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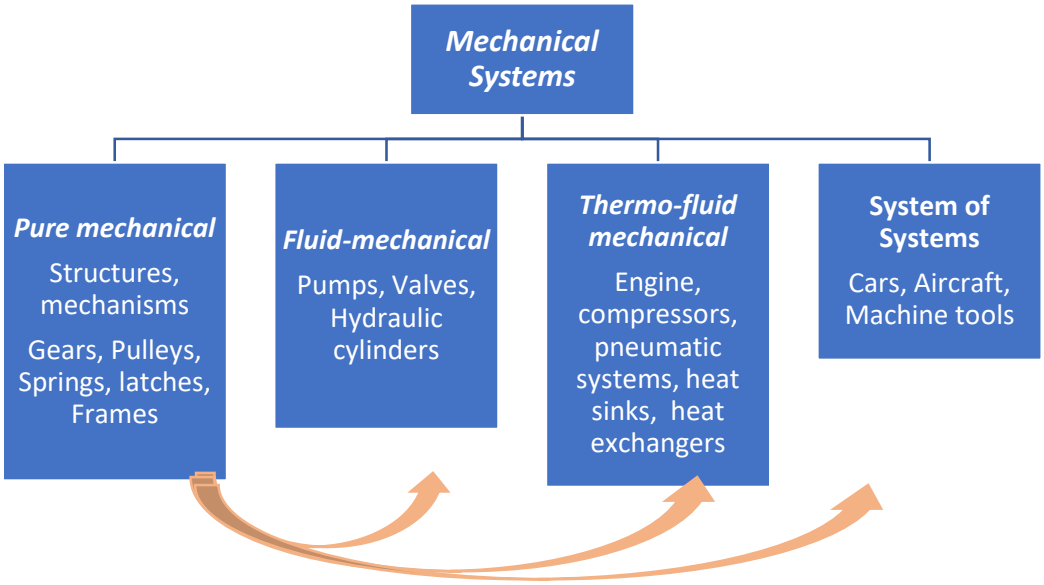
A Self - Learning guide for the Design engineer to build competency in product design and development

Purpose:

To guide design engineers on a self-learning path towards competency in Mechanical design engineering and product development.

It is based on a top down approach of arriving at solutions from the design problem posed.

Types of Mechanical Systems:



Learning Guide

1. **Foundations**
2. **Core skills of Mechanical design**
3. **Machine Design**
4. **Engineering Analysis**
5. **Detail Design**

Foundations

- **Basic Math**
  - Strong Math fundamentals are mandatory for mechanical engineering
  - Designing mechanisms, structures requires understanding of geometry, algebra , vectors , calculus at the most basic level
  - *How to learn? Standard textbooks at High school and college level, Khan Academy.*

- **Physics**
  - Mechanical engineering is applied physics and hence a strong hold on concepts of mechanics, thermodynamics and fluid mechanics are based in strong understanding of physics of the phenomenon.
  - Mechanics is the central theme of mechanical design of structures and mechanism
  - *How to learn? Standard textbooks, Khan Academy, YouTube videos.*

- **Chemistry**
  - Mechanical design requires understanding of material sciences to use appropriate materials in applications.
  - Chemistry is a big part of Material science whether it be for metals or plastics.
  - *How to learn? Standard textbooks at High school and college level, YouTube videos.*

- **Problem solving attitude and aptitude**
  - Engineers solve problems and hence building a natural tendency for solving problems is essential
  - Solving problems based in basic sciences or problems in general logical reasoning, verbal reasoning, quantitative aptitude, qualitative aptitude
  - Developing a good **"common sense"** in solving mechanical problems is a big plus
  - *How to learn? Practice solving logic-based problems.*

- **Problem formulation for Engineering design problems**
  - It is the process of determining the constituent of a problem: its important factors and variables, and the interrelationships between them

- Problem formulation is one of the most important first step in solving a mechanical design problem.
- Converting a real life problem in to an engineering problem which can be solved using principles of engineering and math.
- Studying the problem space and understanding requirements and constraints.
- *How to learn? Deliberate practice - Continuous practice of solving design problems**.***

- **Understand the nature of physical product design**
  - Understanding shapes, proportions, structures and how things work at a general level.
  - *Learning Resource: "Design of everyday things" by "Donald Norman" is a very good book to get started.*

