Introduction to Engineering, Engineering Design & Steps for Design to Product Levels

By

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What is Engineering?

"…the purposive (done with purpose) **adaptation of means to reach a pre-conceived end…"** **E.T. Layton, Jr.**

"***Technological activity to solve problems***"

Human Creativity

Engineering as a "Thinking-Making" Activity

The use of technology to make products and systems for societal benefit.

- Most engineering designs can be classified as inventions of devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems.

- Inventions, or designs, do not suddenly appear from no where. They are the result of bringing together technologies to meet human needs or to solve problems.

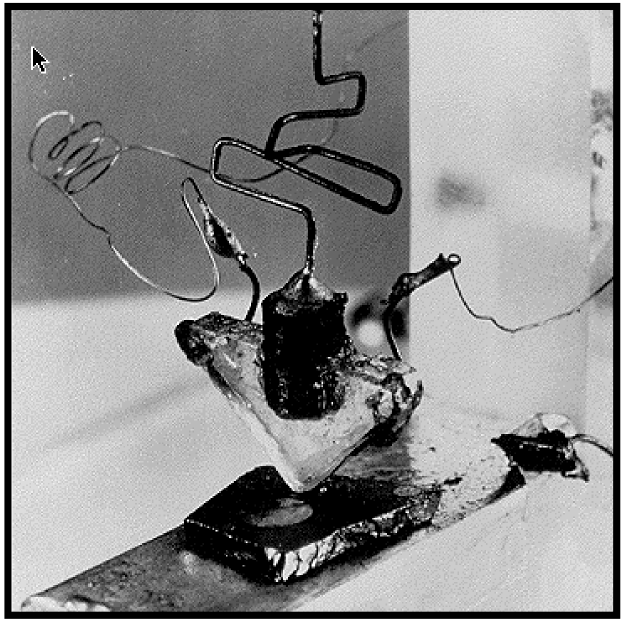
- Design activity occurs over a period of time and requires a step-by-step methodology.

Industrial Revolutions in the Human History

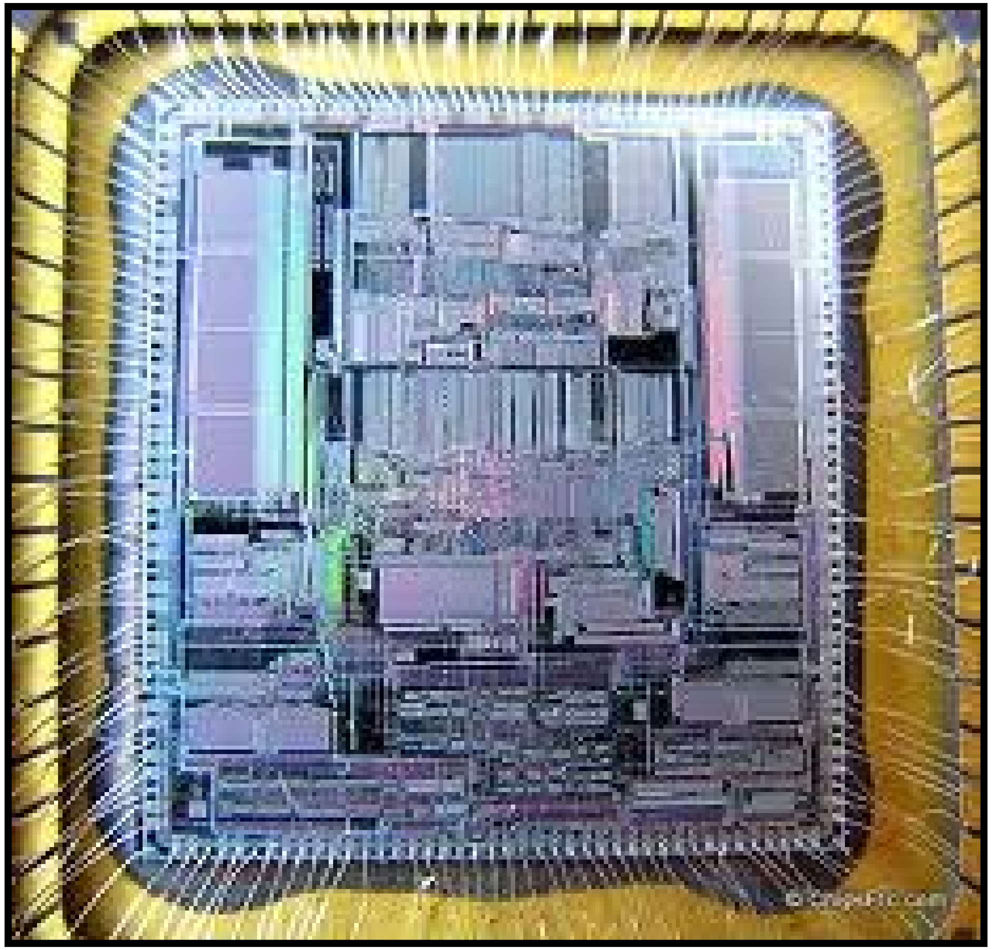
First IR: **1775** **Triggered by the Prime Movers. Technology and Manufacturing became the deciding factor for World Power**

Second IR: **1970** **Triggered by the Transistors. Microelectronics, Computers and Communication. Knowledge-based industry and Information Technology transformed the society and started playing a major role in World Economy.**

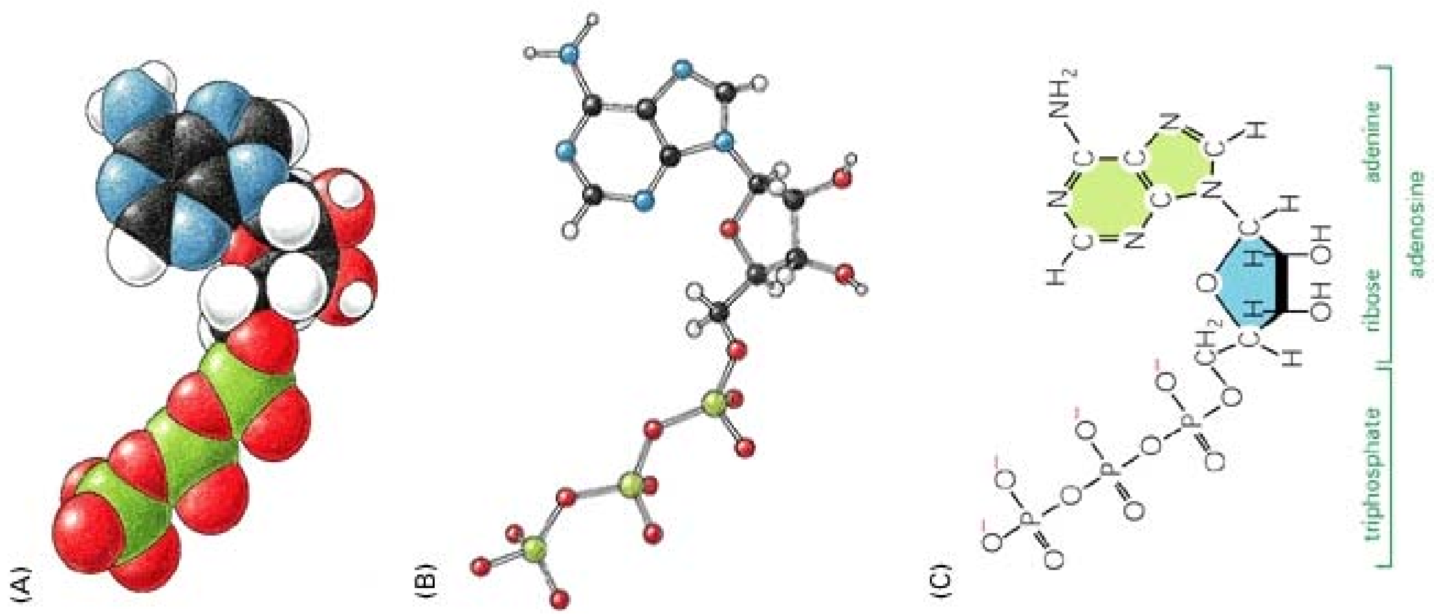
High-Tech Industry is linked to availability of strong and well-trained engineer corps



FIRST TRANSISTOR BY BARDEEN 1947



A MODERN VLSI CHIP CONTAINING MILLIONS OF TRANSISTORS IN AN AREA OF ABOUT 1 cm^2



Energy is stored in the covalent bonds between phosphates.

