Engineering Design

School of Mechanical and Aero. Eng.
Seoul National University

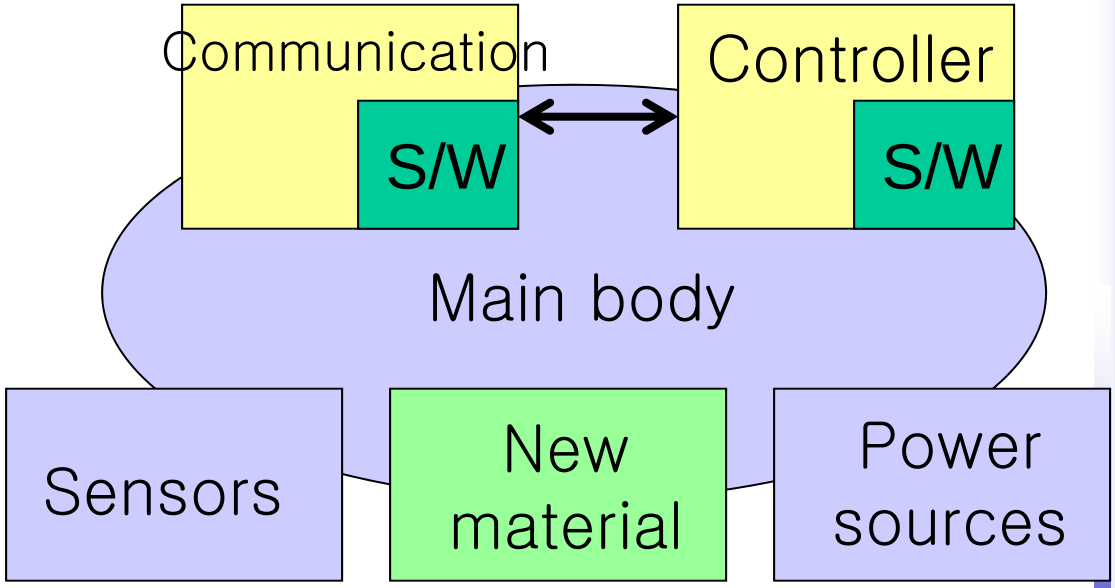
Suk Won Cha

PREMA
PRECISION ENGINEERING & MANUFACTURING

Engineering

- Engineers design a useful product for human integrating fundamental principles and components.
- Engineers can solve either optimization or innovative problems.

  Example of a innovative system: Mars explorer“Opportunity”



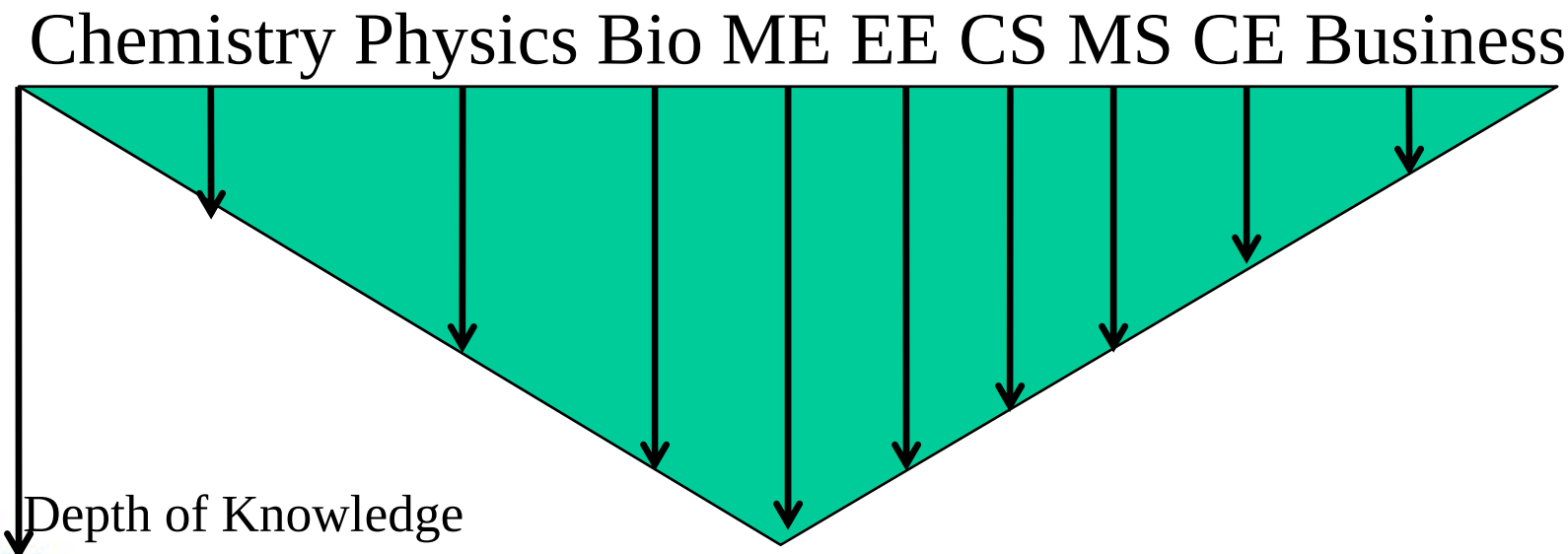
Optimization vs Innovation

- Takes specialist skills
- Existing product or service
- Customer expectations are understood, behaviors are easily measured
- Skill sets: analytical, data-driven, financial certainty

- Takes generalist skills
- Entirely new approach to product/service
- Customer expectations unknown
- Understanding behaviors requires research, prototyping
- No “right way”
- Skill sets: iterative thinking, prototyping, play, social consideration

Engineers Need Open Minds

- In modern society, one engineer cannot design everything by himself.
- Engineers need to have broad and deep knowledge to communicate with other engineer.



Team Work

- Not every task can be solved on your own!
- A single person often does not have the time or knowledge needed to succeed.
- Effective **team work** is needed in order to make the most of your team's collective abilities.

What is a Team?

- A group of individuals working together to achieve a common goal through collaborative working and decision making

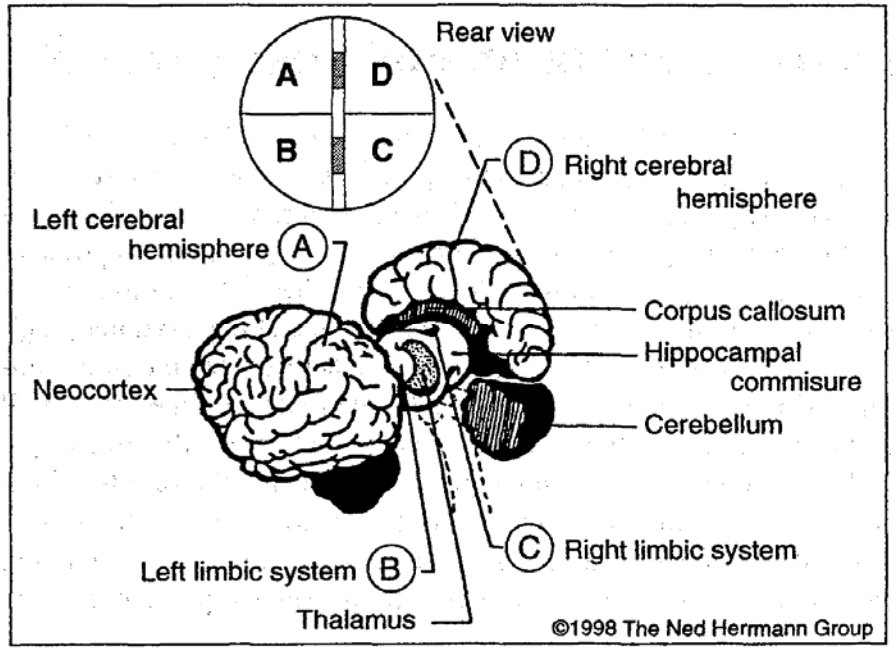
Advantage

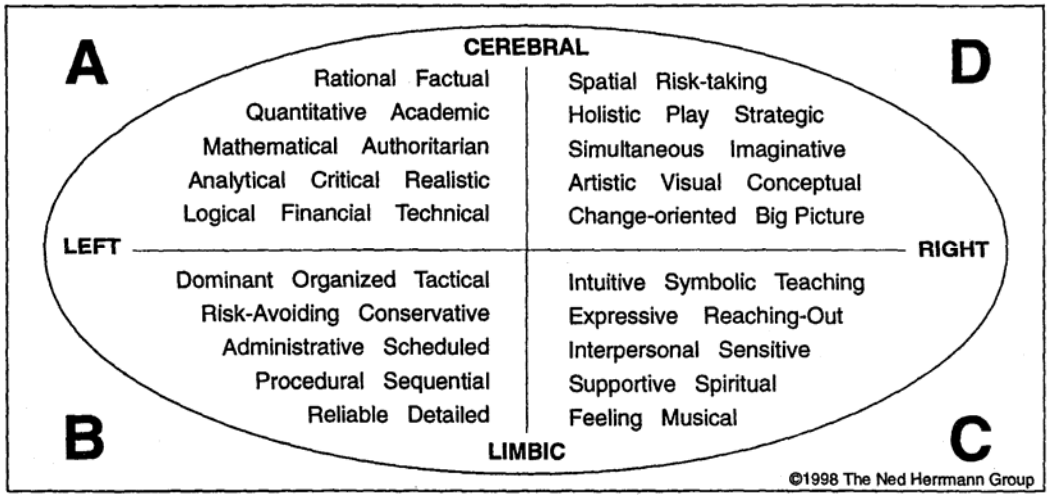
- Collective (more) knowledge by team members.
- Idea creation, feedback, development via communication.
- Search for the best solution in wider domain.
- Learn from other members knowledge.
- Leadership skill can be developed.