- **Awareness and knowledge of product design and development process**
  - Learn why mechanical engineering knowledge matters in the big picture and where do engineers fit in manufacturing organizations
  - Learn the stages of product development – concept development, prototyping, detail design, production
  - Learn the nature of mechanical design and a generic idea of how to go about designing a mechanical product.
  - *Learning Resource : Product Design and Development - Karl Ulrich and Steven Eppinger*

- **Physical practical orientation , hands-on practice**
  - Engineering is a very practical profession. Learning how things work physically is very important to design efficiently.
  - Knowledge and experience to be built in
    - How things assemble?
    - How are things made? Good source – YouTube videos
    - How things work?
  - Ways to develop this competency
    - Make projects, get hands dirty and build projects, there is no better way to learn these skills.
    - Visit the nearest workshop , factory, mechanic, carpenter
    - Observe how they work, ask questions and learn.
    - Watch YouTube videos of "How it's made"

- **Idea and Concept generation – Original thinking**
  - Mechanical design is a creative profession and hence requires the engineer to develop original ideas to solve problems
  - *Good ideas are developed through practice and actively looking of different creative approaches*

Core Skill set for mechanical Design

- **CAD skill**
  - CAD has become an essential skill for any engineer developing products.
  - It is a tool to visualize ideas in your head
  - A tool to generate the 3D virtual prototype which will be used all along the product life from concept to implementation.
  - Capability to design industrial machine geometry in 3D and 2D is essential for a design engineer.
  - Practice, practice and more practice start with simple and slowly move towards complex.
  - Concentrate on learning about **design workflows** and applying them to projects.
  - *Built through deliberate practice*

- **Engineering mechanics basic knowledge** – **Static and Dynamics**
  - The primary analysis which any engineer will do when tasked with a design problem is make a layout of the parts and calculate the static forces acting on it.
  - Making Free body diagrams as a skill is very important..
  - Basic Concepts of dynamics to calculate torques and forces and their effects.
  - Concepts of centre of gravity and moment of inertia.
  - *Learning Source: Engineering Mechanics – Hibbeler, Vector mechanics – Beer and Johnston, other text books, NPTEL.*

- **Strength of materials Principles**
  - Probably the most important area of study in mechanical engineering for design of structures.

- Evaluating structures for their strength and stiffness whether they are beams, rods, shafts or Vessels in tension, compression torsion and bending.
- Finding Principal stresses for elements in a mechanical system
- *Learning source: Strength of Materials - Timoshenko , Mechanics of materials – Beer and Johnston, NPTEL*
- *Online course: Basics of Mechanics of Materials of Machine design*

- **Materials and Manufacturing process knowledge and selection**
  - Material properties and how they affect the design. Knowledge of various materials and their criteria for selection.
  - One of the most important set of knowledge which sets the feasibility of ideas you develop during the process of mechanical design.
  - Know what the possibilities of design are. Learn about Sheet metal forming, injection moulding, CNC machining, Casting.
  - Knowledge of manufacturing processes is needed to practice DFMA.
  - *Learning Source : Manufacturing Engineering and technology - - Serope Kalpakjian, Stephen Schmidt, other textbooks on manufacturing engineering*
  - Material properties and how they affect the design. Knowledge of various materials and their criteria for selection.
  - Selection of apt material for the usage.
  - *Learning Source : Materials selection in Mechanical design- Ashby , other similar textbooks*

- **Basics of Fluid mechanics and Thermodynamics**
  - For Pure mechanical design which involves structures and mechanisms usage of fluid mechanics and thermodynamics except for the case of understanding Thermal stresses is minimal
  - Both the fields are very important when fluids, gases and extreme temperatures are involved.
  - Understanding the nature of Fluid flow, heat transfer and Energy conversion are key concepts
  - *Learning Source : Standard engineering textbooks*

Machine Design

- **Generic Machine element design for strength**
  - Designing loaded elements, building on concepts of strength of materials
  - Understanding of Theories of Failure and application to problems for various loaded elements
  - *Learning Source : Shigley's Mechanical Engineering Design*
  - Design for Fatigue and Endurance
    - Finding the Endurance strength for the element in applications.

