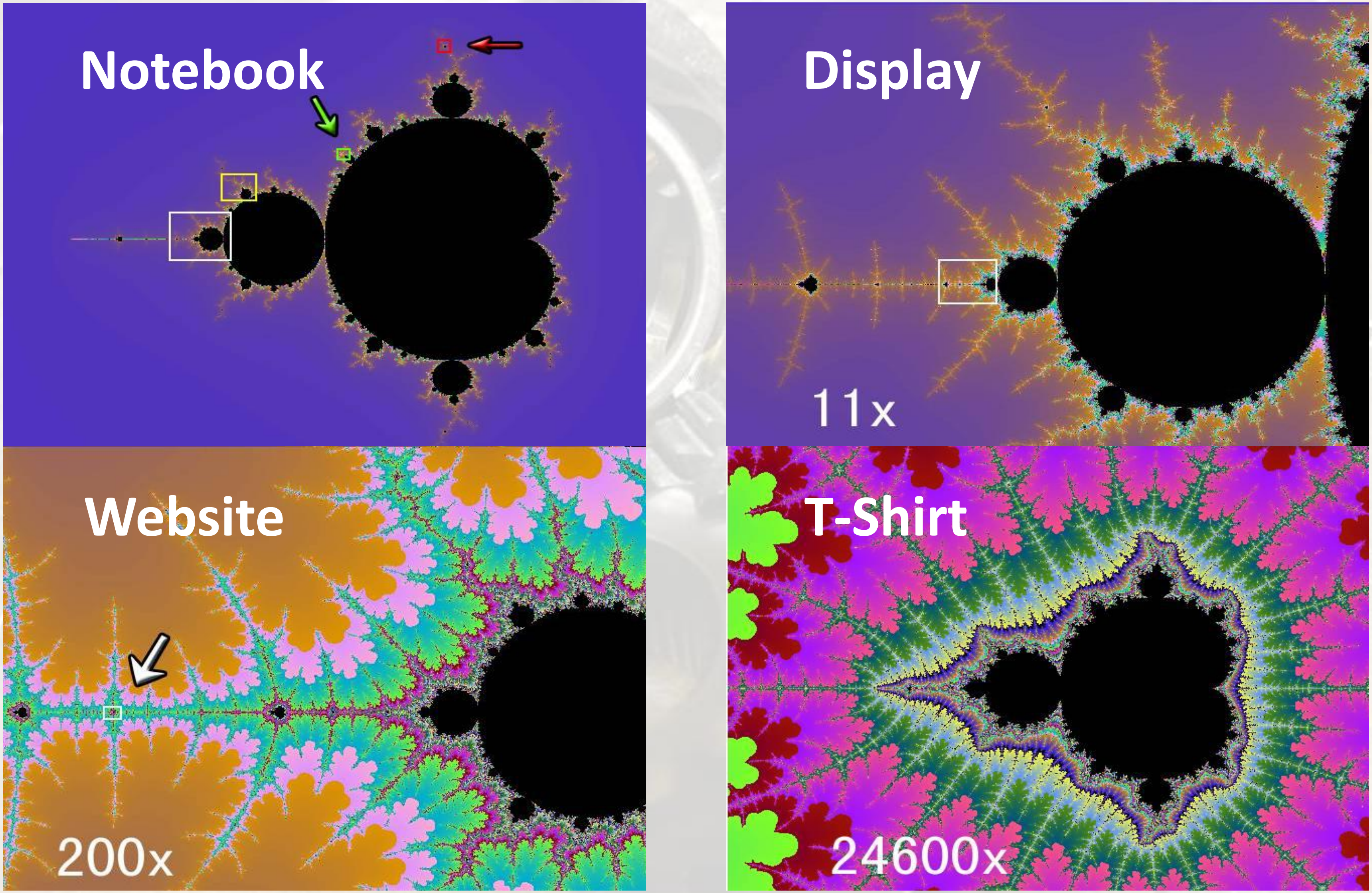
The Engineering Design Process can help organize the chaos.