ADP + Pi + Energy → ATP

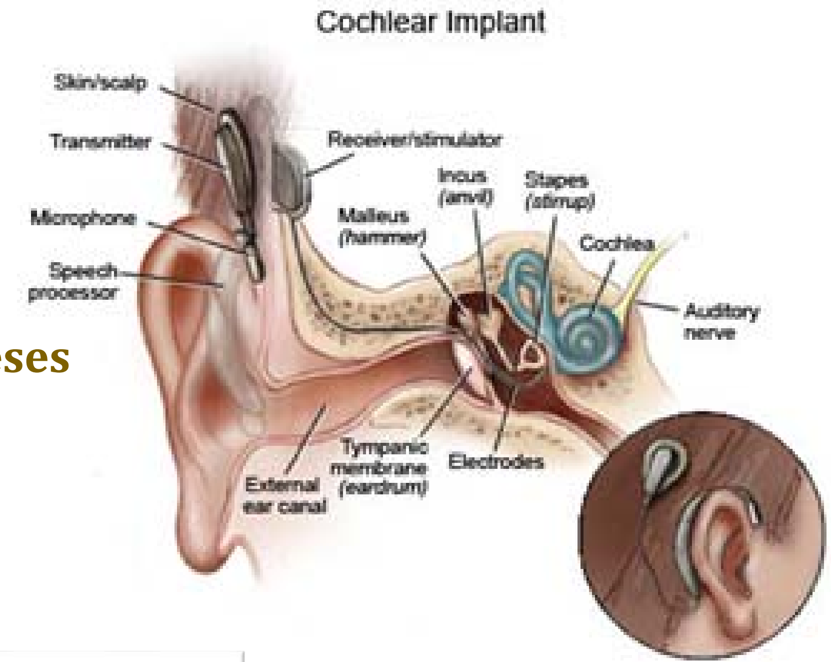
Hydrolysis of ATP

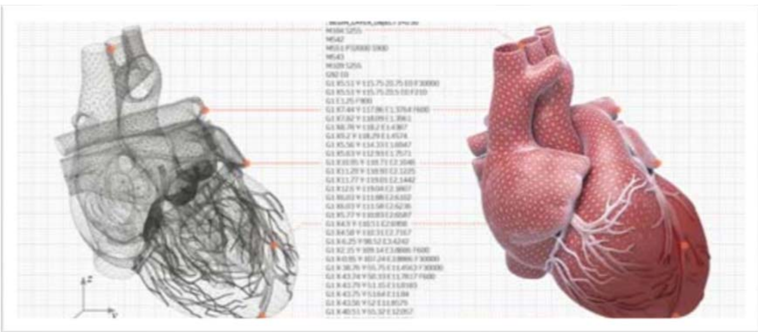
ATP → ADP + Pi

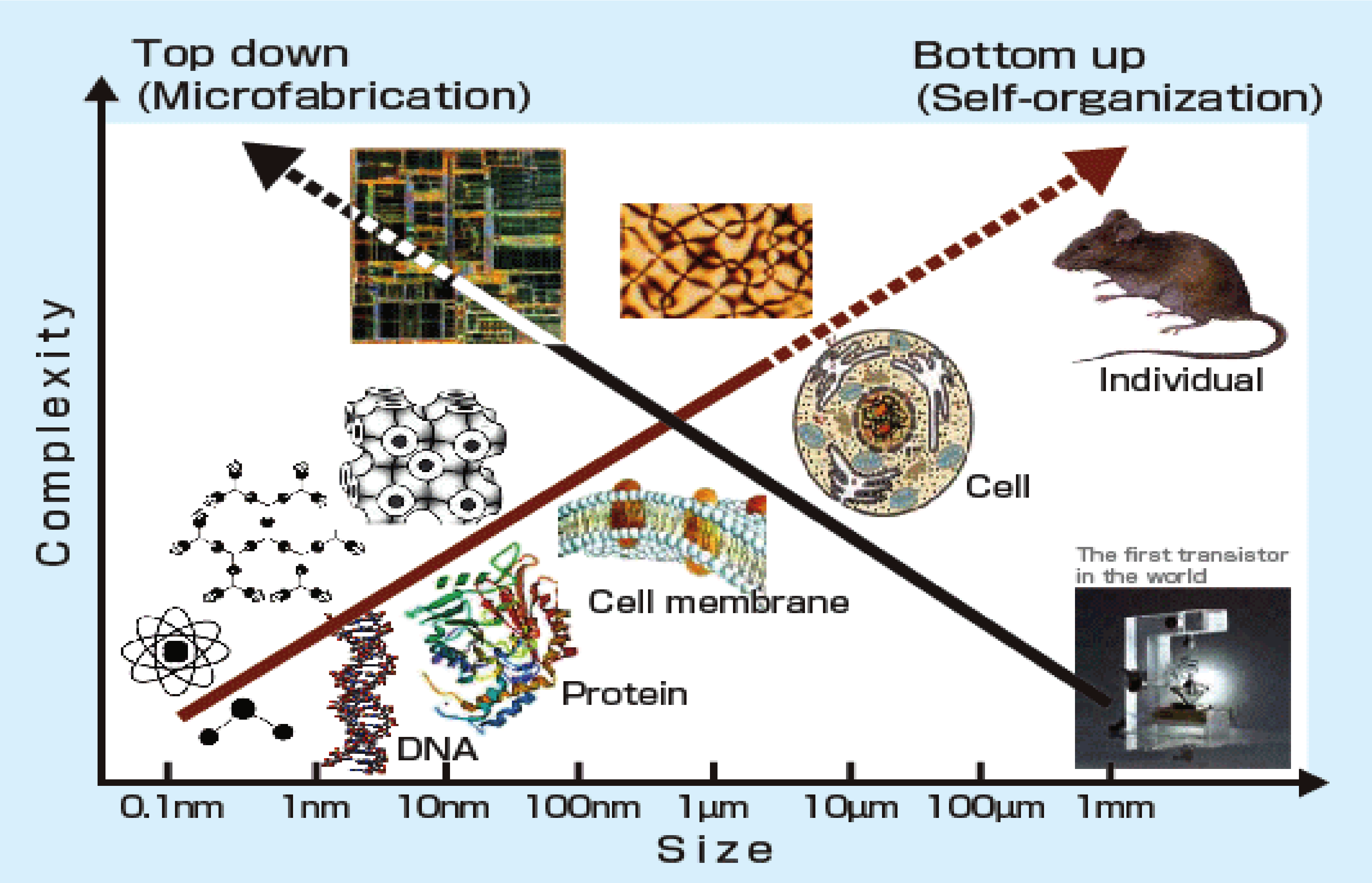
ENERGY

Intersection of Life Sciences & Engineering

- Data and Image analysis
- Genomics, Proteomics, Biomics
- TEM, FE-SEM
- Telemetry
- Bio- Informatics
- Materials for Implants and Prostheses
- Robotics, cognitive, sensory
- Real Time *In vivo* sensors
- Biochips







Top down
(Microfabrication)
Bottom up
(Self-organization)
Complexity
Individual
Cell
Cell membrane
Protein
DNA
The first transistor
in the world
0.1nm
1nm
10nm
100nm
1μm
10μm
100μm
1mm
Size

Indian Reform in Engineering Education (1990-2014)

- **Many engineer graduates are unable to take into consideration economic, societal, and ethical considerations; unable to work in teams. We require to look for remedies.**

- **Increased economic gap between engineering and practitioners of the 'professions'. Also there is very little understanding among the graduates about functioning of the industries & government.**
- **Requirement of new concepts (especially wrong interpretation of Industry-academia connect) for better pedagogical approaches for engineering . This issue requires more focus and better understanding.**

- **'Objectives' and 'Outcome' are deciding parameters :**

- **Six progressive stages of cognitive thinking are:**

(i) Recall, (ii) Comprehension, (iii) Application,

(iv) Analysis (v) Synthesis (vi) Evaluation

- **Cognitive learning is demonstrated by knowledge recall and the intellectual skills: comprehending information, organizing ideas, analyzing and synthesizing data, applying knowledge, choosing among alternatives in problem-solving and evaluating ideas or actions.**

What is **STEM?** For Design to Product Level

- What is **S**cience?
- What is **T**echnology?
- What is **E**ngineering?
- What is **M**athematics?

