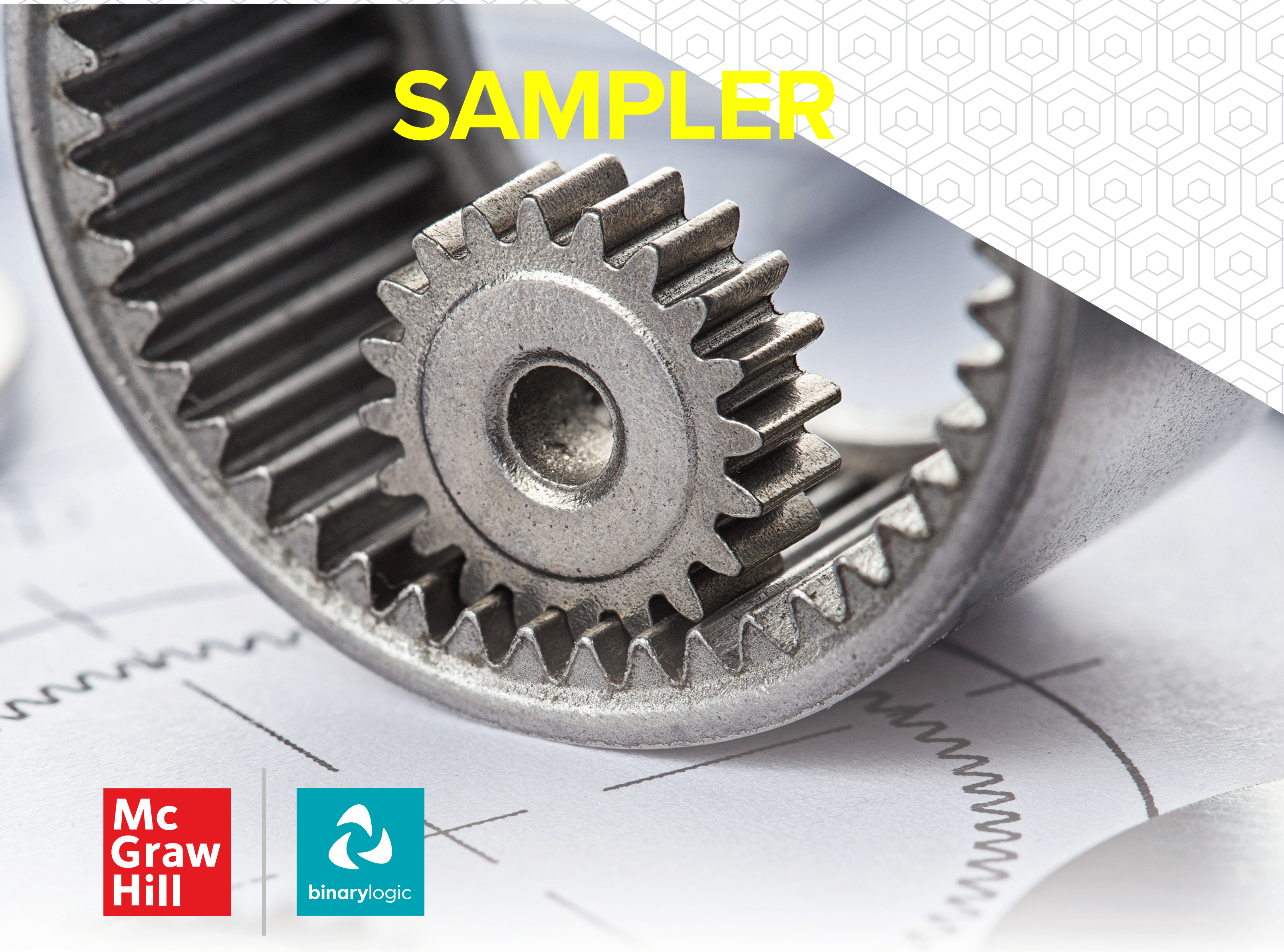
Foundations of STEM

Engineering Design

SAMPLER



McGraw Hill

binarylogic

For Review Purposes Only

Foundations of STEM

Engineering Design

Foundations of STEM:
Engineering Design

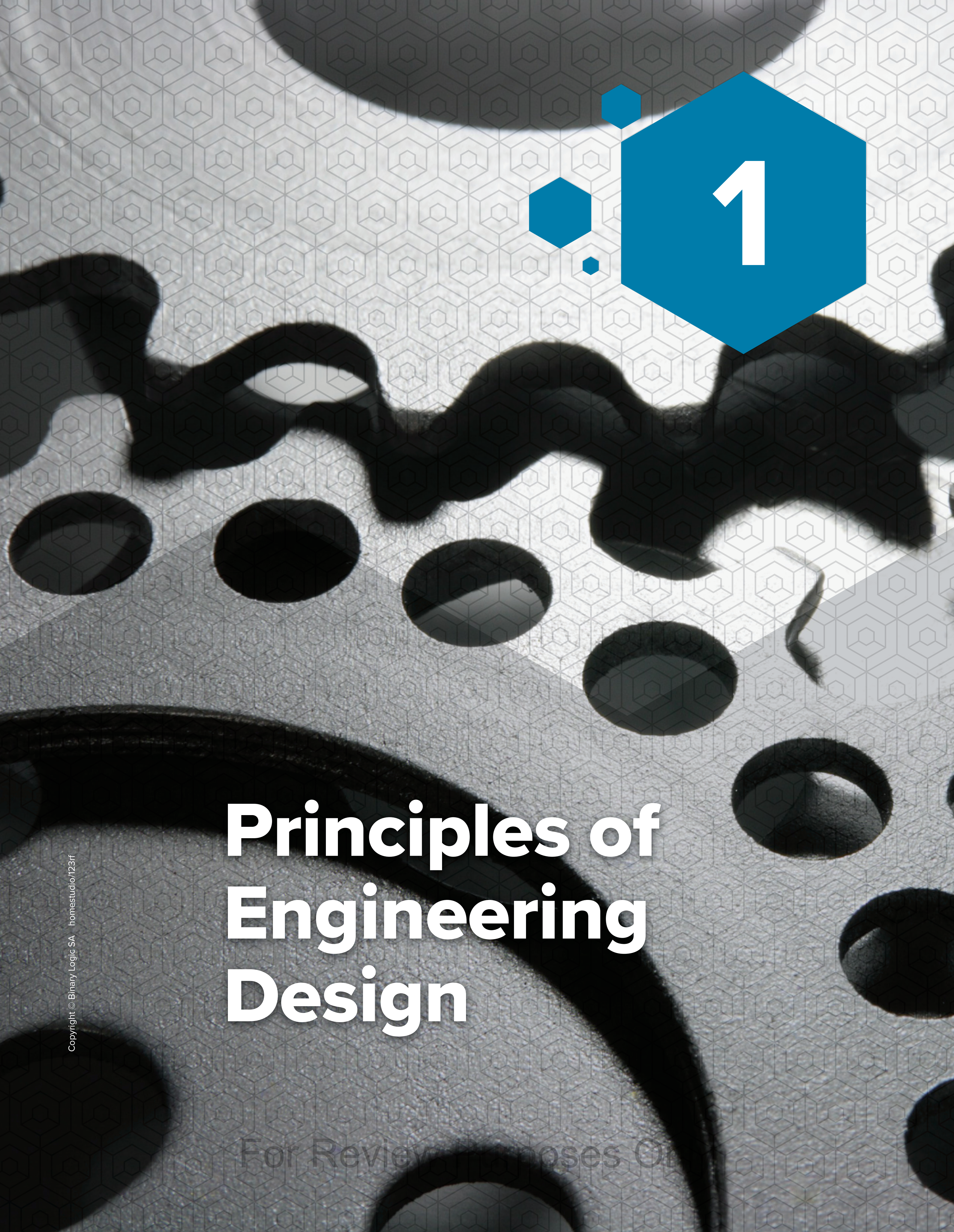
Printed and distributed by McGraw Hill in association with Binary Logic SA.

Cover Credit: © evkaz/123rf

 MHID: 1266247548 ISBN: 9781266247545

mheducation.com **binarylogic.net**

Contents



1

Principles of Engineering Design

1

Principles of Engineering Design

INTRODUCTION

Engineering design is a powerful tool that helps us solve real-world problems and create products that improve our lives. This unit covers the foundations of engineering design, explore different career opportunities in this field, and practice skills like analyzing materials, measuring accurately, and planning projects from start to finish.