- **Specific Machine component Design and selection**
  - Knowledge of design of standard components is important in products which have multiple mechanisms.
  - Design selection of Gears, springs, bearings, pulleys, drive systems, motors.
  - *Learning Source : Shigley's Mechanical Engineering Design*

- **Structural Design**
  - Practical skill developed by doing projects in design of structures and analysing them for stiffness and strength at the elementary level
  - Requires knowledge of existing structural designs to develop original ideas.
  - Developing knack to design structural concepts which are inherently strong and package them for the application.
  - *Developed through deliberate practice*

- **Mechanism Design - Synthesis and Basic Motion/ Force analysis**
  - Coming up with the mechanism geometry and analysing its forces and motion for a specific application
  - Developing knack to design mechanism concepts which are functional and package them for the application.
  - *Learning Source for Theory : : Theory of machines – Rattan, Theory of machines – Shigley*
  - *Developed through deliberate practice*

Engineering Analysis

- **Engineering Math** –
  - Advanced Calculus, Linear Algebra, Differential equations, Numerical analysis as they are used in mathematical modelling of systems.

- **Finite Element Method–**
  - Knowing The theoretical basis of computational simulation of physical phenomena is important for understanding and processing simulation results
  - Understanding of concepts of Discretization, meshing, solving and post processing.

- **Practical FEA analysis for structural and vibration analysis ***
  - Getting comfortable with practical usage of FEA to solve structural design problems is a key skill and extension of structural design.
  - Includes appropriate application of Boundary and loading conditions for various applications.
  - Linear and Non-linear analysis.

- **Mathematical modelling of systems - programming**
  - Developing mathematical models which represent mechanical systems and then analysing them for various outputs
  - From Excel sheet programs to programs in MATLAB / C /Python
  - Lumped parameter modelling of mechanical systems.
  - Problems in structural analysis, mechanism analysis, Vibration analysis, system analysis generally require such mathematical models.

Detail Design

- **Prototyping , Design for prototyping**
  - Methods of prototyping and making a representation of a feature of product- 3D printing, sheet metal fabrication machining.
  - Planning and executing the prototyping strategy
  - Designing especially for prototyping is activity done to adapt designs which are planned for production to be prototyped cheaply and effectively to simulate function.

- **Testing, measurement and metrology:**
  - Testing prototype to evaluate function or any of the parameters from durability to usability
  - Designing testing methods for checking various aspects of function
  - Understanding the measurement equipment and instrumentation used for various test outputs is a key knowledge set in this area.
  - Testing methodologies and approaches
  - Example: Strain gauges, Force measurements, Distance measurements etc.

- **Engineering Drawing and documentation**
  - 2D drafting , generating views and visualization of 3D on 2D
  - Basic understanding of how parts fit with each other and what are the different types of fits?
  - GD&T application - For making communicative engineering drawings which show design intent and guide to manufacturer and inspector using the GD&T symbols and controls.
  - Inspection methods and metrology
  - Creating Bill of materials and Engineering design release management.

- **Tolerance stack up analysis**
  - Impact of gathered variations of parts in an assembly. Very important for mass production of multi-part assembly.
  - Understanding assembly shifts and finding worst case gaps or interference.

- **Design for manufacturing and Assembly**
  - Designing details of the product such that they are easy to manufacture and assemble. Very important activity and skillset
  - Sheet metal design
  - Design with Plastics
  - *Learned through deliberate practice while developing different types of products*

- **Design for X**
  - **Cost and Weight –** The most important attributes of the product which have to be controlled through the design process
  - **Durability** – Considerations for product to last long things like environmental protection, fatigue life, looseness of parts, resistant to impacts etc.

- **Safety** – Considerations for the product to have fall back mechanisms for safety
- **Reliability** - the quality of being trustworthy or of performing consistently well.
- **Usability** - the degree to which something is able or fit to be used.
- **Ergonomics** - Ergonomics is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system
- Each of these can possibly be a separate field of study**.** depending on the project requirements
- *Learned through deliberate practice while developing different types of products*

Additional topics

- **Systems Engineering**
  - Breaking down mechanical systems into sub systems.