Disadvantage

- Requires time and efforts for team development
- Team process is slow and not efficient.
- Team conflicts can reduce the productivity.
- Leader may decide everything if leadership is too strong. (one leader + several “yes” persons = one leader)

Roles of a Brain: Ned Hermann Model





- Each part of a brain has different role
- One part of a brain is dominant for most people.
- Some people possess multi-dominant brain
  - Mozart, Galileo, Curie, Roosevelt…..

Individual Role in a Team

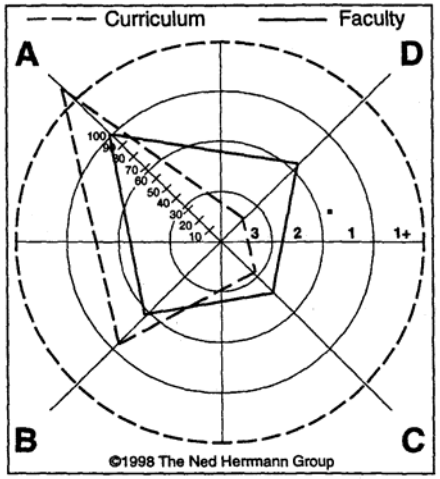


Figure 3.5 Typical average HBDI profile for engineering faculty together with a proforma profile of a mechanical engineering curriculum.

- Each person has unique capability and role
- Sometimes role may be what one prefers, not what one performs well
- A good team is compose of individuals with diverse roles

A Analyzer	**D** Synthesizer
Applying mathematical models.	Brainstorming wild and crazy ideas.
Calculating specifications.	Conceiving new approaches to design problems.
Comparing alternatives.	Creating an imaginative work environment.
Computing benefits and costs of solutions.	Creating new models of system behavior.
Drawing inferences from statistical information.	Developing metaphors for projects and goals.
Drawing physical and mathematical analogies.	Developing several competing design alternatives.
Evaluating and optimizing conceptual designs.	Drawing solutions from fields outside engineering.
Formulating reasoned, analytical approaches.	Framing problems in new formats.
Generating quantitative results.	Leading teams to innovative solutions.
Generating predictions based on math models.	Leading with vision; seeing the whole picture.
Quantifying criteria for solution evaluation.	Looking for innovation and break-through ideas.
Performing preliminary engineering analyses.	Presenting results in imaginative ways.
Solving mathematical equations.	Redefining old problems with new insights.
Separating factual data from opinion.	Recognizing opportunities for improvement.
Taking principles and data to logical conclusions.	Visualizing new connections or arrangements.
Verifying assumptions and arbitrary parameters.	Using crazy ideas as triggers to innovative concepts.
Writing computer programs.	Sketching possible design solutions.
Writing project proposals and technical reports.	Synthesizing solutions from other engineering fields.
Checking drawings for errors.	Being sensitive to team members' feelings.
Checking specifications against codes.	Brainstorming concepts with teams.
Collecting and safe-guarding project records.	Building effective relationships with all customers.
Debugging computer programs.	Communicating effectively at all stages of design.
Developing checklists.	Continuously teaching yourself/others new techniques.
Drafting bills of material.	Cultivating enthusiasm.
Expediting design details.	Developing environmentally benign concepts.
Following design procedures.	Encouraging/training coworkers in new technology.
Issuing change orders and tracking design changes.	Enjoying teamwork.
Linking complex project plans and schedules.	Involving implementers of solutions in their creation.
Optimizing procedures.	Maintaining ethics and values.
Organizing and scheduling design projects.	"Seeking first to understand, then to be understood."
Producing "as-built" drawings.	Seeking win-win solutions that benefit all parties.
Synchronizing product and process design.	Selling solutions and ideas.
Supervising design drafters.	Sensing customer needs.
Taking action to implement design plans.	Sharing goals and experiences.
Tracking project expenditures.	Using senses and intuition to define the design problem.
Updating software; scheduling required training.	Working toward synergy rather than compromise.
B Administrator	Collaborator **C**

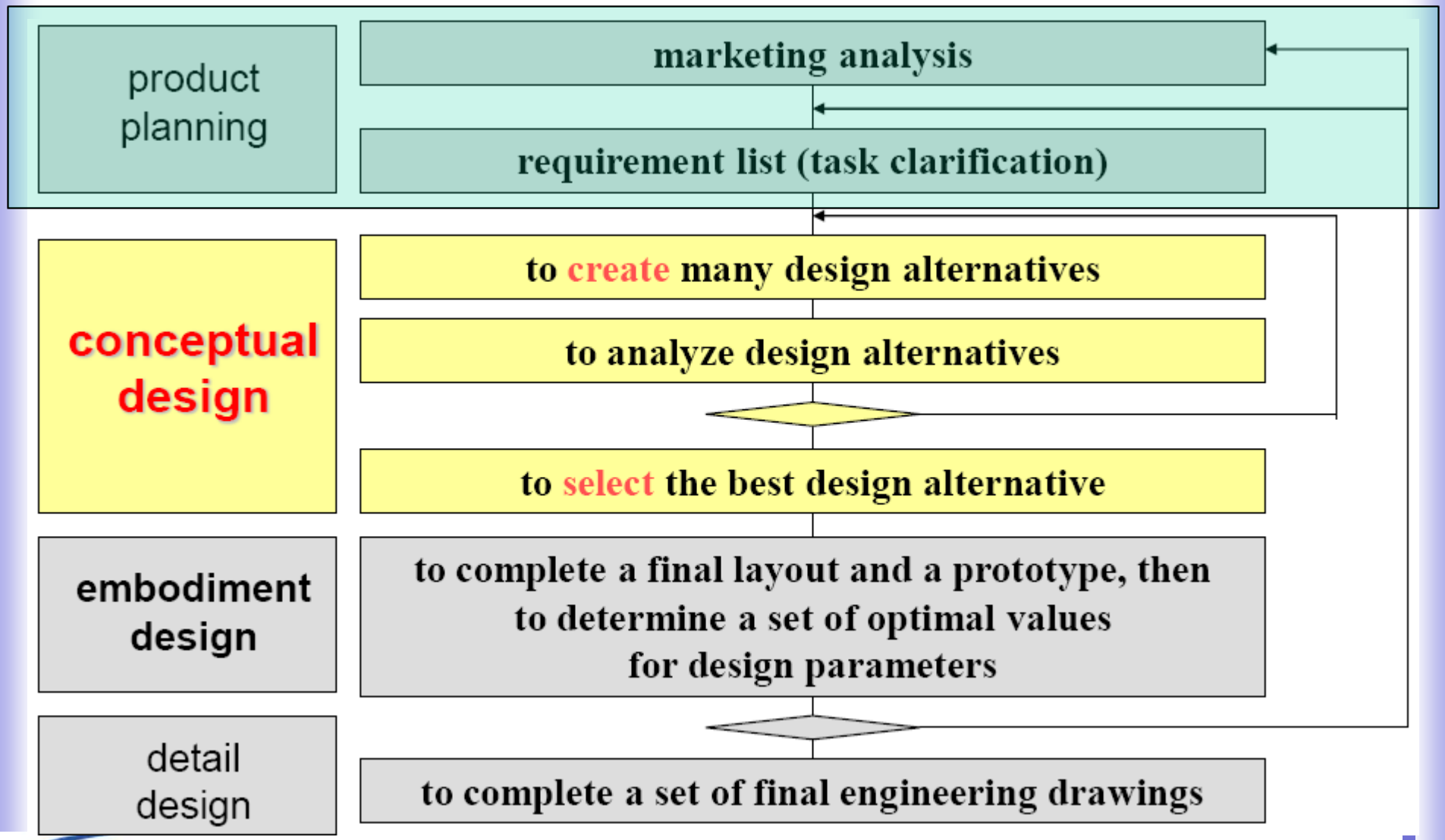
A Good Team

- Creatively diverse
- Members have well defined roles
- Individual leadership in each roles
- Individuals have responsibility
- Supports other’s leadership and roles
- Learn from other peoples (individual develpement)

Engineering Design

- Create as many as possible design alternatives satisfying customers needs using the knowledge on science and engineering
- Determine the best design alternative
- Optimize the selected design
- This entire process must satisfy all the limitations and regulations by technology, business, law, environment, human and etc.