LEARNING OBJECTIVES

In this unit, you will:

> define engineering design.

> list the job roles in engineering design.

> identify design thinking.

> distinguish the various design strategies.

> interpret measurements in engineering design projects.

> understand how materials are chosen in projects.

> classify different types of material properties.

> define the product life cycle and identify its stages.

> outline product engineering processes and best practices.

> analyze product life cycle management processes and techniques.

> explain the pyramid of production systems.

> define project management.

> outline the technical properties that a project manager should consider.

> construct a project management plan for developing an engineering design product.

TOOLS

> GanttProject

LESSON 1

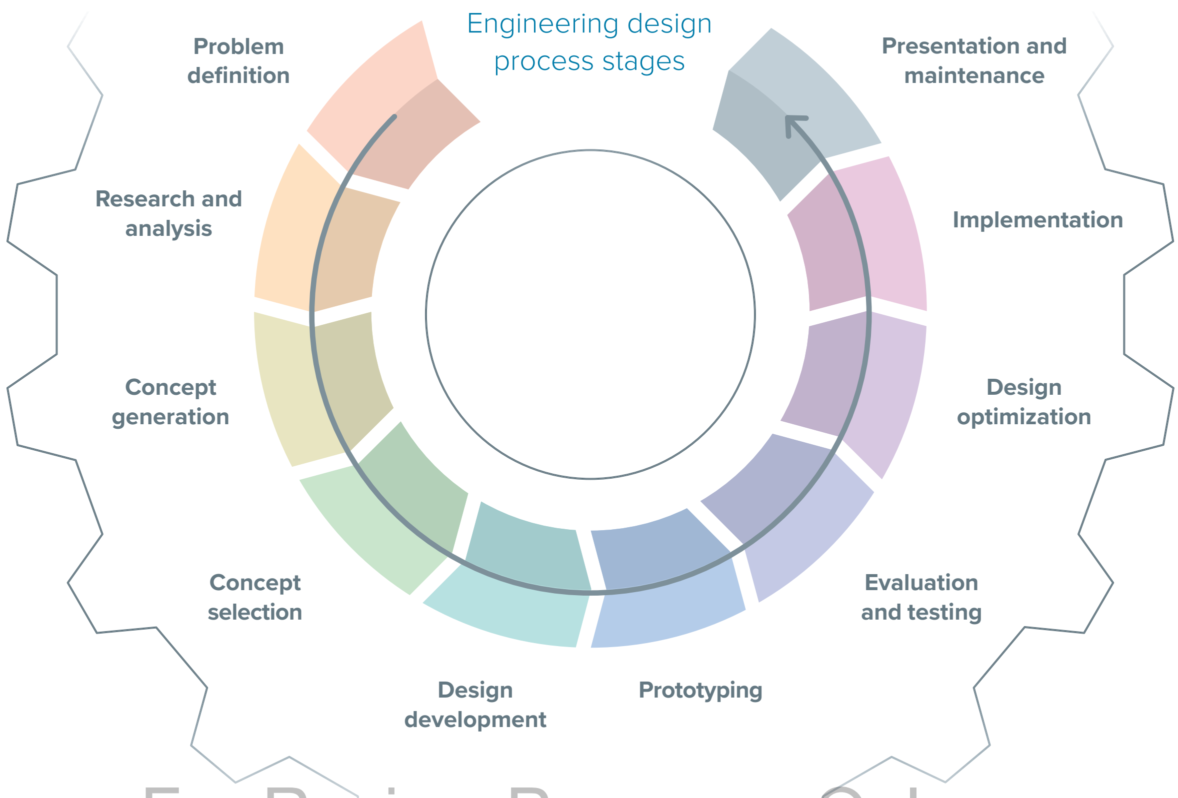
Introduction to Engineering Design

What is Engineering Design?

Engineering design involves building a system, component, or process to meet specific needs. It involves the creative implementation of scientific principles, and mathematical analysis to design, develop, and optimize a solution that meets the needs and constraints of a given problem or task. The **design process** often includes iterative prototyping, testing, and refinement cycles, which may involve collaboration with other engineers, scientists, and **stakeholders**. This is where engineers take a problem and, through a series of steps and processes, develop a solution that can be manufactured, tested, and used.