- **Mechatronics- Basic Electrical & Electronics engineering and practice :**
  - With the increasing electrification of mechanical systems it's no wonder that knowledge and skills related to electrical engineering would be an important value-add.
  - Electrical machines and their control
  - Data acquisition , sensors and actuators
- **Quality function deployment**
  - Tool to transform the voice of the customer into engineering characteristics for a product
- **Root cause Analysis and investigation**
  - Concern resolution is a big part of problem solving in design engineering
  - Fishbone diagrams

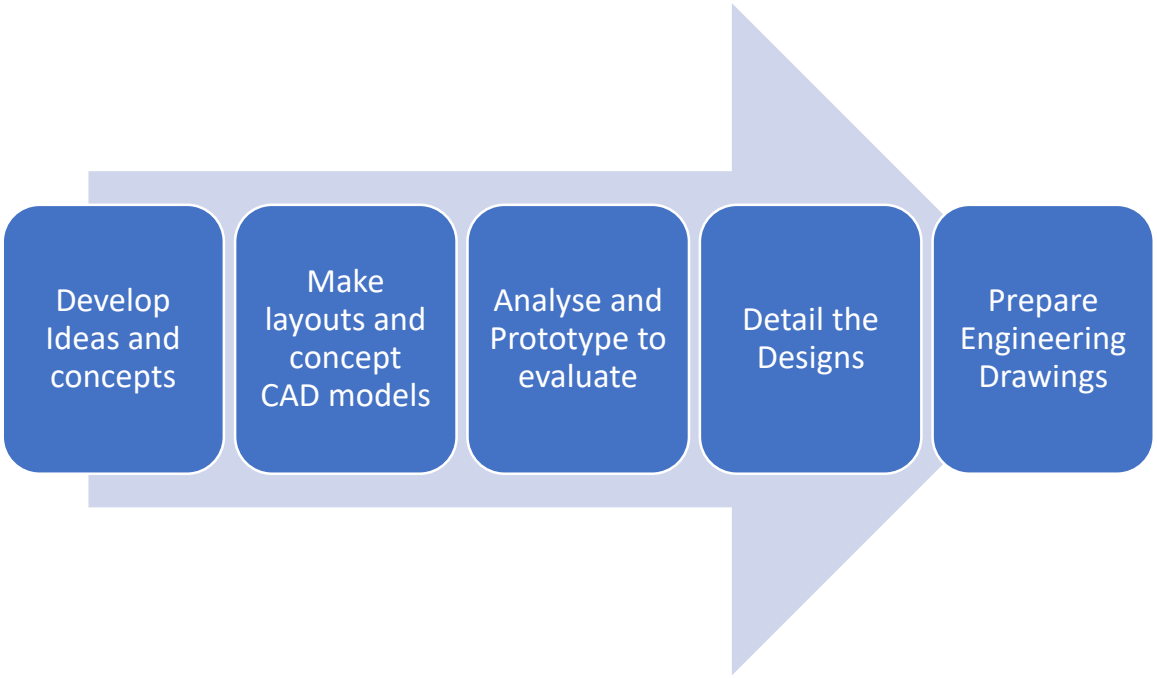
- **Design failure mode effect analysis**
  - Highly structured, systematic techniques for failure analysis, predicting failure and remedying them.

- **Advanced design concepts - Modular design**
  - An advanced and highly creative based concept of making modules of the assemblies such that they are interchangeable.

- **Design of Experiments & Design optimization techniques**

- **Design of experiments** (DOE) is a systematic method to determine the relationship between factors affecting a process and the output of that process
- Used extensively for research, design engineers use it to understand a problem which is not well known about.
- Optimizing designs for Weight, cost and function with respect to mathematical techniques and creative skills.

Simplified workflow of generic design process



Keep in mind, mechanical design is a very huge and varied field and its always a continuous learning process, so no amount of curriculum can cover creativity and detail in engineering design.

All the above topics are relating to **pure mechanical system design** with minimal use of electronics.