Steps of Engineering Design



Product Planning

- Discover new idea for a new product
- Start with Marketing:
  - Bridge between customer and the company.
    - Monitor the customer requirements and satisfaction
    - Should be representative of customers in a company (Not sales department)
    - Market survey is important
  - Determine the concept and direction of new product development from the market
    - Market fluctuation and future of the current product sales
    - Market trend and change
    - Customer feedback
    - Competency of the product over other companies
  - Product advertisement strategy

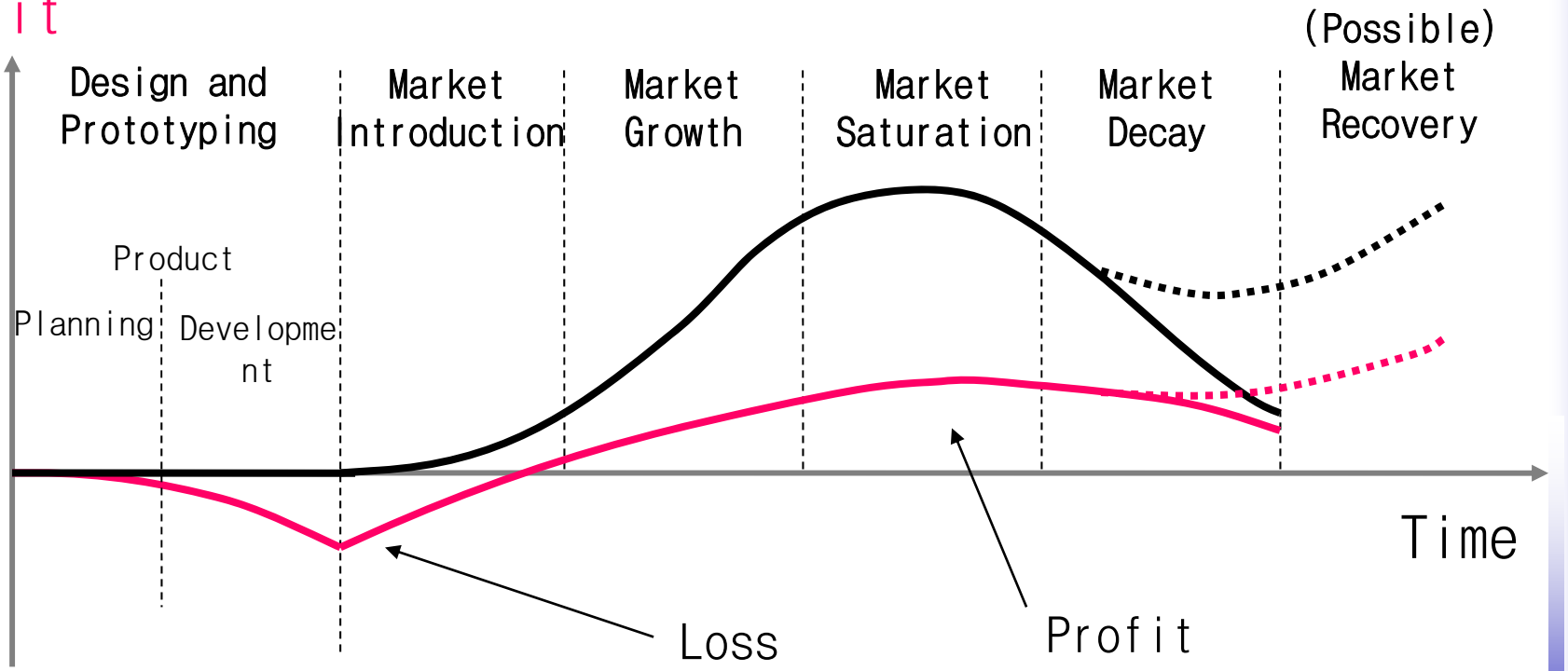
Steps of Product Planning

1. Market survey and market trend
   - Which step in product life cycle?
   - Sales point of the product?
   - Trend of new product
2. Discover new idea
   - Organized the requirements
3. Define new product
   - Develop the new idea in detail
   - List requirements of the new product