Scientists
Investigate our natural world

Technologists
Apply science and math to designs

STEM
Working together to solve problems based on societal needs and wants

Mathematicians
Use numbers and symbols to solve problems

Engineers
Create our designed world

How are they all needed to Create a Product?

Example	Science	Technology	Engineering	Math
Pencil 	Discovery of graphite and the fact that rubber (eraser) will remove graphite	Creating a writing device that doesn't use ink	Designing a device with graphite insert, exterior holder, and attached eraser	What is the optimal length, diameter, or shape for the device?

Engineering uses scientific, technological, and mathematical knowledge to solve practical problems.

Science v/s Engineering

- **Science:**
  - Investigation, understanding, and discovery of nature, its composition, and its behavior (i.e., “laws of nature”)
  - Why
  - Build (experiments, tools, devices, etc.) to learn
- **Engineering:**
  - Manipulating the forces of nature to advance humanity
  - How
  - Learn to build (products and services useful for humans)

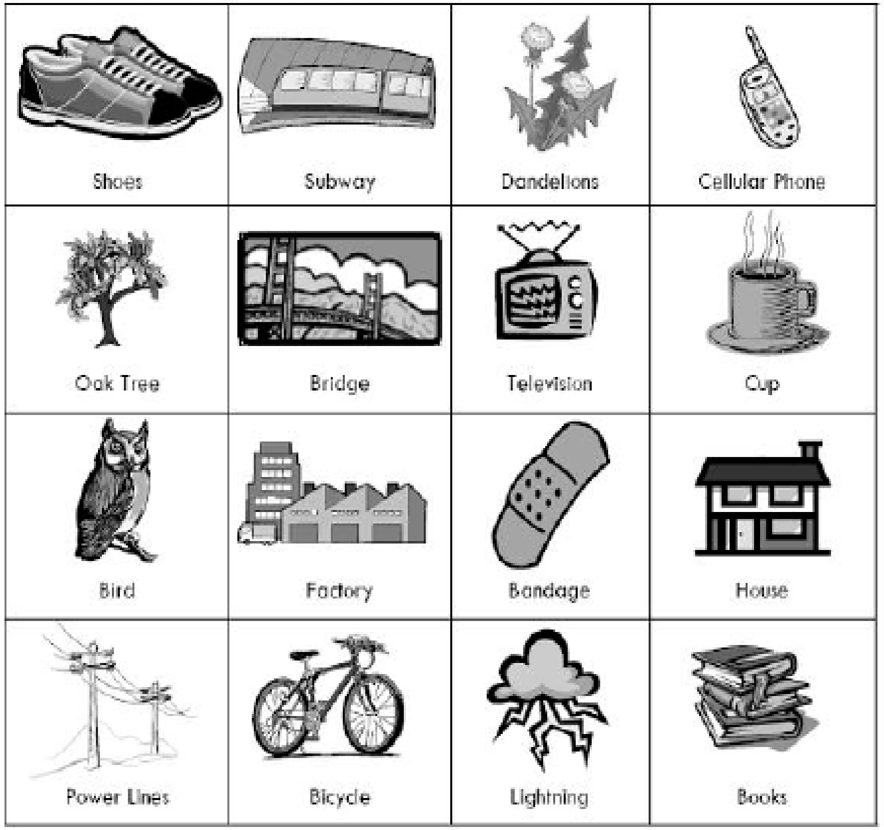
Engineering Misconceptions

What is an Engineer?

What kinds of work do engineers do? Circle the kinds of work that you think engineers do for their jobs.

Which of these things are examples of technology?

How do you know something is technology?



Cont…..Engineering Misconceptions

Plumber

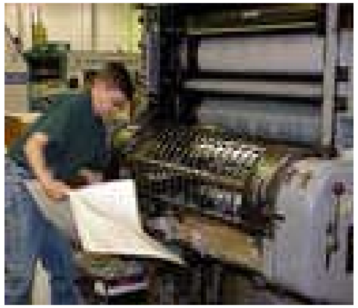
Electrician

Carpenter

Auto Mechanic

Building Supervisor/Handyman

Train Operator



Printing Press Operator

PC Technician

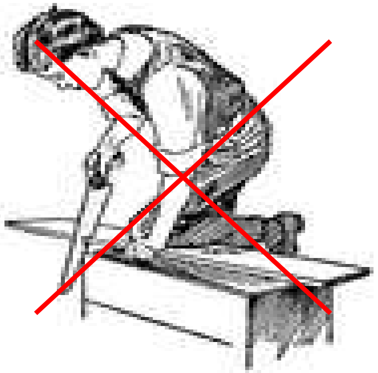
Welder

Machinist

Cont.....Engineering Misconceptions

Plumber

Electrician



Carpenter

Auto Mechanic

Building Supervisor/Handyman

Train Operator

Printing Press Operator

PC Technician

Welder

Machinist

Cont…..Engineering Misconceptions

~~Trade~~

The primary objective of a **business** is to earn profit.

Profession

A form of economic activities, wherein special skills, knowledge, and expertise is required to be applied by the person, in his occupation is known as the **profession**.

Whereas **profession** is aimed at providing services.

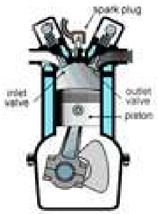
What is Engineering

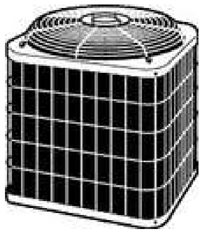
- **Engineering: Latin root, ingeniere, to design or to devise**
- **Engineering is <u>design</u> under constraint**

↓

device, component, subsystem, system such as


Airplane


Engine


Air Conditioner


Heart Valve


Skyscraper


Microcontroller


Prosthetics


Bridge

- *Successful engineering design improves quality of life while working within technical, economic, business, societal, and ethical constraints.*
- **Technology:** *Outcome of engineering*

Identify and Establish the Need

- Engineering design activity always occurs in response to a human need. Before you can develop a problem definition statement for a design problem, you need to recognize the need for a new product, system, or machine.

Thomas Newcomen saw the need for a machine to pump the water from the bottom of coal mines in England. Recognizing this human need provided him the stimulus for designing the first steam engine in 1712.

Before engineers can clearly define a design problem, they must see and understand this need.

Example: Automobile Airbag Inflation - How Not to Solve a Problem

A company that manufactures automobile airbags has a problem with an unacceptably high rate of failure in the inflation of the bag. During testing, 10 percent of the bags do not fully inflate. An engineer is assigned the job of solving the problem. At first the engineer defines the problem as a failure in the materials and construction of the inflation device. The engineer begins to solve this problem by producing a more robust inflation device. After considerable effort, the engineer discovers that improving the inflation device does not change the failure rate in the bags. Eventually, this engineer re-examines the initial definition of the problem. The company investigates the airbag inflation problem further and discovers that a high degree of variability in the tightness of folds is responsible for the failure of some bags to inflate. At the time the bags were folded and packed by people on an assembly line. With a more complete understanding of the need, the engineer redefined the problem as one of increasing the consistency in tightness of the folds in the bags. The final solution to this problem is a machine that automatically folds the bags.

Often the apparent need is not the real need. A common tendency is to begin generating a solution to an apparent problem without understanding the problem. This approach is exactly the wrong way to begin solving a problem such as this. You would be generating solutions to a problem that has never been defined.

Problems That Solve Our Needs and Wants

What are our human needs?

PHYSICAL NEEDS:	BIOLOGICAL NEEDS:	PSYCHOLOGICAL NEEDS:
• Basic shelter	• Water	• Family
• Basic clothing	• Food	• Friends
• Can you think of more?	• Can you think of more?	• Can you think of more?

What are our human wants?