Summarised skillset

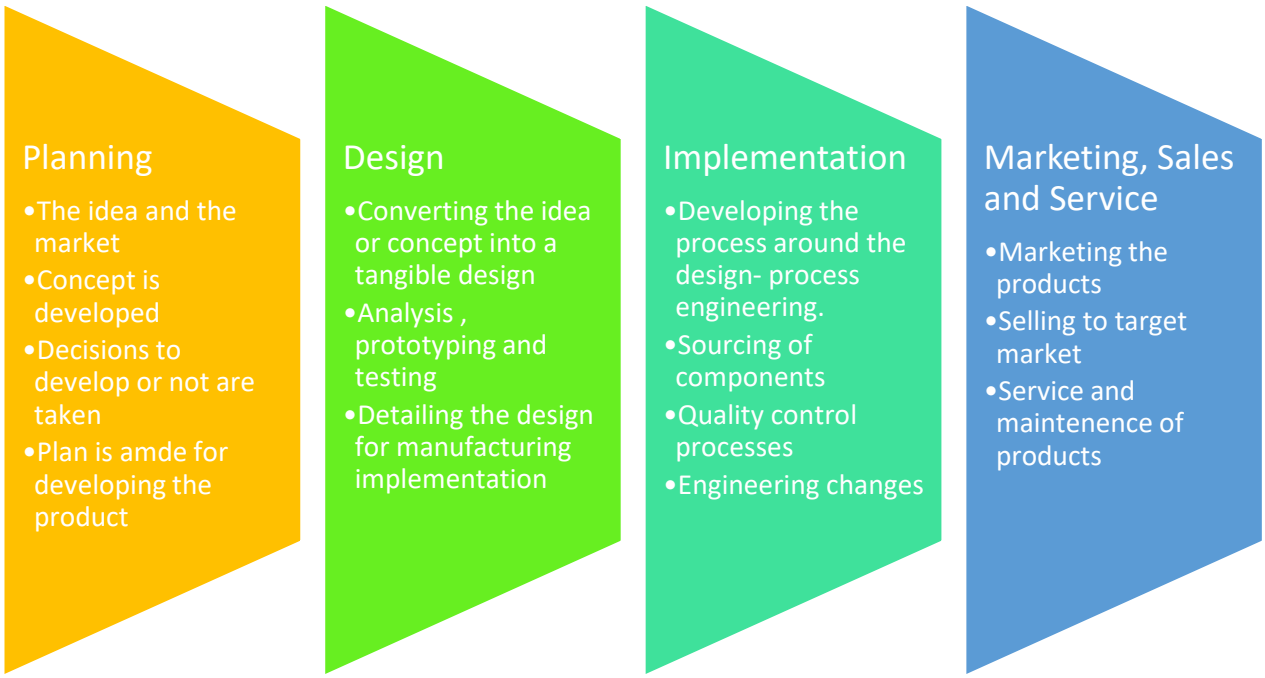
1. Concept generation and development – To create ideas
2. CAD- to visualize and work on them
3. Basic engineering calculations – To analyse and optimize

4. Prototyping – To test in reality
5. DFMA- To detail and make them feasible
6. Engineering drawing and documentation– Convey to the manufacturing team and productionize/implement.

A set of Guiding principles which to follow when solving a design problem.

- Ask the right questions which are related to the product you are designing.
- Be objective in approach. Always make decisions based on data unless data is not accessible.
- Building a mechanical product which is reliable safe, durable requires a lot of perseverance and patience.
- Generate a curious mindset, always keep learning. The more you learn the better you design.
- Don’t get trapped in the idea that Analysis or calculations are enough to design. They are just one part of it
- While generating Ideas do not evaluate them. Generate first Evaluate next.
- Be open minded to suggestions and do not keep your idea too close to your heart. Let go of ego.
- Love assembling, dismantling stuff to learn about the inner workings. This will improve your creative idea generation capability.
- The more you know the better your ideas are.
- Always have a structured way to solve a technical problem.
- Do not analyse just for the sake of it, analyse with outcome in mind. It will confuse your decision process.
- Always compare and take decisions never take decisions on gut feelings if you have a possibility to compare.
- Give priority to design outcomes. Durability is important or performance? Usability is more important than durability? Each product has different questions.
- Document learnings from each activity will always be useful in future stages of product development.

How a product gets developed in an organization?



Why understanding product development is very important for design engineers?

Design is not a one off work, it starts from conceptualization of product to final implementation. So knowing the whole lifecycle is critical for delivery of work.

To basically understand their role in overall product development.

By understanding the role played in the big picture the engineer can understand the value of his/her knowledge and skills and how it translates to business for the organization.

Also in most companies the product development process is nothing but the way people work and knowing the system is important in understanding their responsibilities and accountability towards the team.

What skills does the Industry require from Design engineers?

- To conceptualize and create new products to cater to business opportunities
- To improve existing products make them better than the competition
- To help solve issues in existing products

To accomplish these tasks Design engineers need to have the skills and knowledge mentioned in the learning guide.
Ability to conceptualize, Design, analyse and test the designs & implement in a cost effective manner.

Why Project experience and working hands on is best form of learning?