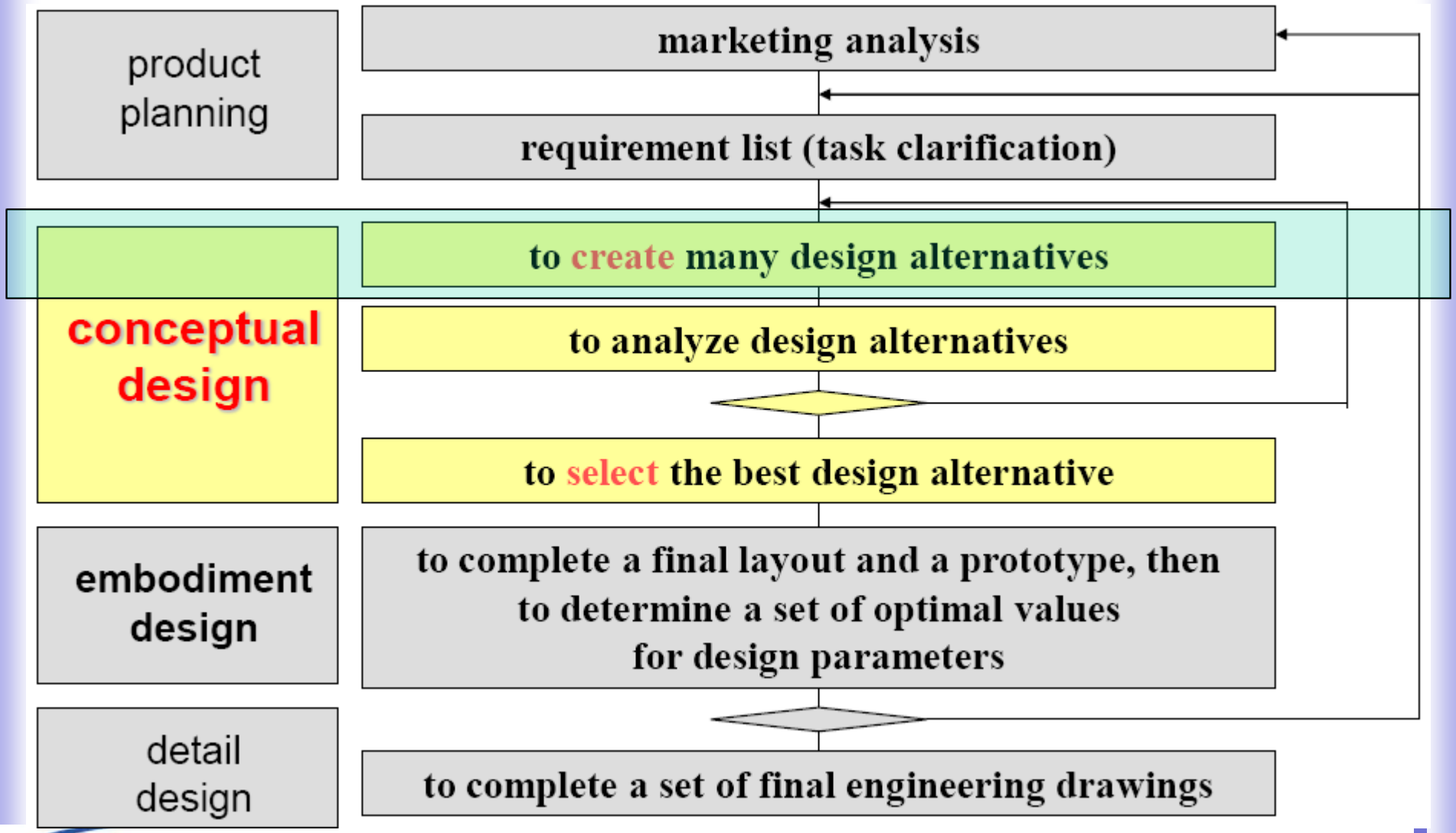
Product Life Cycle

Revenue

Profit



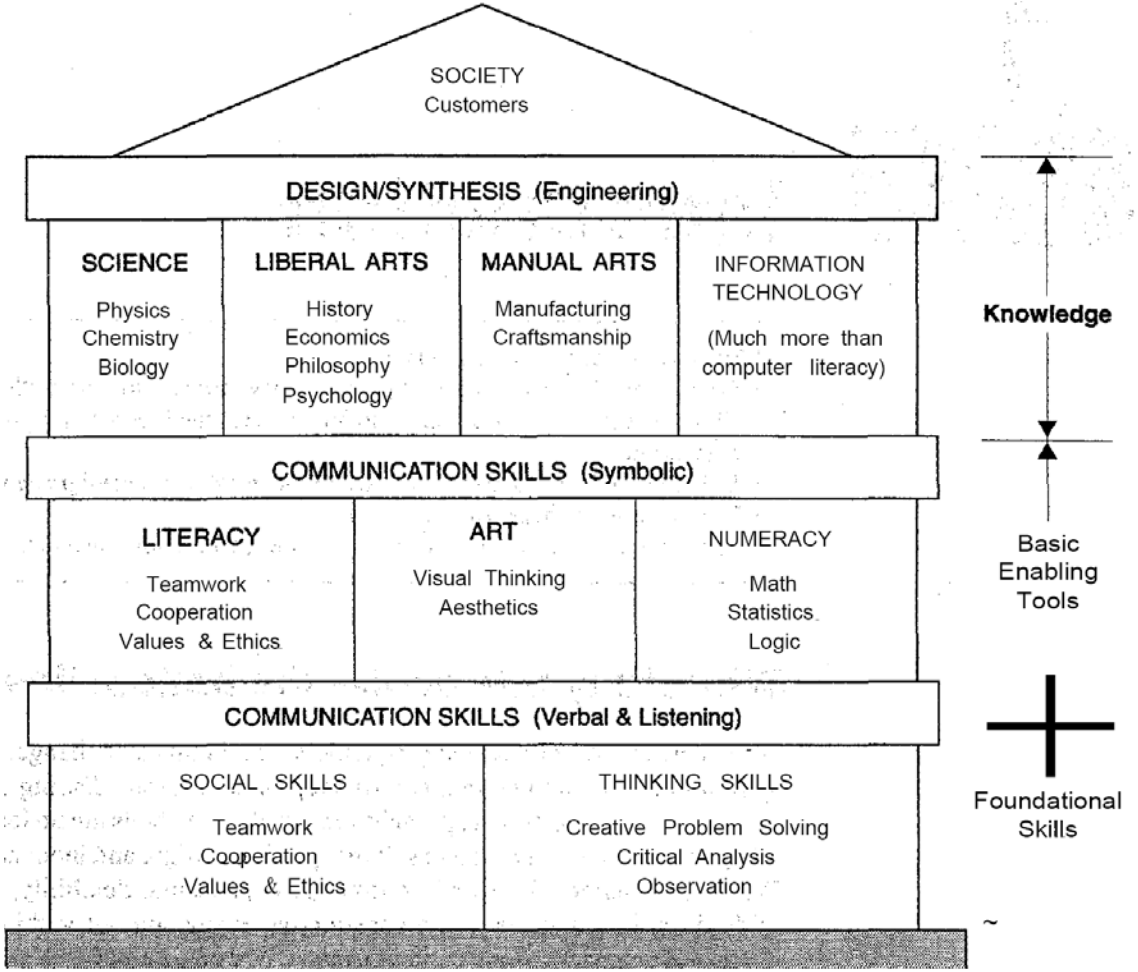
Steps of Engineering Design



Conceptual Design

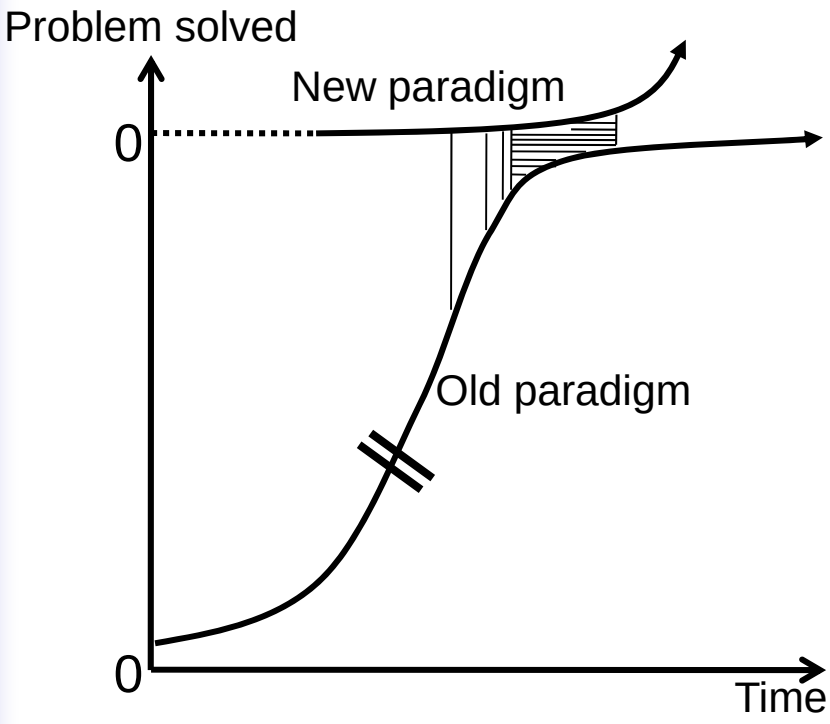
- Input : Requirements from product planning
- What to do : Create as many design alternatives as possible and choose the best one
- Output : the best design alternative

What Engineers Have to Learn



- Successful engineers considers everything.

Creativity Changes Paradigm



Paradigm life-cycle

- A new paradigm solves problems in S-shaped curve.
- When a paradigm becomes obsolete(do not contribute to problems solving anymore), a new paradigm may emerge.
- A gap between old and new paradigm has to be filled to make the new paradigm to take off. Creativity does this.
- Example
  - Mechanical vs. Quartz Watch
  - Vacuum tube vs. Transitor
  - Film vs. Digital Camera

Impediments for Creativity

- Cultural impediments
  - No question is allowed, tradition…
- Environmental impediments
  - Physical environment, criticism..
- Emotional impediments
  - Fear for risk, instability, lack of motivation..
- Intellectual impediments
  - Limited knowledge, communication, information..
- Perceptual impediments
  - Misunderstanding of a problem, defective perceptions…
- Technical impediments
  - Limitation on materials, manufacturing, analysis…

Conceptual Design

- **Original Design (25%)**
  - **Invent something out of nothing**
  - **Most challenging**
  - **e.g. : phone, space shuttle**
- **Adaptive Design (55%)**
  - **Adapt existing solution for different task**
  - **e.g.: 2005 Hyundai Grandeur(TG) vs. 2004 Hyundai Grandeur(XG)**
- **Variant Design (20%)**
  - **Change of size or arrangement**
  - **No change in principle or functionality**
  - **e.g.: 2008 Hyundai Grandeur(TG) vs. 2007 Hyundai Grandeur(TG)**

Strategies for Creative Design

- Duplication
- Combination of conventional elements
- Historical evolution
- Hypothesis-and-test
- Brainstorming (for a team)
- Analogy
- Morphology
- Empathy
- Biomimetics
- Checklist
- TRIZ(Theory of Inventive Problem Solving)
- Synetics

Duplication

- Adapt a design from similar product
- Literatures and patent search
- Reverse engineering

Marker pen

Stain remover from Tide

Combination of Conventional Elements

- New solution from the combination of familiar components.
- Requires broad knowledge
- Key factor is to recognize of the importance of the combination

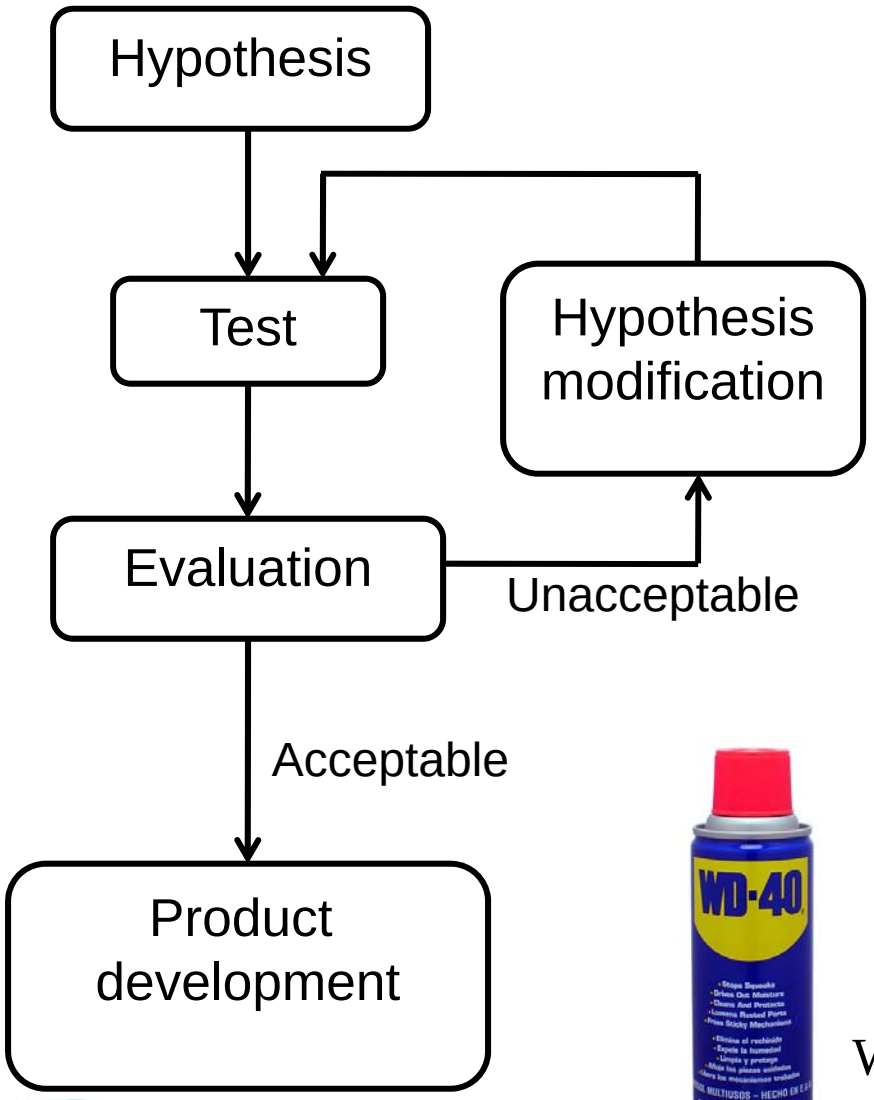
Motorcycle by Daimler in 1885
(bicycle + 4 stroke engine)