PHYSICAL WANTS:	BIOLOGICAL WANTS:	PSYCHOLOGICAL WANTS:
• Nice house	• Fresh water	• Talk with family
• Nice car	• Fancy food	• See friends
• Nice clothes	• Healthy living	• Entertainment
• Can you think of more?	• Can you think of more?	• Can you think of more?

Cont.…Identify and Establish the Need

Develop a Problem Statement

The first step in the problem-solving process, therefore, is to formulate the problem in clear and unambiguous terms. Defining the problem is not the same as recognizing a need. The problem definition statement results from first identifying a need.

Example the statement *"Design a better mousetrap." This statement is not an adequate problem definition for an engineering design problem. It expresses a vague dissatisfaction with existing mousetraps and therefore establishes a need. An engineer would take this statement of need and conduct further research to identify what was lacking in existing mousetrap designs. After further investigation the engineer may discover that existing mousetraps are inadequate because they don't provide protection from the deadly Hantavirus carried by mice. Therefore, a better mousetrap may be one that is sanitary and does not expose human beings to the Hantavirus. From this need, the problem definition is modified to read, "Design a mousetrap that allows for the sanitary disposal of the trapped mouse, minimizing human exposure to the Hantavirus."*

A Better Mousetrap: Certain rodents such as the common mouse are carriers and transmitters of an often fatal virus, the Hantavirus. Conventional mousetraps expose people to this virus as they handle the trap and dispose of the mouse. Design a mousetrap that allows a person to trap and dispose of a mouse without being exposed to any bacterial or viral agents being carried on the mouse

Establish Criteria for Success

Criteria for success are the specifications a design solution must meet or the attributes it must possess to be considered successful. The following is a list would be included in the problem definition statement.

- The design must be low cost.
- The design should be safe.
- The design should not be detrimental to the environment.
- The design should be simple to operate, with minimum human effort.
- The design should not cause undue pain and suffering for the anyone.
- Is there really a need for a new solution or has the problem already been solved?
- What are the existing solutions to the problem?
- What are the economic factors governing the solution?

Solutions to engineering design problems do not magically appear. Ideas are generated when people are free to take risks and make mistakes. Brainstorming at this stage is often a team effort in which people from different disciplines are involved in generating multiple solutions to the problem.

Generate Multiple Solutions

The next step in the design process begins with creativity in generating new ideas that may solve the problem. Creativity is much more than just a systematic application of rules and theory to solve a technical problem.

- ❖ Psychological research has found no correlation between intelligence and creativity.
- ❖ People are creative because they make a conscious effort to think and act creatively.
- ❖ Everybody has the potential to be creative. Creativity begins with a decision to take risks.
- ❖ Listed below are a few characteristics of creative people. These are not rigid rules to be followed to experience creativity. You can improve your creative ability by choosing to develop these characteristics in yourself.

- · Curiosity and tolerance of the unknown. Creative people have a positive curiosity of the unknown. They are not afraid of what they don't understand.
- · Openness to new experiences. Creative people have a healthy and positive attitude toward new experiences.
- · Willingness to take risks. Creative people are not afraid to take risks and try new experiences or ideas, knowing that they may be misunderstood and criticized by others. They are self-confident and not afraid to fail.
- · Ability to observe details and see the "whole picture." Creative people notice and observe details relating to the problem, but they also can step back and see the bigger picture.
- · No fear of problems. Creative people are not afraid to tackle complex problems, and they even search for problems to solve. They seek solutions to problems with their own abilities and experience if possible. They have the attitude of "if you want something done, you'd better do it yourself."
- · Ability to concentrate and focus on the problem until it's solved. Creative people can set goals and stick to them until they're reached. They focus on a problem and do not give up until the problem is solved. They have persistence and tenacity.

What is Engineering Design?

- **Engineering Design problems are usually more vaguely defined than analysis problems.**

- *Suppose that you are asked to determine the maximum height of a snowball given an initial velocity and release height. This is an analysis problem because it has only one answer.*

If you change the problem statement to read, "Design a device to launch a 1-pound snowball to a height of at least 160 feet," this analysis problem becomes a design problem.

- *The solution to the design problem is a system having specified properties (able to launch a snowball 160 feet), whereas the solution to the analysis problem consisted of the properties of a given system (the height of the snowball).*

- **The solution to a design problem is therefore open ended**, since there are many possible devices that can launch a snowball to a given height. The original problem had a single solution: the maximum height of the snowball, determined from the specified initial conditions.

- **Solving design problems is often an iterative process:** As the solution to a design problem evolves, you find yourself continually refining the design. While implementing the solution to a design problem, you may discover that the solution you've developed is unsafe, too expensive, or will not work.

Cont…What is engineering design?

- ***Engineering design is the set of decision-making processes and activities used determine the form of an object given the functions desired by the customer.***

- ***Engineering design is the process of devising a system, component, or process to meet desired needs.***

- ***It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective.***

- ***Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation.***

For example, the Wright brothers' airplane did not fly perfectly the first time. They began a program for building an airplane by first conducting tests with kites and then gliders. Before attempting powered flight, they solved the essential problems of controlling a plane's motion in rising, descending, and turning. They didn't construct a powered plane until after making more than 700 successful glider flights.

❖ **Design activity is therefore cyclic or iterative in nature, whereas analysis problem solving is primarily sequential.**

Engineers Can Do Anything

Invent – Develop a new product, system, or process that has never existed before

Innovate – Improve an existing technological product, system, or method

Invent

Design Build

Analyze

Orchestrate

Create

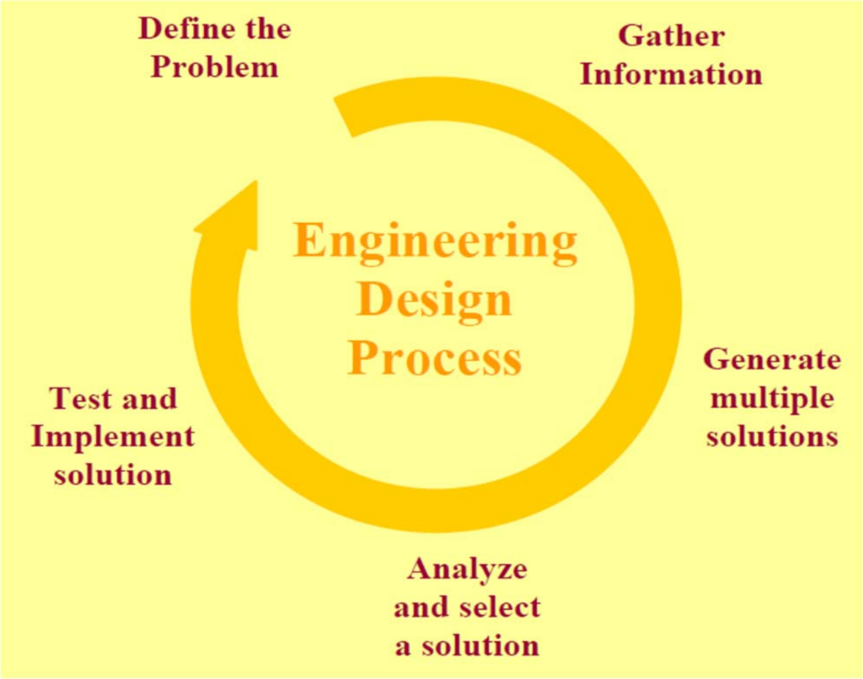
Conceive

Improve Evaluate

THE DESIGN PROCESS

The basic five-step process usually used in a problem-solving works for design problems as well. Since design problems are usually defined more vaguely and have a multitude of correct answers, the process may require backtracking and iteration. Solving a design problem is a contingent process and the solution is subject to unforeseen complications and changes as it develops.