Mechanical design is a highly practical and varied profession. No two problems solved are the same and hence design approaches, creative ideas and understanding of practical limitations can be very different for different situations. Knowing what to use when and what to analyse? By how much? , it is a skill developed through practice.

Design engineering is not only being good at creating CAD models which are complex. Neither is it only about doing long winded calculations on a specific analytical study. But it’s the whole package. That holistic mind-set and aptitude is built through going through the activity of actually doing the project or developing a product. The challenges faced, the issues which arise and the creative problem solving carried out are always unique for each problem.

The more varied problems you solve the more these skill and knowledge set will develop implicitly.

Difference between industrial designers and design engineer?

Often Industrial design is confused with design engineering. Below is a comparison of two roles in an automotive product development setup.

Automotive Industrial designer	**Automotive design engineer**
Designs the aesthetics features, look and feel of the car – Interiors and exteriors. The style of the car, the fabric of the seats and trims.	Design and engineering the systems and components of the automobile.
Don't worry about the detailed function only about superficial function , form and how it will be experienced by the customer	Work on the functional aspect and work on how the design will be reliable and functional to the customer.
Works with market research team and product planning team to establish the style of cars.	Works with the manufacturing team to establish the production ready design
Their outputs are transferred to the engineering team	Their outputs are transferred to the manufacturing and testing teams
Their designs do not require extensive testing, they are validated visually and by look and feel	Engineered designs need to be extensively validated in test rigs and actual testing condition s to ensure durability.

What activities do Design engineers do?

- Concept generation – Making concepts on paper in sketches or in CAD.
- CAD modelling and management
- Engineering analysis calculations
- 2D drafting and creating drawings
- Attending to products undergoing testing in lab
- Brainstorming on finding solution to issues on product
- Studying and learning about concepts, refining fundamentals, learning about products
- Engineering Design release for production
- Preparing FMEA and arranging team meetings to discuss failure modes and remedies.
- Design reviews to review the designs and improve them.

Why curiosity, open mindedness and learning mind-set are important for mechanical design?

Because mechanical design is a highly creative profession. Being curious and having a lifelong learning mind-set are very important to keep growing in the career.

It is always "the more you know the better

General observations through experience

- Develop Spatial and 3D visualization skills. Almost all mechanical engineers need them. They are basically understanding of 3D space in your mind and help in imagination of how things assemble and how things occupy space.
- Basics in engineering should not be avoided for software or application knowledge. You can design many things from first principles using basic engineering principles. Being application focused makes you a non-versatile and rigid engineer.
- Develop research skills. These include searching for relavent information from the relevant sources. As a mechanical engineer you will be overwhelmed by the huge ocean of information which you should know but knowing which is the most important and pursuing it can save you lot of time.
- Basic Math is extremely important whether you are in core R&D type role or not. Be it algebra, Trigonometry, analytical geometry, Sets, Matrices. If you have lost touch get updated. Some really god ways are through Khan Academy, Udemy courses.
- Build a persevering and patient mindset. Most of the returns you get (in terms of product or project success) will not be immediate and there will be many failures (whether they are in your control or not) . Being patient and learning from failures is very important.
- Learn to separate Design and analysis. Design is deciding shape, form, function, and configuration and taking decisions. Analysis is the calculations and testing part.
- Look things from Top down. If you are in a team developing a product. Don’t just be aware of what knowledge and skills you need

to perform job, rather look at how the work you do impacts the larger organization. Know your value. A small change in a productionized part (a weight reduction) can save millions for an organization. Be aware of the impact you create.

- Always keep learning. If you are designing stuff. Knowledge of the things which the design interacts with will always help you design better. Even otherwise don't stop absorbing interesting things
- Social and Communication skills are important. Being humble, respectful and listening is very important to work in teams. Respect others achievement. While communicating convey your ideas in a crisp and clear manner. Be assertive and share ideas, views opinions.
- Be Open minded to learn stuff about other disciplines. Most products nowadays require multi-disciplinary knowledge. Having a strong base in mechanical engineering and knowing electronics, computer programming can enhance your ideas and concepts greatly.
- Understand manufacturing process not only how they work but also their limitations, possibilities and their comparative advantages.

R&D role and project role?

R&D roles don't have stringent timelines and require much more amount of study and experimentation whereas Project roles are highly deliverable driven. Require the design teams to deliver solutions to compete in the market.

Example: Design engineering in space vehicle design will not be the same as design engineering in automotive design where competition is fierce.