Historical Evolution

- Look for trend and evolution in products to predict future design
- Find the defective design in a product
- Introduce a new technology

- Everybody wants a bigger and thinner TV.
- Plasma and LCD technology outdate cathode ray tube.

Hypothesis-and-Test

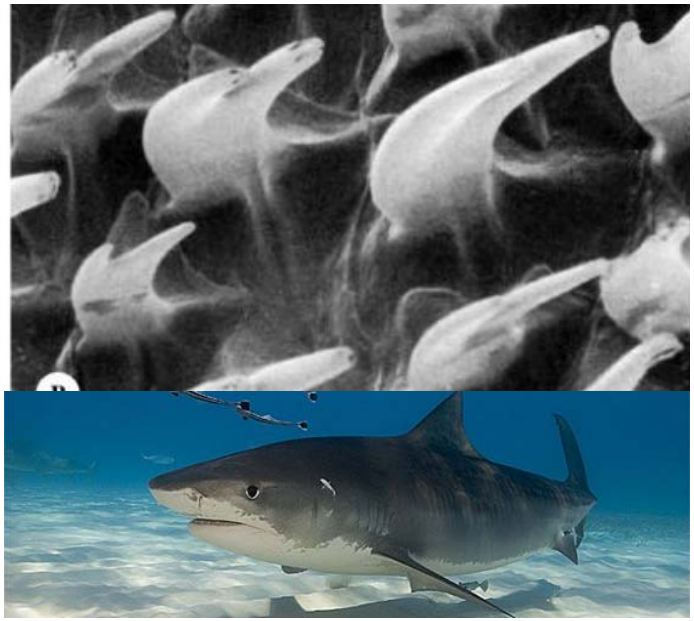


- Simple but inefficient
- Requires numerous trial and error
- Sometime reveals serendipitous discovery
- Very popular and successful in industries
  - e.g. light bulb by Edison

WD-40 (Water displacement 40th formula) developed after 40 trial and error

Analogy

- Find the similarity among differently looking objects
- Biomimetics

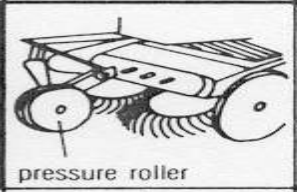
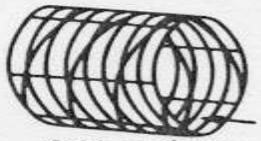
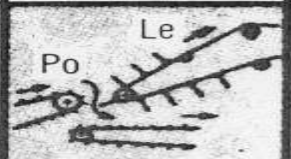
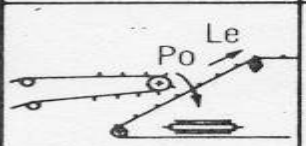
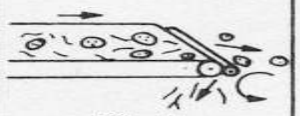
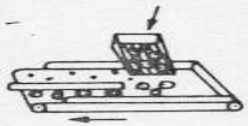
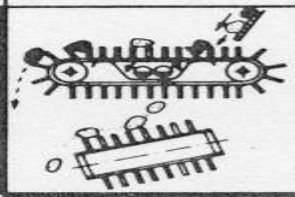


Denticles in sharks and swimming suit reduces drag.

Morphology

- Define subproblems (subfunctions) and organize them
- Reduce the number of subproblems by selecting key subproblems
- List all possible solutions for each subproblem
- Combine solutions of each subproblem to create possible design options

Morphology Example: Potato Collector

Sub-functions		1	2	3	4	. . .
1	Lift					. . .
2	Sift	 Sifting belt	 Sifting grid	 Sifting drum	 Sifting wheel	. . .
3	Separate leaves			 Plucker	. . .	. . .
4	Separate stones					. . .
5	Sort potatoes	by hand	by friction (inclined plane)	checksize (hole gauge)	check mass (weighing)	. . .
6	Collect	Tipping hopper	Conveyor	Sack-filling device	. . .	. . .

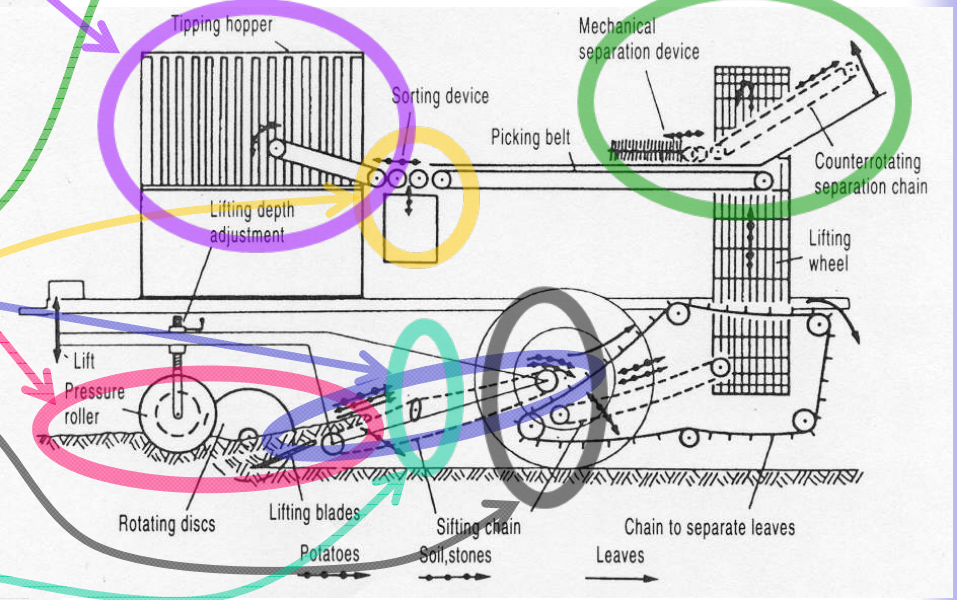
Combination of principles

Subproblems(subfunction) and solutions for a potato collector

Morphology Example : Potato Collector

Sub-functions \ Solutions	1	2	3	4	...
1 Lift	and pressure roller	and pressure roller	and pressure roller	pressure roller	
2 Sift	Sifting belt	Sifting grid	Sifting drum	Sifting wheel	
3 Separate leaves	Le Po	Le Po	Plucker		
4 Separate stones					
5 Sort potatoes	by hand	by friction (inclined plane)	checksize (hole gauge)	check mass (weighing)	...
6 Collect	Tipping hopper	Conveyor	Sack-filling device	...	...

Combination of principles



Design option by combination of solutions

Empathy

- Imagine the problem environment to stimulate the creative problem solving process

Einstein's imagination to develop relativity:

"How does it feel when I travel at the speed of light?"

Checklist

- Ask questions in a common checklist to create ideas.

  Rearrangement

  - exchange, reorder, reschedule, reshape, realign…

  Reverse

  - Flip, change of role, upside down…

  Combination

  - Blend, alloy, idea, requirements, elements..

  Minimization

  - subtract, shorten, compress, lower, lighter, thinner, divide..

  Alternative

  - material, components, process, power, place, approach….