The stages of engineering design refer to the step-by-step process engineers follow when developing a new system, component, or process. The specific stages of the design process can vary depending on the specific project and the engineering discipline involved, but many engineering design processes include the following stages:

> **The Design Process**
>
> A design process is a structured approach to solving a problem or developing a new system, component, or process. It is a series of steps that engineers or designers follow to take a project from the initial concept to the final implementation.



Stages of the engineering design process

1. Problem definition
Identifying and clearly defining the problem or need that the design will address.

2. Research and analysis
Research to gather information and data on the problem, including existing solutions and constraints.

3. Concept generation
Brainstorming and exploring multiple potential solutions, concepts, and ideas for the design.

4. Concept selection
Evaluating and selecting the best concept based on feasibility, cost, and performance.

5. Design development
Developing detailed specifications and plans for the chosen concept, including drawings and 2D/3D models.

6. Prototyping
Building and fabricating physical or virtual prototypes of the design.

7. Evaluation and testing
Evaluating the prototype based on the design requirements, criteria, and constraints and testing its functionality and performance.

8. Design optimization
Making improvements and adjustments to the design based on testing and evaluation.

9. Implementation
Producing and implementing the final design, including manufacturing, installation, and training product users and maintainers.

10. Presentation and maintenance
Monitoring and maintaining the design over time and evaluating its performance.

It is important to note that the design process is often iterative, with engineers returning to earlier stages to make changes and adjustments as needed. This will result in a better and more robust design.

Job Roles in Engineering Design

The job roles in engineering design can vary depending on the specific field and the stage of the design process. However, the following are some of the common job roles in engineering design:

Design engineer

A design engineer is responsible for creating and developing new designs, products, and systems. They use engineering principles and knowledge to create new designs that are safe, efficient, and functional.

Project engineer

A project engineer is responsible for managing the design and development of a specific project. They work with engineers and designers to ensure the project is completed on time, within **budget**, and to the required specifications.

Systems engineer

A systems engineer is responsible for the overall design and **integration** of complex systems. They work with other engineers and designers to ensure that all components and subsystems work together effectively and efficiently.

Research engineer

A research engineer is responsible for conducting research and development (R&D) to improve existing products and systems or develop new ones. They are responsible for gathering and analyzing data, testing new designs, and developing new technologies.

Manufacturing engineer

A manufacturing engineer is responsible for designing and developing new manufacturing processes, equipment, and tools. They ensure that the production process is efficient and cost-effective and can produce high-quality products.

Quality engineer

Quality engineers ensure that the design meets the quality standards and specifications. They work with other engineers and designers to identify and resolve issues and implement quality controls in the design process.

CAD engineer

A CAD (computer-aided design) engineer is responsible for creating and maintaining a design's detailed technical drawings, 2D and 3D models, and specifications using computer-aided design software. They work closely with design and project engineers to create and update the technical drawings and models.