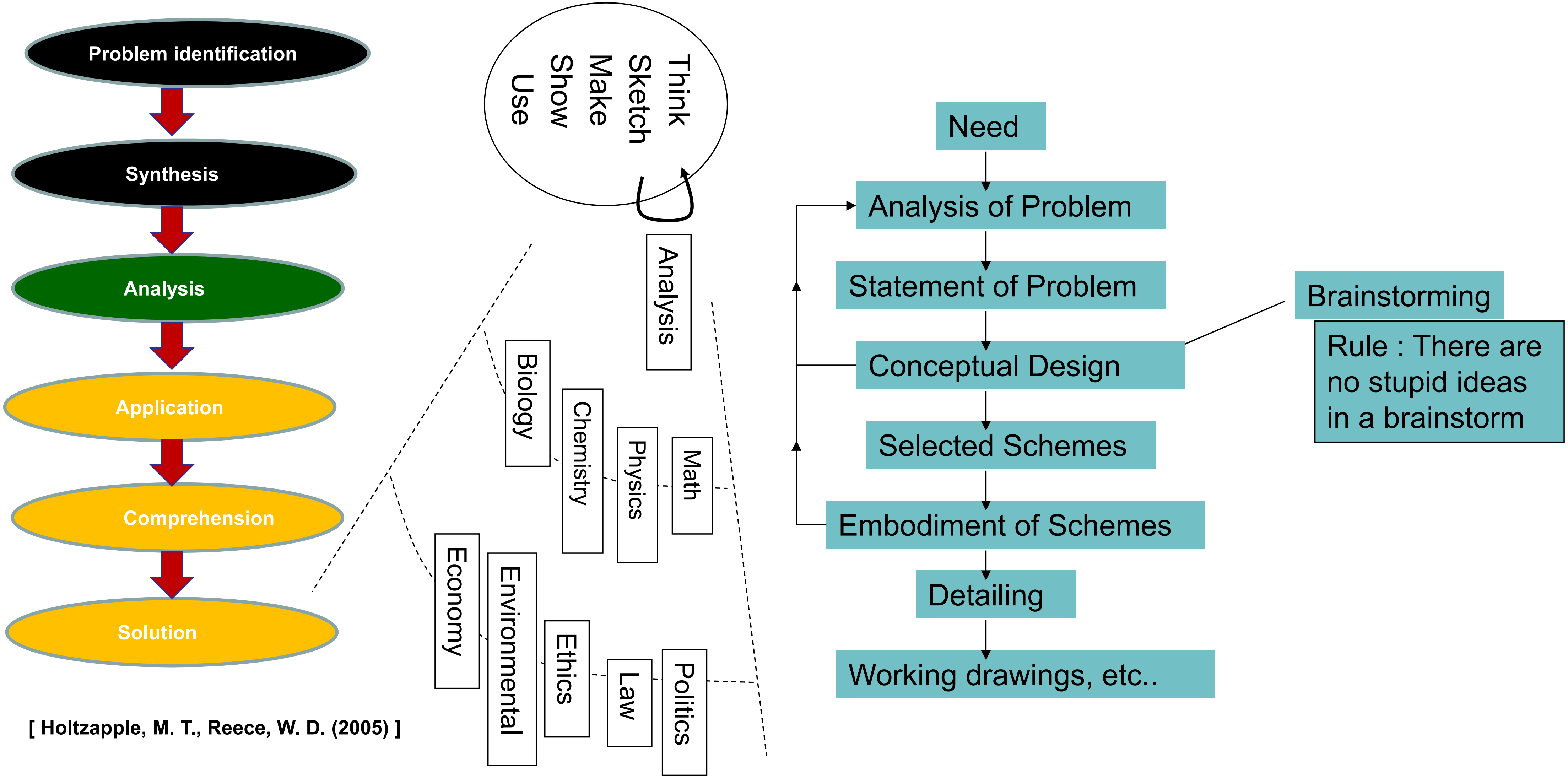
Until the Wright brothers actually built and tested their early gliders, they did not know the problems and difficulties they would face controlling a powered plane.



The five steps used for solving design problems are:

1. Define the problem
2. Gather pertinent information
3. Generate multiple solutions
4. Analyze and select a solution
5. Test and implement the solution

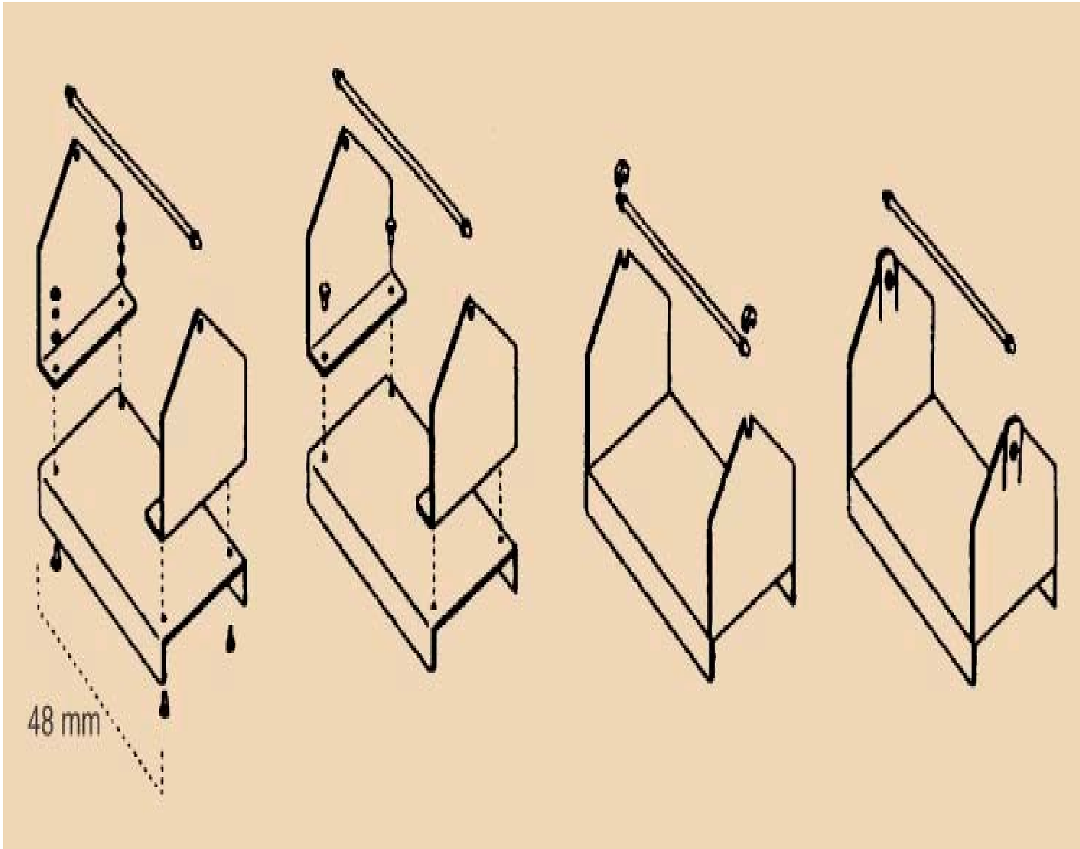
Engineering as Problem Solving



[Holtzapple, M. T., Reece, W. D. (2005)]

Factors Impacting Product Design

- Must **Design for Manufacturing** – **DFM**
- **Guidelines to produce a product easily and profitably**
  - **Simplification - Minimize parts**
  - **Standardization**
    - **Design parts for multiply applications**
  - **Use modular design**
  - **Simplify operations**