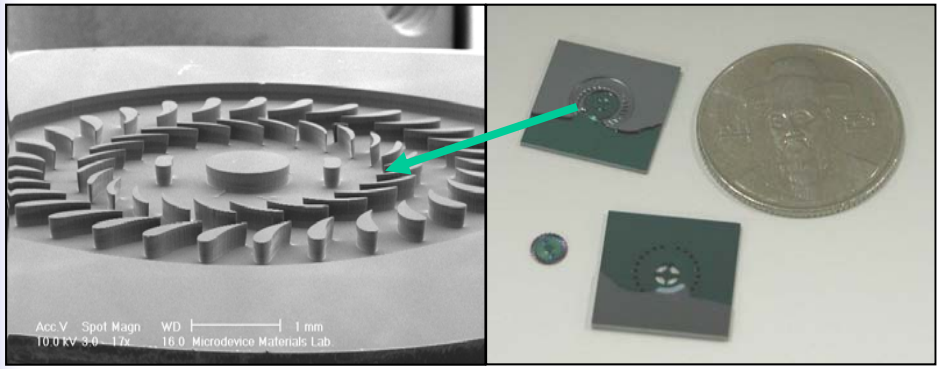
  ……

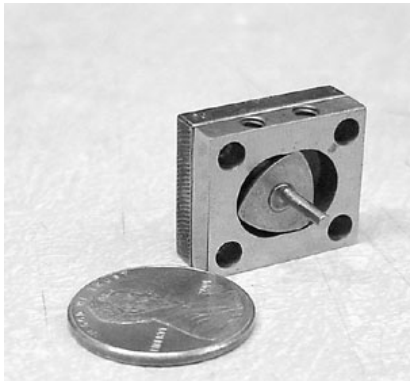
Checklist Example: Minimization

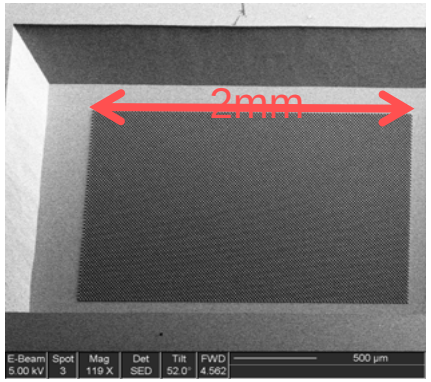
Miniaturized power sources for mobile devices

- Turbine engine
- Internal combustion engine
- Battery
- Fuel cells

- Micro turbine
- Micro engine
- Micro battery
- Micro fuel cell







PREMA
PRECISION ENGINEERING & MANUFACTURING

TRIZ(Theory of Inventive Problem Solving)

- Proposed by Genrich Altshuller from Russia in 1940's
- Altshuller observed only 1 out 6 patents is innovative. (Others are just logically simple improvement.)
- Definition of "innovation"
  - Fine solutions for problems that contradicts each other
  - e.g. make a bigger car that consumes less fuel. How can you do it?
- 5 levels of innovation defined by Altshuller

Level	Characteristic	% in patents
1	Simple and local solution	32%
2	Small improvement in a system	45%
3	Improve conventional system	19%
4	New idea based on unfamiliar principles	3.7%
5	Innovation based on unknown principles	0.3%

TRIZ(Theory of Inventive Problem Solving)

- From patents, Altshuller found 39 parameters that contradict each other.
- He also found 40 common problem solution patterns to resolve the contradiction in parameters.
- He claimed that creative solution can be found from the tables of parameters and solution patterns.

Parameters	Innovation method
Power, wasted energy, wasted material, reliability, pressure, shape, stability, strength, temperature, brightness, weight, length, volume, area, velocity, force, automation, convenience, adaptibibility, accuracy of measurement, accuracy of manufacturing, manufacturability..	Segmentation, prior action, transformation, replacement, extraction, dynamics, periodic action, mechanical vibration, change color, inversion, copying, local quality, mediator, composite materials, use an inexpensive short-live object, change dimension….

Brainstorming (for a Team)

- Invoke the creativity of the team to create as many idea as possible
- Idea trigger method
  - Idea generation (2min record/2min break/30sec record)
  - Idea association (No time limit)
    - While reading other member's idea, each member remove duplicate idea and write down associated idea in column 2 from the idea in column 1.
    - Repeat the task for the column 2.
    - A member may pass his turn when he has nothing to say.
  - Summarize and discuss
    - Collect and organize the idea list.
    - Discuss about the idea.

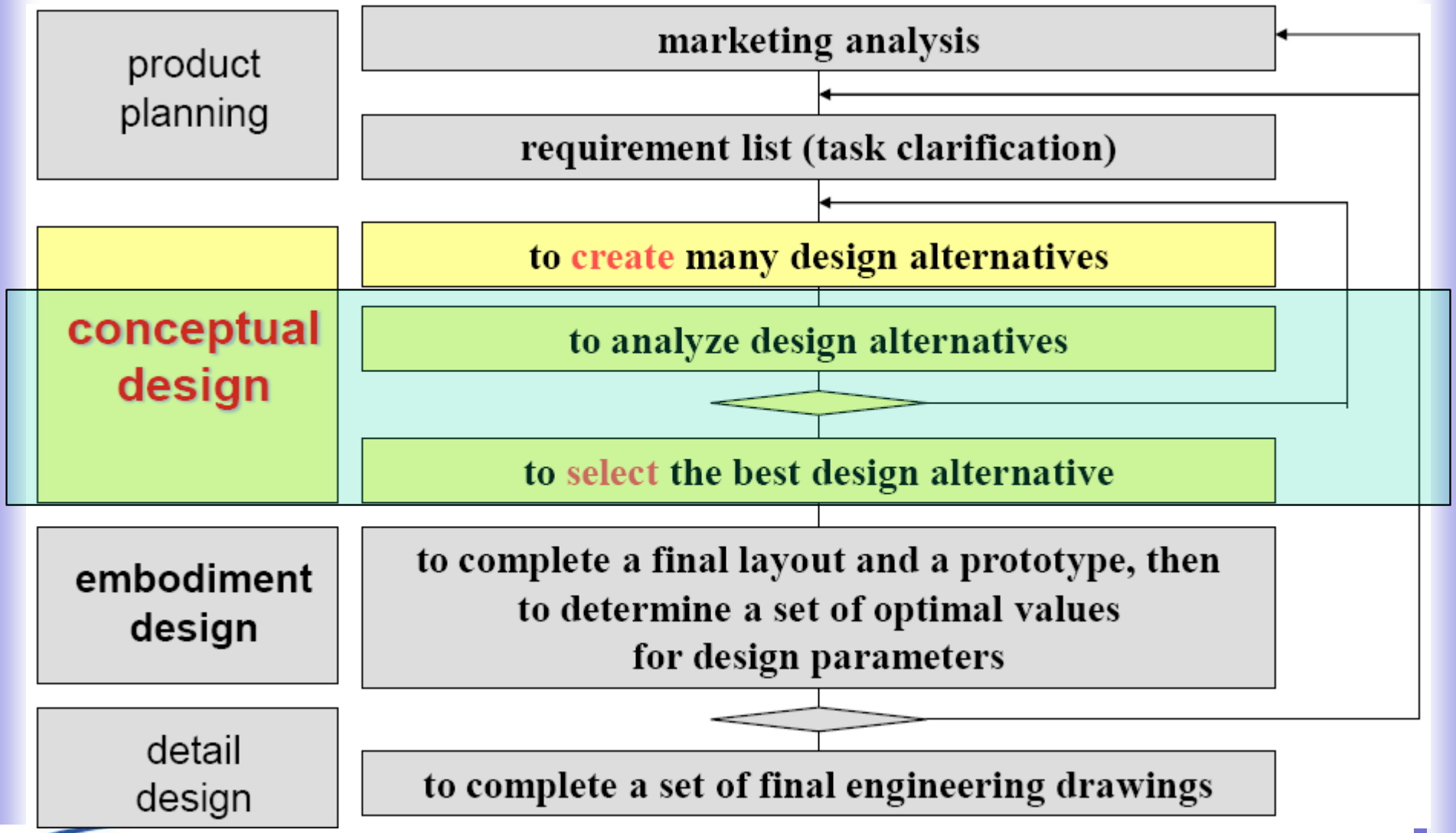
Sample Format for Brainstorming

column 1	column 2	column 3	column 4
2min 30sec			

Rules for Brainstorming

- Never criticize
  - Never criticize other's idea nor give any feedback until the end of the idea generation. No gesture nor face expression allowed .
- Never hesitate
  - Only number of idea matters. Ridiculous, stupid and unrealistic idea are always welcome. Never reject any idea.
  - Write down every idea.
- Quantity than quality
  - Do not stop generation or writing down even though you think you have enough idea.
- Idea belong to no one
  - Do not hesitate adapting other's idea. Improve or use other idea to create new idea.
- Do not think about yourself
  - What you can do, cannot do, will do or won't do doesn't matter. Think as a team.
- Be cheerful. Happiness and excitement create good idea