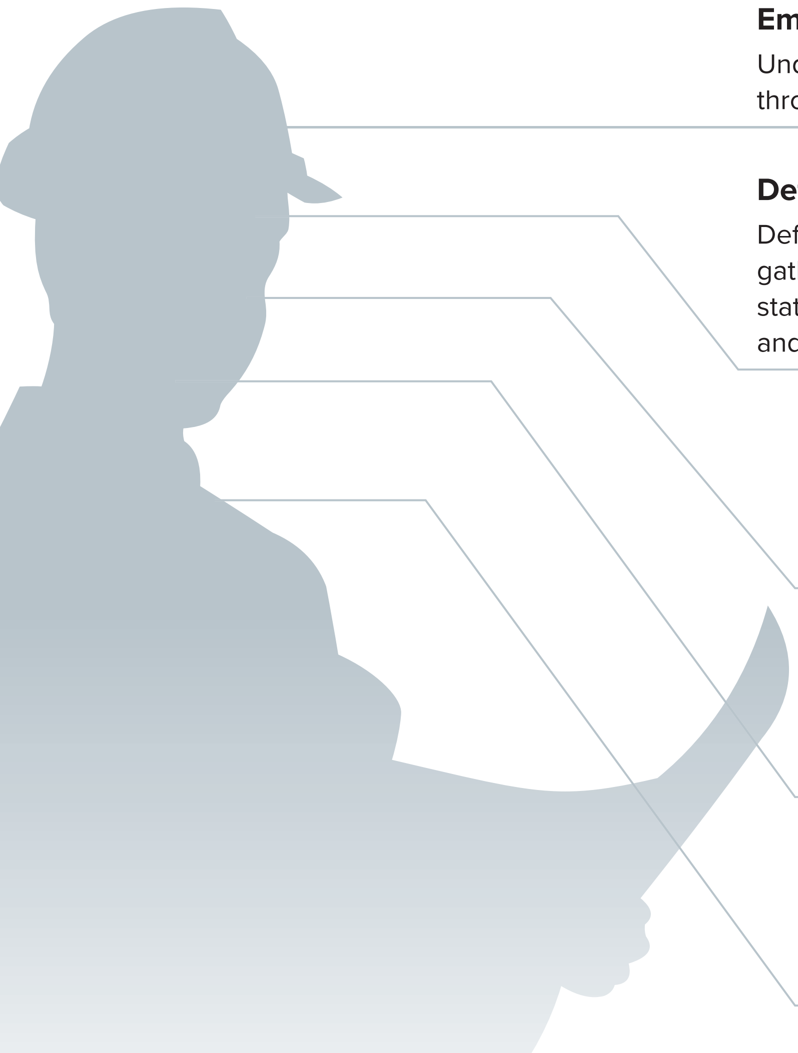
Testing and evaluation engineer

A testing and evaluation engineer is responsible for testing and evaluating the design to ensure that it meets the required performance, safety, and reliability standards. They conduct testing and analysis on the design and provide feedback to the design team to make any necessary improvements.

There are many engineering design job roles besides those mentioned here, and the exact roles and responsibilities can vary depending on the scale of the project and the organization.

Design Thinking

Design thinking is a problem-solving approach to engineering design that emphasizes empathy for the user and rapid prototyping. It is a human-centered design process that helps create innovative and effective solutions by understanding the users' needs, wants, and limitations. The design thinking process typically includes the following stages:



Empathize

Understand the user's needs, wants, and limitations through research, observation, and interviews.

Define

Define the problem by synthesizing the information gathered from the empathize stage. The problem statement is developed based on the user's needs and the desired outcomes.

Ideate

Generate a wide range of ideas to search for solutions through brainstorming, mind mapping, and other techniques.

Prototype

Create physical or virtual representations of the ideas generated in the ideation stage.

Test

Test the prototypes with users and gather feedback to improve the design iteratively.

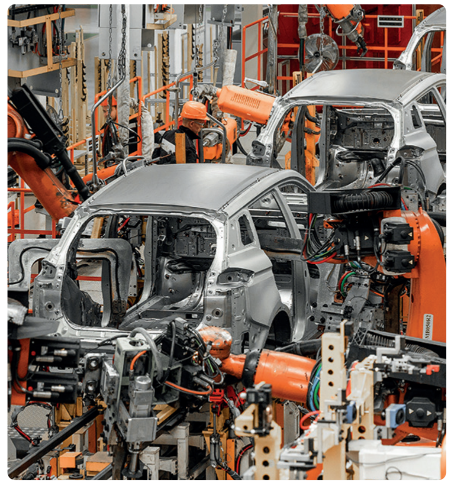
Design thinking is a flexible and adaptive process that allows for iteration and improvement at any stage of the design process. It encourages experimentation, iteration, and rapid prototyping, which allows teams to test and validate assumptions, gather feedback, and make necessary adjustments. It is also a collaborative process that involves a multidisciplinary team of designers, engineers, researchers, and stakeholders working together to create solutions that meet the needs of the users.

Design thinking is used extensively in engineering design processes. It helps teams to create innovative and user-centered solutions by focusing on the needs of the users, and it encourages creativity and experimentation.

Design Strategies

Depending on each project's requirements and needs, various **design strategies** can be followed when developing an engineering design solution. Each design strategy follows a specific design process.

Linear design



The linear design process is a step-by-step approach that involves moving through a series of stages in a linear, one-directional fashion, with little or no iteration. This approach is used in projects where the problem is well-defined and the solution is known, with fixed requirements. An example of this is designing a bridge, where each stage of the linear process must be completed before moving on to the next, with little room for iteration or changes to the design once construction begins.