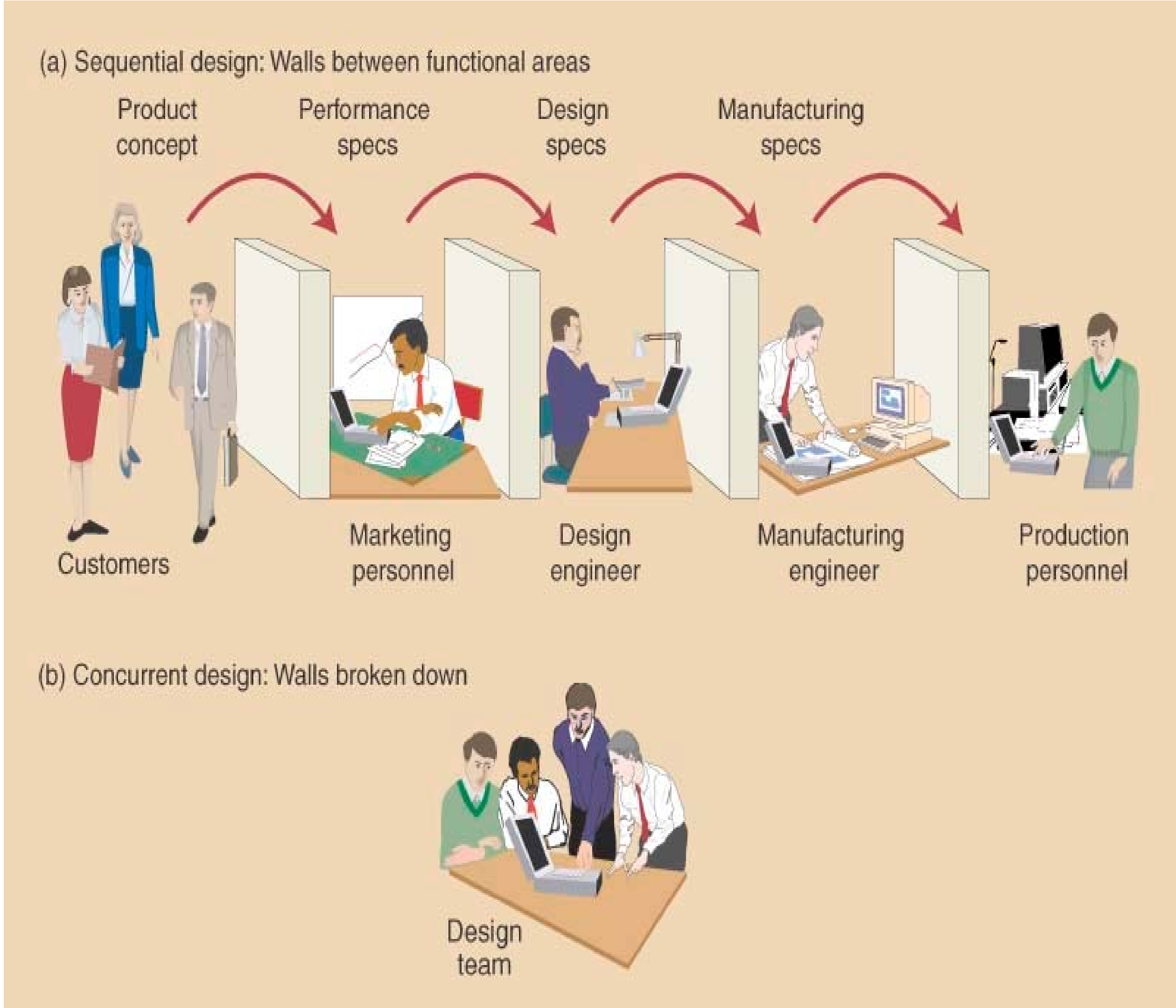
Concurrent Design Engineering

Old "over-the-wall" sequential products design process

- Each function did its work and passed it to the next function

Improved Concurrent Engineering process

- All functions form a design team that develops specifications, involves customers early, solves potential problems, reduces costs, & shortens time to market



Analysis of Design Solutions

Before deciding which design solution to implement, you need to analyze each alternative solution against the selection criteria defined in step I. You should perform several types of analysis on each design. Every design problem is unique and requires different types of analysis. The following is a list of analysis that may need to be considered; bear in mind that the importance of each varies depending on the nature of the problem and the solution.

- Functional analysis
- Industrial design/Ergonomics
- Mechanical/Strength analysis
- Electrical/Electromagnetic
- Manufacturability/Testability
- Product safety and liability
- Economic and market analysis
- Regulatory and Compliance

Test & Implement the Solution

The final phase of the design process is implementation, which refers to the testing, construction, and manufacturing of the solution to the design problem. You must consider several methods of implementation, such as prototyping and concurrent engineering, as well as distinct activities that occur during implementation, such as documenting the design solution and applying for patents.

- *Prototyping*
- *Concurrent Engineering*.
- *Documentation*
- *Applying for Patents*.
- *Testing and Verification*.

Example: Aluminum Can Crusher

Students are being asked to design a simple device to crush aluminum cans. A student design team proposes four solutions to the problem. They develop six criteria that are important to a successful design. The student team agrees that the most important criteria (or desirable attributes) of the design and assigned weights are

- Safety: 30 percent (30 points)
- Ease of use: 20 percent (20 points)
- Portability: 20 percent (20 points)
- Durability and strength:10 percent (10 points)
- Use of standard parts:10 percent (10 points)
- Cost:10 percent (10 points)

This team also proposes four alternative solutions to this problem, which are illustrated in the following Figure. They are

1. A spring-loaded crusher
2. A foot-operated device
3. A gravity-powered dead weight crusher
4. An arm-powered lever arm crusher

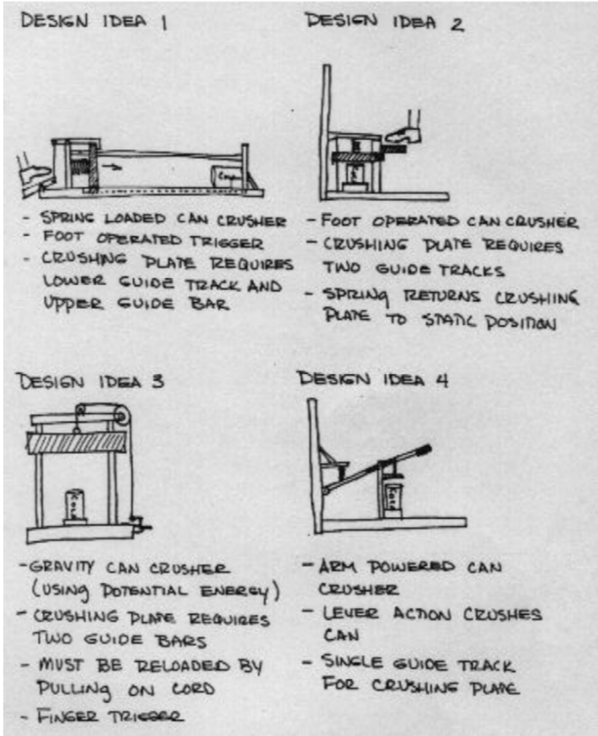


Table Decision matrix for evaluating alternative can crusher designs

Criteria	Weight(%)	Design 1	Design 2	Design 3	Design 4
Safety	30	2	9	2	9
R x Weight		60	270	60	270
Ease of Use	20	8	9	6	9
R x Weight		160	180	120	180
Portability	20	5	3	2	8
R x Weight		100	60	40	160
Durability	10	8	8	6	8
R x Weight		80	80	60	80
Standard Parts	10	7	7	8	8
R x Weight		70	70	80	80
Cost	10	6	5	7	8
R x Weight		60	50	70	80
Total	100	530	710	430	850

Although rating each design against the six stated criteria is subjective, the rating factor for each design alternative is assigned according to the consensus of the design team. The results of an analysis are used to evaluate and rate each design. The rating factor R is assigned according to the following scale:

- Excellent 9-10
- Good 7-8
- Fair 5-6
- Poor 3-4
- Unsatisfactory 0-2

Design 4 was chosen the best design largely due to the rating assigned for safety, criterion l. The team felt that the chances of human injury were negligible for this design. Since safety is the most important factor (30% of the total weight), the high safety rating for design 4 gives it the highest overall score (9 x 30, or 270).

Product Design & Process Selection - Defined

Product design – the process of defining all of the product characteristics

- **Product design must support product manufacturability (the ease with which a product can be made)**
- **Product design defines a product's characteristics of:**
  - **appearance,**
  - **materials,**
  - **dimensions,**
  - **tolerances, and**
  - **performance standards.**

Process Selection – the development of the process necessary to produce the designed product.