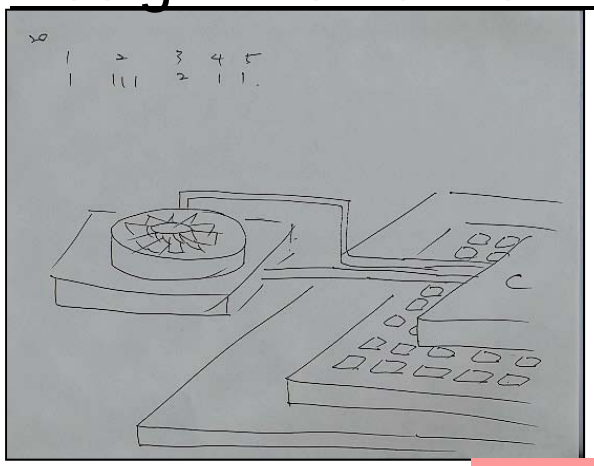
Steps of Engineering Design

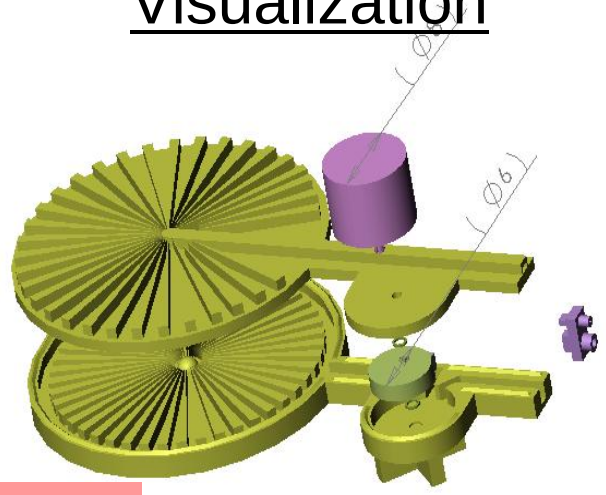


Design Visualization

- Select realistic design alternatives. Visualize designs in detail
  - You may apply engineering analysis or simulation to the design.

Design Alternative #1 ➔ Visualization





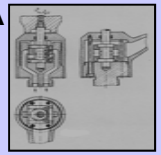
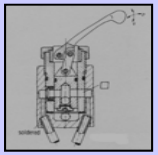
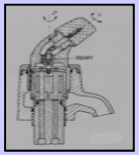
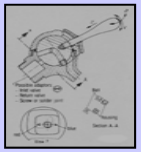
A micro-cooler

Evaluation and Final Design

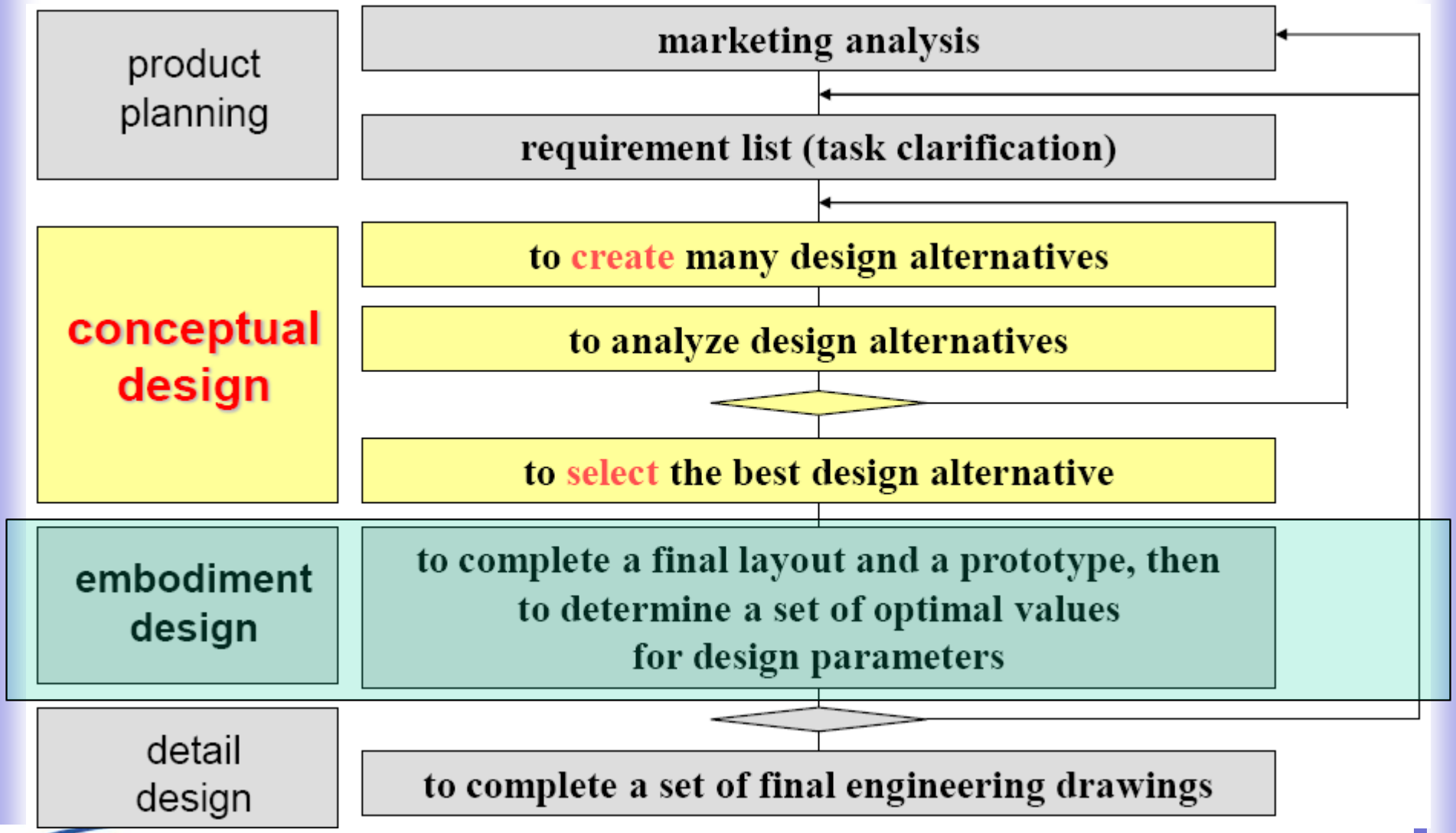
- Discuss the advantage and disadvantage of design alternatives
  - Check with requirement list
  - Throw any design that does not satisfy the requirement
  - Compare the advantage and disadvantage of each design
- Make a comparison table and list evaluation criteria. Quantify each design alternative for evaluation criteria (You may use weighting factor for each criteria).
- Select final design.

Example: Evaluation Table of Faucet Design

- Design B is the best choice, however design C has significantly less assembly parts. Reevaulate design to reduce parts number further. Improvement. Review design alternatives in 3 weeks again and decide the final design

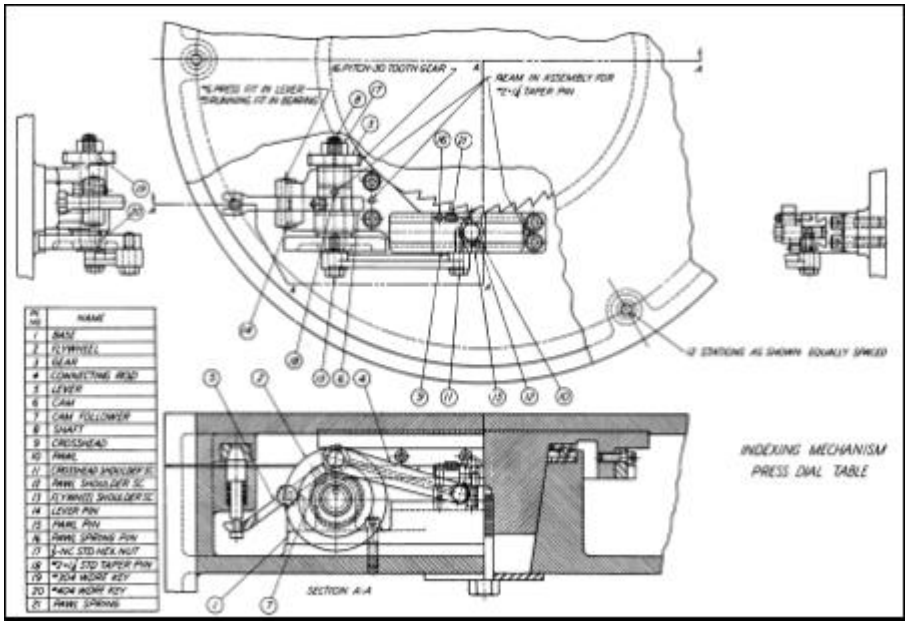
No	Evaluation Criteria			A 	B 	C 	D 
	Item	Explanation	W.F				
1	기능	누수가 없이 차단하는 신뢰성	2.0	2	6	6	2
2	원리	기능의 변화가 작은 견실설계	2.0	4	6	4	4
3	구현성	작은 공간을 차지하는가	1.0	3	2	2	4
4	가공성	부품의 수효가 작은가	3.0	3	6	3	9
5	가공성	부품의 가공이 단순한가	1.0	1	3	2	1
6	조립성	조립이 용이한가	1.0	2	3	2	2
7	사용성	조작이 간편? 조정이 간편?	2.0	2	6	8	4
8	사용성	청소가 쉬운가	1.0	4	2	3	2
9	보수유지	특수공구 필요한 것은 아닌가	1.0	1	3	2	1
합계		(가중치 x 점수) 의 총합		22	37	32	29
		순위		4	1	2	3
결론		최적 설계대안으로서 B 를 선택하되, 설계대안 C 에 대해서 부품의 수효를 획기적으로 줄일 수 있는지를 3주 정도 더 검토한 후 최종 결정을 한다.					