The linear design process is less flexible than modern design processes such as iterative design, user-centered design, and design thinking, which are more iterative and allow for frequent testing and feedback.

Iterative design

Iterative design is a process of refinement and improvement in which steps are repeated to make the design better. It allows for feedback and iteration at each step, and the process is cyclical in nature. An example of iterative design is the development of a drone, where each step from problem definition to prototyping and testing is repeated until the drone is ready for market, and feedback from users is used to improve the design continuously.

Iterative design is more flexible than linear design, allowing for frequent feedback and changes, and is commonly used in user-centered design and design thinking.

Inclusive design

Inclusive design is an approach that considers the needs of users of all abilities, ages, genders, cultures, or economic status. It aims to create flexible and adaptable solutions to meet diverse needs, such as accessibility, usability, and universal design. An example of inclusive design is the development of a computer that has an ergonomic design and can be used comfortably by people with disabilities, the elderly, and children. The design of the computer includes features such as adjustable height, large fonts for writing, and text-to-speech capabilities to make it easier for users with different needs to interact with the computer.

Inclusive design engages with diverse users and stakeholders in an iterative, human-centered design process that fosters social inclusion and creates accessible solutions for a diverse population.

User-centered design

User-centered design (UCD) involves understanding and addressing user needs through empathy, research, and iterative design. The UCD process begins with user research to gather data on user needs, which is then used to inform the design process, including the development of user personas and scenarios. The design concepts are tested with users, and feedback is used to improve the design iteratively. An example of UCD is the development of a car, where the designers conduct user research to understand the needs of drivers and passengers and then develop user-friendly features, such as intuitive controls, adjustable seats, and temperature control systems, to meet their needs.

Sustainable design

Sustainable design is an iterative, multidisciplinary design approach that aims to create environmentally friendly and resource-efficient solutions. It involves assessing the environmental impact of a design, identifying opportunities for resource efficiency, and considering the design's life cycle, from sourcing materials to end-of-life disposal. An example of sustainable design for a physical product is the development of a solar-powered flashlight, which uses renewable energy sources to reduce waste and pollution and promote resource efficiency.

Ergonomic design

Ergonomic design focuses on creating products and environments that are optimized for users' comfort, safety, and efficiency. The ergonomic design process involves assessing the physical and cognitive demands of tasks and users, identifying opportunities for improvement, and incorporating adjustable and customizable features. The computer mouse is an example of successful ergonomic design, as it was created to replace less efficient keyboard commands and was designed based on users' natural hand movements for ease of use.

1 Choose the correct answer.

1. Engineering design relies on which of the following?
   - **A.** A mix of mathematical analysis and creative thinking.
   - **B.** Only mathematical analysis.
   - **C.** Pure intuition without any structured approach.
   - **D.** User feedback alone.

2. What happens after an engineering design project is completed?
   - **A.** Further optimization is always carried out.
   - **B.** No further optimization is carried out.
   - **C.** It is immediately deployed to users.
   - **D.** It undergoes a review but no changes are made.

3. Design thinking involves which of the following?
   - **A.** Only the engineer's needs.
   - **B.** The needs of different users.
   - **C.** Technical requirements alone.
   - **D.** Marketing and sales strategies.

2 Define engineering design.

3 What are the stages of the engineering design process?

4 List various job roles in engineering design.

5 List the stages of the design thinking process.

6 Compare the linear design and iterative design strategies.

7 Explain how inclusive design places the human user at the forefront of the design process.

LESSON 2

Measurements and Materials

Introduction to Measurements in Engineering Design

In engineering design, measurements determine the size, shape, and location of components and systems. These measurements are typically made using specialized instruments such as rulers, calipers, thermocouples, pressure gauges, load cells, and torque sensors. Additionally, computer-aided design (CAD) software is often used to create detailed models and simulations of engineered systems, which can be used to analyze and optimize their performance.