Idea development: all products begin with an idea whether from:

- **customers,**
- **competitors or**
- **suppliers**

Reverse engineering: buying a competitor's product

Idea developments selection affects

- **Product quality**
- **Product cost**
- **Customer satisfaction**
- **Overall manufacturability – the ease with which the product can be made**

The Flaw in the Intel Pentium Chip (case study by C. Fleddermann)

- In late 1994 media started reporting flaw in Intel's pentium microprocessor
- It was the chip used in 80% of all personal computers in the world
- Flaws in the integrated circuits of microprocessors are not uncommon (most of these cannot be detected by the user and do not affect operation)
- The 1994 flaw was different. It caused incorrect answers when performing double-precision arithmetic (common operation, easily detectable)

- **Intel response:**

– Acknowledged error but said that defect was insignificant and the vast majority of users would never even notice it

– Chip would be replaced for free only for users who could demonstrate that they needed an unflawed version

- Users found this unsatisfactory
- IBM, a major pentium user, cancelled the sales of all computers using the chip

- After much negative press, and an outcry from Pentium users, Intel agreed to replace the faulty microprocessor with an unflawed version for any customer who asked to have it replaced

- Note: Long before news of the flaw surfaced, Intel was aware of the problem and corrected it on subsequent versions

- But, they continued to sell the flawed chip

- New Intel policy: Flawed chips should be replaced on request, regardless of how insignificant the flaw is

- Public relations problem, with ethical issues

Questions:

– Should flaws always be revealed to customers?

– Is it an ethics problem only if safety is involved?

– What if they added a label “This product may contain unexpected flaws and might not operate correctly under all conditions”. Does this solve the ethical problems for the company?

How can an engineer be sure that there are no defects in a product? Testing! Before/after product release

– If it is impossible to eliminate all defects in a product, what level of defects is acceptable?

– Does this depend on the type of product?

The Steps for Product Design Process

Step 1 - Idea Development - Someone thinks of a need and a product/service design to satisfy it: ***customers, marketing, engineering, competitors, benchmarking, reverse engineering***

Step 2 - Product Screening - Every business needs a formal/structured evaluation process: ***fit with facility and labor skills, size of market, contribution margin, break-even analysis, return on sales***

Step 3 – Preliminary Design and Testing - ***Technical specifications are developed, prototypes built, testing starts***

Step 4 – Final Design - ***Final design based on test results, facility, equipment, material, & labor skills defined, suppliers identified***

Product Screening Tool – Break-Even Analysis

Break-even analysis is a tool used to compute the amount of goods that have to be sold just to cover costs.

Computes the quantity of goods company needs to sell to cover its costs

$$Q_{BE} = F/ (SP - VC)$$

Q_{BE} – Break even quantity

F – Fixed costs

SP – selling price/unit

VC – Variable cost

Break-even analysis also includes calculating

Total cost – sum of fixed and variable cost

$$\textbf{Total cost} = F + (VC)*Q$$

Revenue – amount of money brought in from sales

$$\textbf{Revenue} = (SP) * Q$$

Q = number of units sold

Some Examples of Product Design

Indian cellphone startup called **LAVA** decided to introduce a revolutionary new product. It's a cell phone with a **full QWERTY keyboard** – with one **"minor"** difference. In an attempt to innovate they did away with the keyboard layout

The LAVA B5 could have been a big hit, but we'll never know. It flopped miserably. Apparently people didn't want to relearn everything they knew about typing just to use their new cellphone.

Smart Phones

A **smartphone** (or **smart phone**) is a mobile phone with an advanced mobile operating system. They typically combine the features of a cell phone with those of other popular mobile devices, such as personal digital assistant (PDA), media player and GPS navigation unit. Most smartphones have a touchscreen user interface, can run third-party apps and are camera phone

Good Examples of Design

AnglePoise is a balanced-arm lamp designed in 1932 by British designer C. George.

The joints and spring tension allow the lamp to be moved into a wide range of positions which it will maintain without being clamped.

Successful Design Elements

- **Cognition**-Expectations of the user
- **Ergonomics**-human factors usage of device
- **Utility**-ease of use
- **Image**-user’s perception and its operation
- **Ownership-**level of commitment

Avoid some common pitfalls about engineering design

- Don’t deviate from expected behavior unless strictly necessary. This will only lead to confusing your users.

- Test your products in a real-life situation before you take it to production.

- More eyes are better. Sometimes other people will see things just because they aren’t as deeply involved in the design process. Utilize fresh eyes.

- Customers are sensitive. A product might perform as advertised, but nobody will buy it if the product offends them

Reverse Engineering (J. Wallberg)

- While working at a large information technology company over the past two summers, I have been involved with the hard disk drive group of the semiconductor division. One of the products that this group designs is the read channel chip. This chip communicates between the computer and the disk. This is a very competitive area in the semiconductor business, because the demand for computer performance has increased (and continues to increase) exponentially over the past decade. One common practice that I have heard discussed more than once is to use reverse engineering to see what the competitors are doing. …

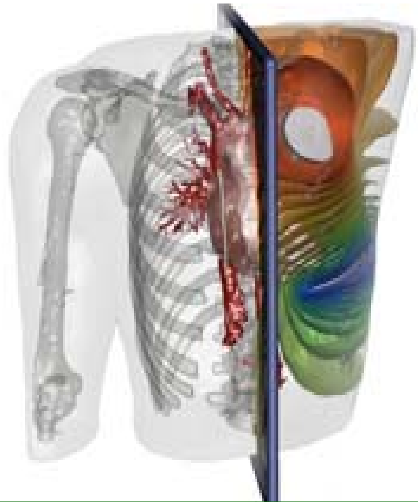
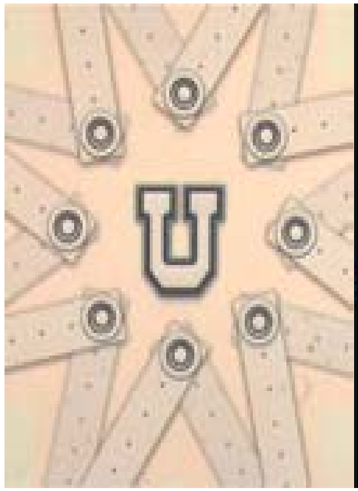
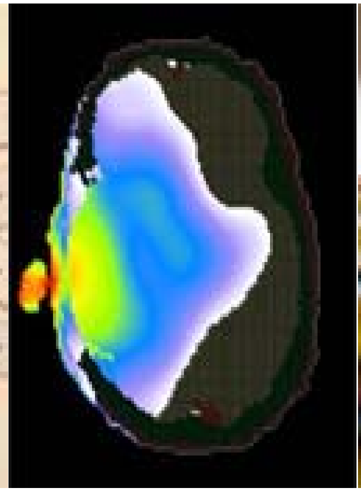
- This involves taking a microscopic picture of the chip as it is laid out in silicon, and try to work backwards to the transistor and system levels. The accuracy and amount of information that can be deduced varies, but it is certainly possible to obtain system level designs

- Question: Is such reverse engineering of competitor’s products ethical?

What is Electrical Engineering ?

Electrical Engineers are inventors and innovators who apply knowledge of signals, circuits, physics, and systems to develop technologies to improve people's lives




Electrical Engineering: Bridging the Gap Among Disciplines in the 21st Century

WHAT DO ELECTRICAL ENGINEERS DO?

❖ Develop the technologies which allow people to communicate with each other and access information from wherever and whenever.

❖ Collaborations with: CS, Math

❖ Develop the technologies which will enable us to generate and distribute power from renewable resources and become energy independent.

❖ Collaborations with: MechE

WHAT DO ELECTRICAL ENGINEERS DO?

- ❖ Develop the technologies for affordable, clean, efficient solar power generation

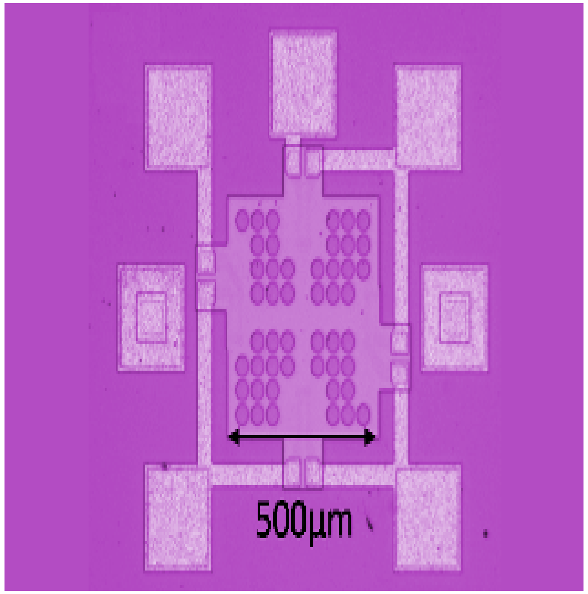
- ❖ Collaborations with: Material Science

Motors & Generators

Motor

Generator

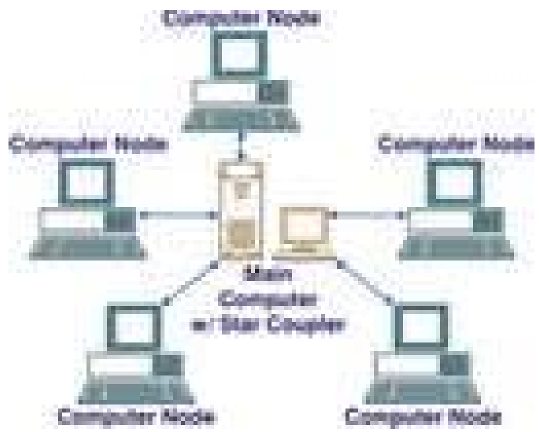
Electricity



WHAT DO ELECTRICAL ENGINEERS DO?