Steps of Engineering Design



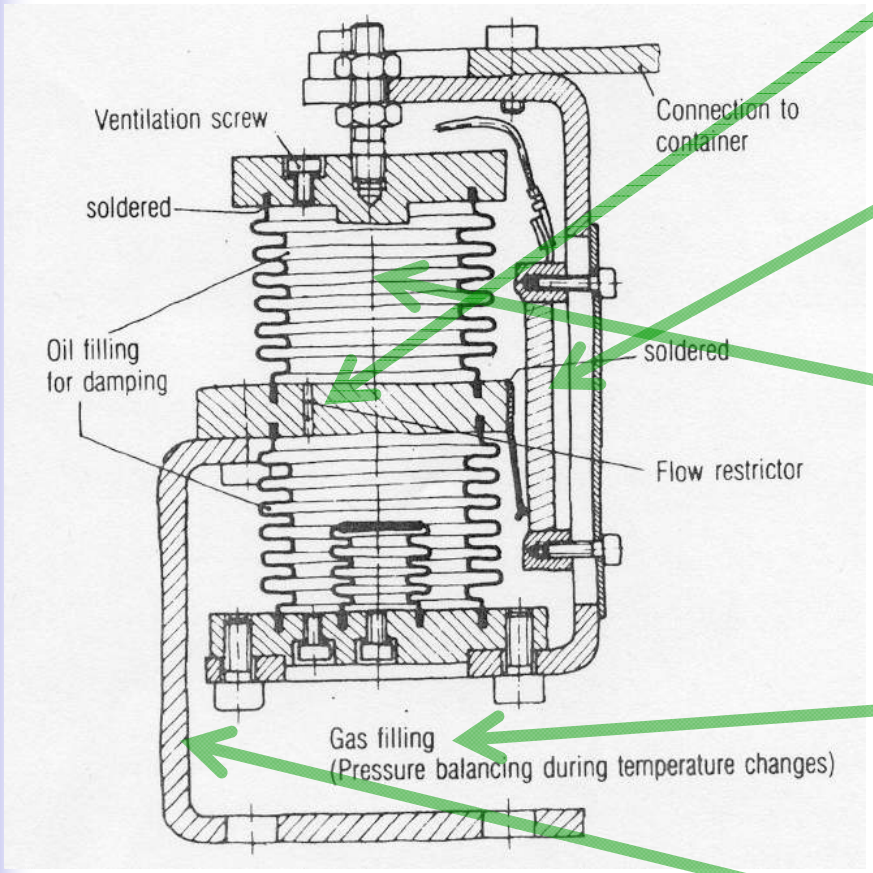
Design Embodiment

- Finalize the product assembly drawings based on the final design decision.



- Construct a prototype.
- Optimize the design parameters.

Optimal Design Parameters



Final design of a fuel meter

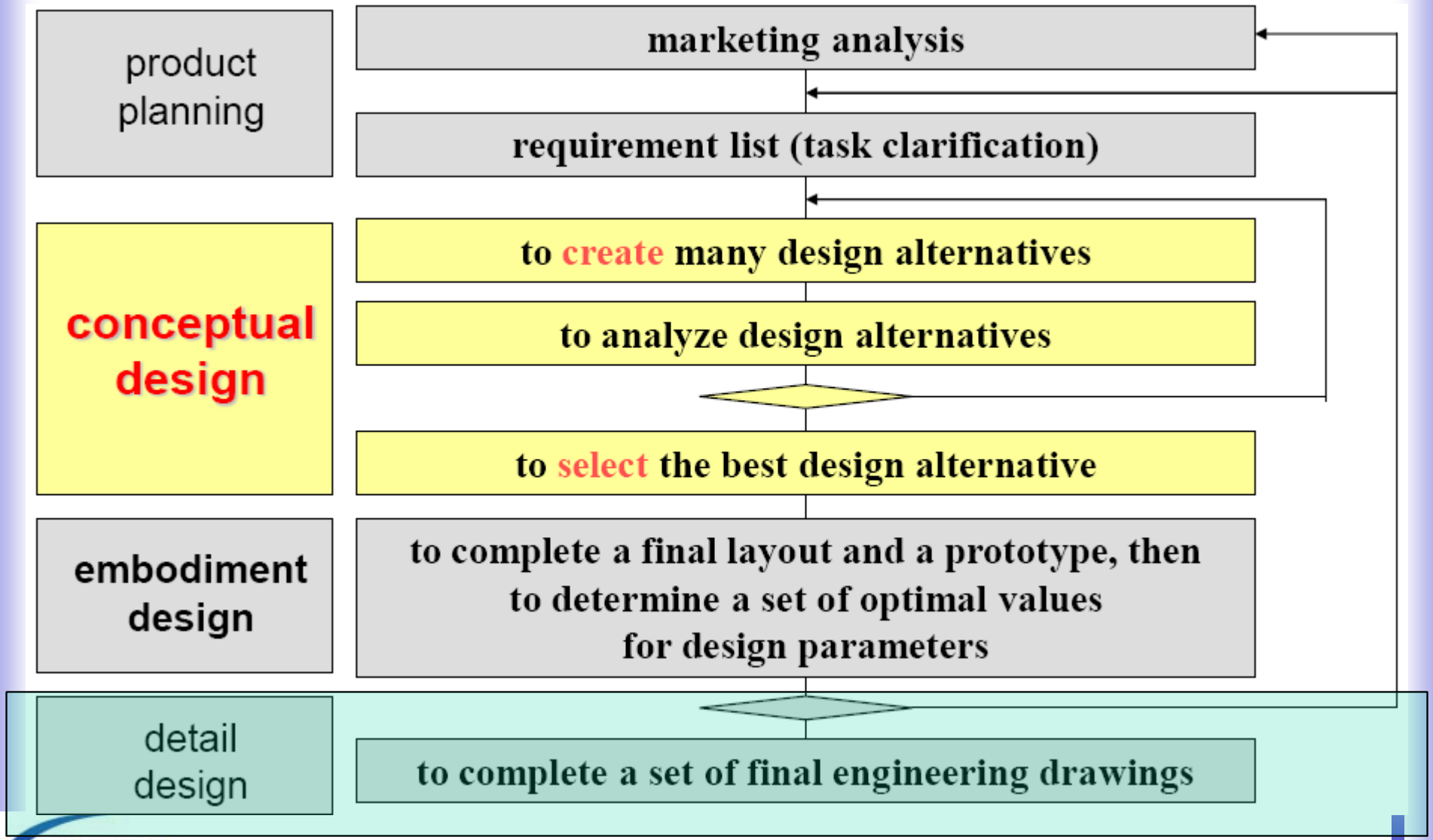
- Flow restrictor
  - Diameter?
  - Shape factor?
- Potentiometer
  - Resistance?
  - Manufacturer? Spec?
- Oil filling for damping
  - Length and diameter?
  - Spring constant?
  - Damping constant?
  - Oil manufacturer? Spec?
- Gas filling
  - Balancing pressure?
  - Shape factor?
- Main frame
  - Thickness? Length?

How to determine the optimal design parameter

1. Old product, reference, literature.
2. Engineering analysis.
3. Engineering simulation.
4. Design experiments using prototypes

   ➔ “Taguchi Methodology” or “Design of experiments”

Steps of Engineering Design



Detail Design

- Complete the final drawing from assembly drawing.
- Final drawing include all information for the mass production in a factory.
- Final drawing includes
  - BOM (Bill of Materials)
  - Assembly drawing
  - Components drawing
  - Package drawing
  - User manual and maintenance manual

Why Creative Engineering Design?

- No right solution for most of the real life problems.
- Can you learn everything from books?
  - You should know how to use the knowledge from the book.
- How to solve a problem?
  - Do you understand the key barriers in the problem?
  - Can you solve it alone?
  - What problem solving strategy will you take?

A good engineer understand key barriers in the open-end problem. He generates creative idea and innovative solutions using engineering, scientific and social knowledge through team work and systematic problem solving skills.

An Advice for Engineering Students

- **Success is determined by you**
- **Learn on your own**
- **Motivation drives everything**
- **Learn to work in groups**
- **Be broad**
- **Be organized**
- **Be honest about your work**