Common units of measurement used in engineering

Physical quantities	SI units	US units
Length	millimeters (mm), centimeters (cm), meters (m)	inches (in), feet (ft)
Mass	grams (g), kilograms (kg)	pounds (lb)
Time	seconds (s), minutes (min), hours (hr)	seconds (s), minutes (min), hours (hr)
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)
Pressure	pascals (Pa)	pounds per square inch (psi)
Force	newtons (N)	pound-force (lbf)
Power	watts (W)	horsepower (hp)
Energy	joules (J)	watt-hours (Wh)

It is important to note that different countries and industries may use different units, and some units may be more appropriate for a specific application than others. For example, the **International System of Units (SI)** is widely adopted in many regions across the world, while the US customary units system is used in the USA. Furthermore, the context of the problem or application can dictate the best units to use.
For example, Celsius is more commonly used for temperature measurement in electronic devices than Fahrenheit. The table above illustrates the different units of measurement in the SI and US systems.

Rather than working with the basic units of a system, engineers often find it more convenient to use multiples and submultiples of those units. For example, they may use nanometers (nm) units for measuring very small distances or kilometers (km) for larger distances. The table below illustrates the multiples and submultiples most commonly used with SI units.

Multiples and submultiples most commonly used with SI units

Prefix	Exa	Peta	Tera	Giga	Mega	Kilo	Hecto	Deca	Deci	Centi	Milli	Micro	Nano	Pico
Symbol	E	P	T	G	M	k	h	da	d	c	m	µ	n	p
Multiplication factor (10n)	18	15	12	9	6	3	2	1	-1	-2	-3	-6	-9	-12

Using measurements in engineering design

Engineers typically use a combination of manual calculations and specialized software tools to make measurements and perform calculations in the design process. While some calculations may be done by hand, many are complex and require specialized software tools to perform them efficiently and accurately. For example, computer-aided design (CAD) software is widely used in engineering for modeling and simulation, and finite element analysis (FEA) software is also commonly used to simulate the response of structures and materials to various loads and conditions. These software tools can automate many calculations, provide visualizations of complex systems, and perform simulations to help engineers optimize the design of a product or system. Engineers rely on these tools to make accurate and efficient calculations, which is crucial for the design process.

Precise, meticulous, and accurate measurement is a critical aspect of engineering design and can greatly influence the success of a project or product. However, some complications must be considered when working with measurements, such as measurement errors and uncertainty, the need for tools to be calibrated before using them in the measurements, and the influence of environmental conditions. Engineers must pay attention to these factors and use appropriate tools and techniques to ensure accurate and reliable measurements. For example, household scales with an inaccuracy of 1% within its 100 kg range can be expected to give a reasonably accurate reading of your weight (within 1 kg) but are not appropriate for measuring the ingredients for making a cake. The table below illustrates the advantages of using accurate measurements in an engineering design project, together with some important considerations.

Advantages and considerations of using accurate measurements

Advantages	Considerations
Allows precise and accurate characterization of components and systems.	Units of measurement must be carefully selected and consistent throughout the design process.
Helps identify and quantify design constraints and requirements.	Measurement errors and uncertainties must be evaluated and minimized.
Enables optimization and analysis of design performance.	Measurement equipment and techniques must be properly calibrated and maintained.
Facilitates communication and collaboration among members of the design team.	Complex systems may require multiple types of measurements and specialized equipment.
Allows computer-aided design (CAD) and simulation software to analyze and optimize the design.	Measurements must be made in an appropriate environment and under controlled conditions.

Introduction to Materials in Engineering Design

In engineering design, the properties of materials are critical in determining their performance and suitability for specific applications. Material selection is a crucial step, requiring engineers to evaluate various properties to identify the most appropriate material for a given purpose. The table below highlights the most common factors considered when selecting materials for engineering projects.

Considerations when choosing materials

Consideration	Description
Mechanical properties	Physical properties such as strength, stiffness, Young's modulus (elastic modulus), ductility, and toughness determine the material's ability to withstand loads and deformations.
Physical properties	Properties such as density, melting point, thermal expansion, and electrical and magnetic properties determine the material's suitability for specific environments and applications.
Chemical properties	Properties such as corrosion resistance, flammability, reactivity, toxicity, and biocompatibility determine the material's suitability for contact with humans or the environment.
Cost	The cost of the material, including the cost of procurement, processing, and manufacturing.
Availability	The availability and readiness of the material for the specific application, including supply chain and delivery time.
Recycling and disposal	The environmental impact of the material, including the ease of recycling or disposing of the material at the end of its life.
Standards and regulations	Compliance with relevant standards and regulations, such as safety, environmental, and industry-specific standards.