Develop new technologies that make sensors smaller, better, and make systems more reliable and energy efficient

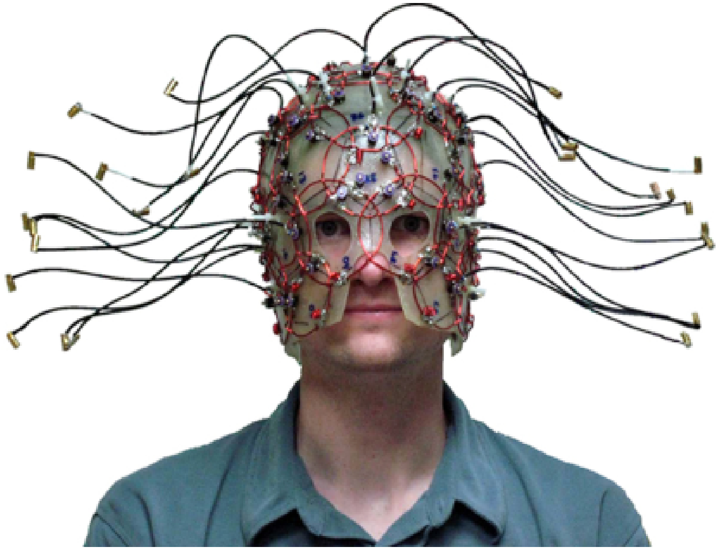
Electrical & Electronic Circuits

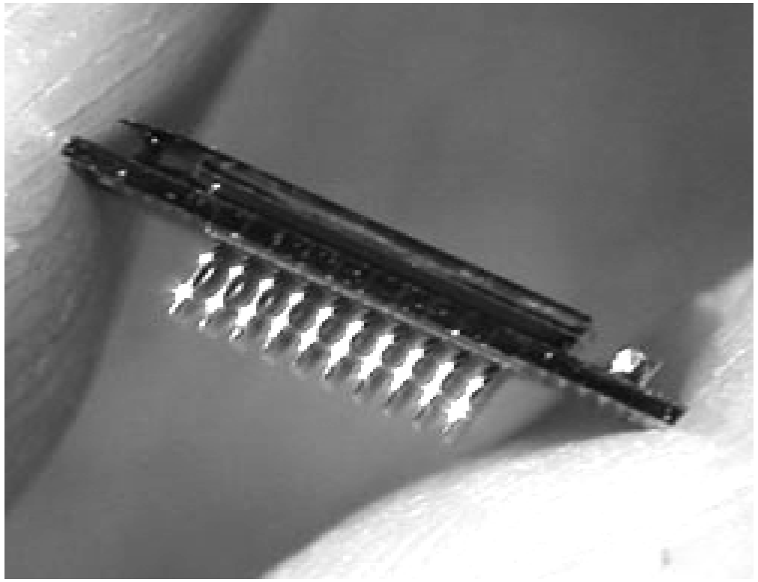


Network

Collaborations with: Many

WHAT DO ELECTRICAL ENGINEERS DO?





Develop the technologies to improve medical care:
Advances in biosensors, prosthetics, and imaging

Collaborations with:
Bioengineering, Medicine

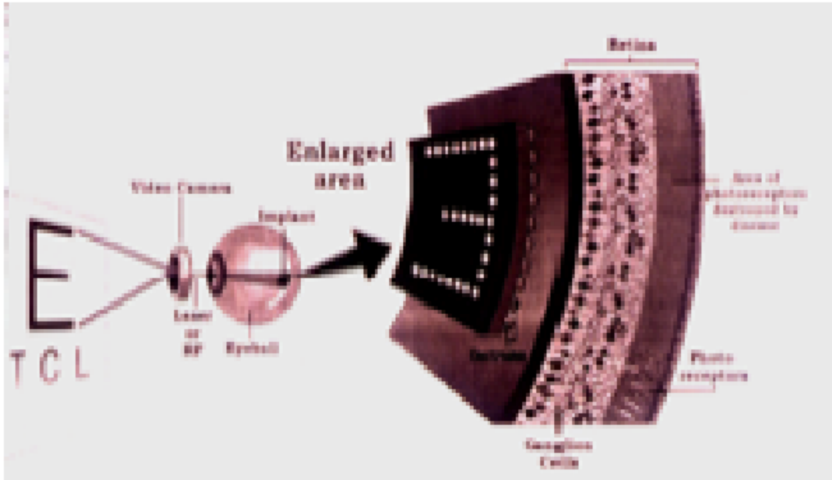
Oscilloscope

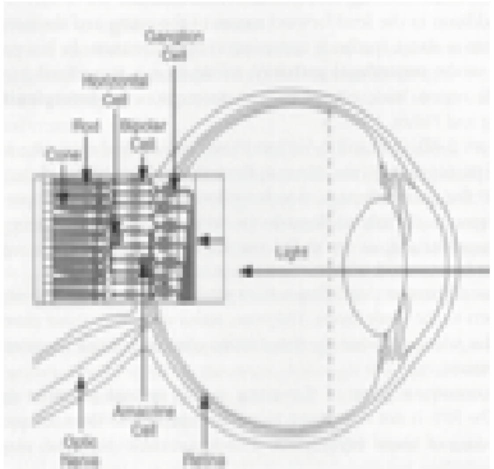
Measurement

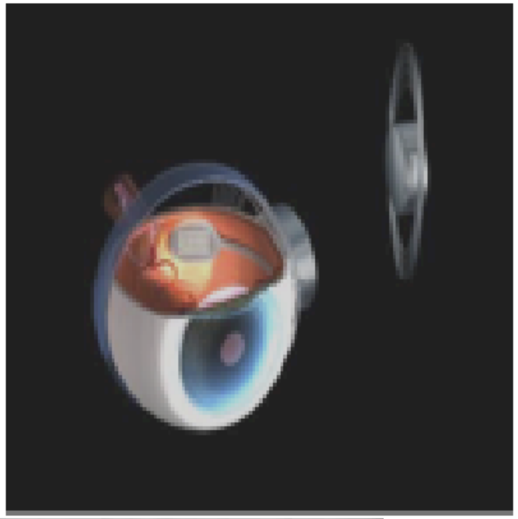
WHAT DO ELECTRICAL ENGINEERS DO?

Artificial Retina: Restore sight to the blind

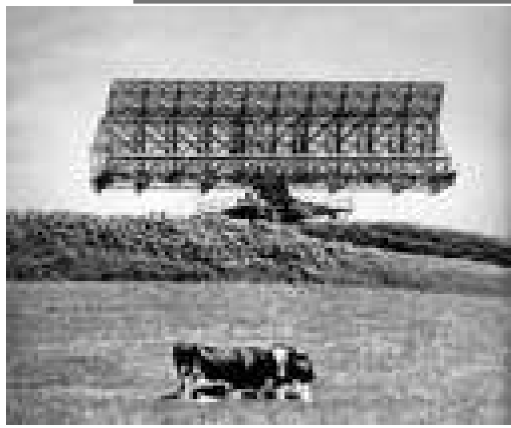
Image data from an external camera is wirelessly transmitted to the implant which stimulates electrodes in an array on the retina to produce formed vision.







Radar



Thank you