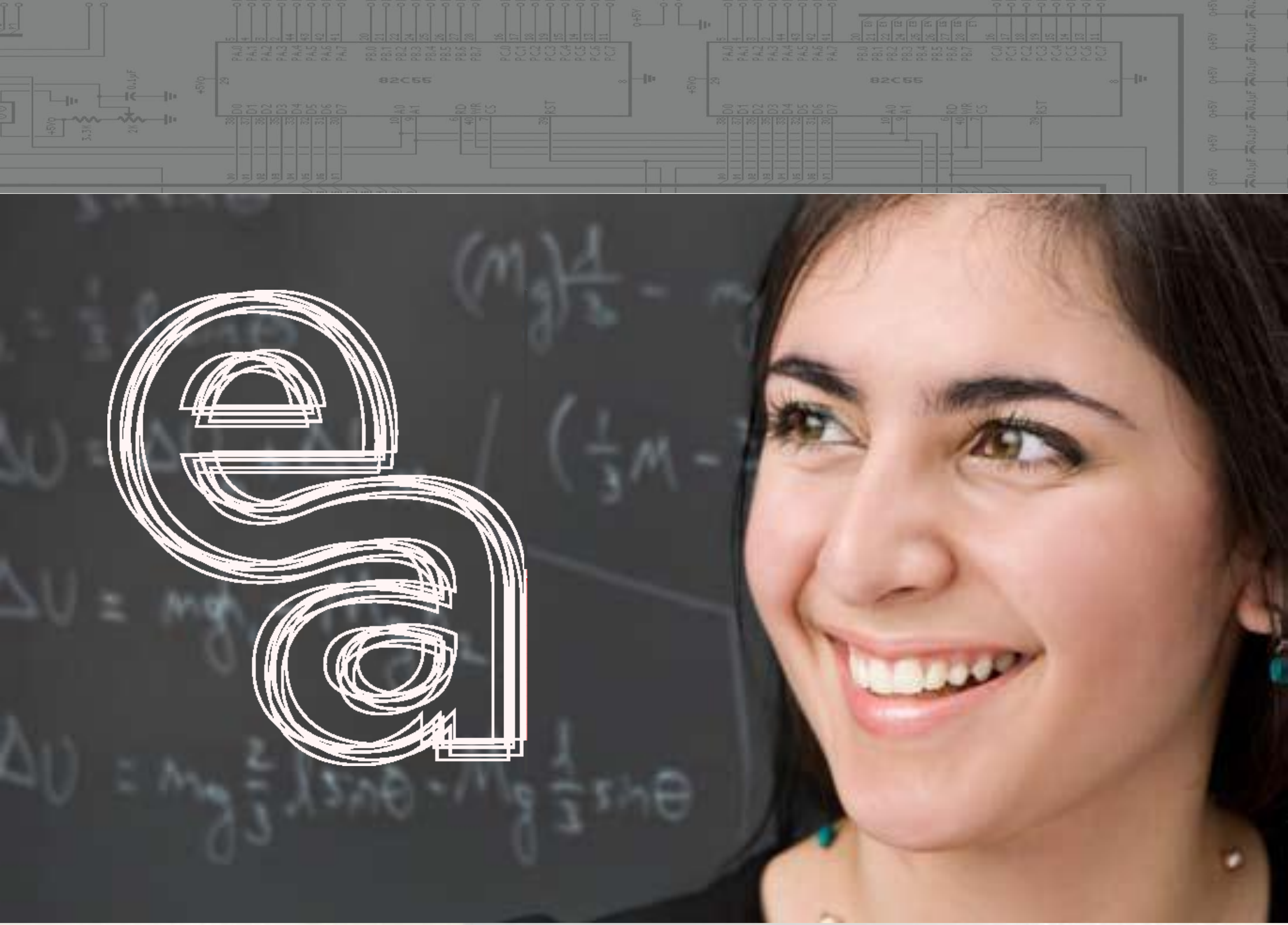


The Engineering Design Process can be applied to the overall robot and each subsystem.



The Engineering Design Process can also be applied to the other aspects of BEST.

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Bonus Slides

Questions for BEST Robot

- **The scoring strategy tends to drive the design**
  - **What type of steering is desired?**
  - **How many degrees-of-freedom does the robot need?**
  - **What maximum reach must the robot have?**
  - **How fast does the robot need to be?**
  - **How much weight must the robot lift?**
  - **What physical obstacles must the robot overcome?**

A Pairwise Comparison Chart for a BEST Robot

- **“0” if column objective > row objective**
- **“1” if row objective > column objective**
- **Higher score = more important**

Goals	Speed	Drive Power	Lift Power	Degrees-of-freedom	Simple Controls	Score
Speed	••••	1	1	1	1	4
Drive Power	0	••••	1	0	0	1
Lift Power	0	0	••••	1	0	1
Degrees-of-freedom	0	1	0	••••	0	1
Simple Controls	0	1	1	1	••••	3

A partial Attributes List for a 2008 BEST robot

- **Must be less than 24 pounds**
- **Must fit into a 24-inch cube**
- **Able to pick up individual plane parts**
- **Able to assemble plane parts**
- **Able to drive over a 1” x 4” board**
- **Able to close and open switch**
- **Should have zero-radius turn**
- **Should be able to carry a fully-assembled plane**
- **Should be able to lift a fully-assembled plane to a height of at least 36 inches**

Sample Goals/Constraints for a 2008 BEST robot

- **Goals**
  - **Assemble parts on the warehouse racks**
  - **Grabber rotation of at least 90 degrees**
  - **Single grabber to grab/hold each individual part and the assembled plane**
  - **Reach the part on the top, back rack position**
- **Constraints**
  - **Must fit in a 24-inch cube**
  - **Must weigh less than 24 pounds**
  - **Fixed height between warehouse racks**