Types of material properties

Mechanical properties

Mechanical properties define a material's behavior when subjected to an external load. The table below illustrates the most common mechanical properties of materials used in engineering design.

Mechanical properties of materials

Properties	Description
Young's modulus (elastic modulus)	A measure of a material's resistance to elastic deformation under load.
Tensile strength	A measure of a material's resistance to breaking under tension.
Yield strength	The stress at which a material begins to deform permanently.
Fatigue strength	A measure of a material's ability to withstand repeated loading cycles.
Shear strength	A measure of a material's resistance to shear stress.
Compressive strength	A measure of a material's resistance to compression.
Toughness	A measure of a material's ability to absorb energy before breaking.
Ductility	A measure of a material's ability to deform plastically without breaking.
Hardness	A measure of a material's resistance to indentation or scratching.

Engineers must consider these properties and select a material with the appropriate mechanical properties for the specific application. For example, a material with high tensile strength and yield strength would be suitable for a component subject to high pulling forces. In contrast, a material with high ductility and toughness would be more suitable for a component subject to high-impact loads. Additionally, hardness is also an important property for materials that will be subject to wear and tear. The selection of the right mechanical properties will ensure that the designed components have the strength, durability, and reliability to function properly and have a long life.

Thermal properties

Thermal properties are a set of characteristics that define the behavior of a material when it is subjected to temperature changes. These properties include thermal conductivity, diffusivity, specific heat, thermal expansion, and melting and boiling points. They are important to consider in engineering design as they can greatly influence the performance and suitability of a material for a specific application. The table below illustrates the most common thermal properties of materials used in engineering design.

Thermal properties of materials

Properties	Description
Thermal conductivity	The ability of a material to conduct heat.
Thermal diffusivity	The ability to transfer heat through a substance.
Specific heat	The amount of heat required to raise the temperature of a unit of mass of a substance by one degree.
Thermal expansion	The change in a material's length, area, or volume when its temperature changes.
Melting point	The temperature at which a solid material turns into a liquid.
Boiling point	The temperature at which a liquid material turns into a gas.

These properties are important when materials are used in high-temperature environments or as thermal insulation. For example, when designing a heat sink for a computer processor, thermal conductivity, specific heat, and thermal expansion are important properties to consider. The melting and boiling points are also crucial as the heat sink must withstand high temperatures without losing its integrity.

Chemical properties

Chemical properties define a material's behavior when exposed to different chemicals or environments. The table below illustrates the most common chemical properties of materials used in engineering design.

Chemical properties of materials

Properties	Description
Corrosion resistance	The ability of a material to resist corrosion or deterioration when exposed to various environments, such as air, water, or specific chemicals.
Flammability	The ability of a material to burn or ignite.
Reactivity	The ability of a material to react with other substances, such as chemicals or gases, to form new compounds.
Toxicity	The ability of a material to cause harm or injury to living organisms, either through direct contact or through the release of toxic substances.
Biocompatibility	The ability of a material to remain in contact with living tissue without causing adverse reactions or negative effects.

In applications where materials will be used in contact with humans or the environment, the choice of materials is critical. These properties are also important in manufacturing, disposal, and recycling.

Electrical properties

Electrical properties define a material's behavior when exposed to an electric field. The table below illustrates the most common electrical properties of materials used in engineering design.

Electrical properties of materials

Properties	Description
Electric conductivity	The ability of a material to conduct electricity.
Electric resistivity	The ability of a material to resist the flow of electricity.
Dielectric constant	The ability of a material to store electrical energy in an electric field, which is also known as its capacitance.
Dielectric strength	The maximum electric field a material can withstand without breaking down.
Loss tangent	The ratio of energy lost to energy stored in a material when an alternating current is applied.

The electrical conductivity, resistivity, and dielectric constant are important in determining the electrical performance of a material. The dielectric strength is important in determining a material's suitability for high-voltage applications, and the loss tangent is important in determining a material's suitability for wireless communications applications.

Magnetic properties

Magnetic properties define a material's behavior when exposed to a magnetic field. The table below illustrates the most common magnetic properties of materials used in engineering design.

Magnetic properties of materials

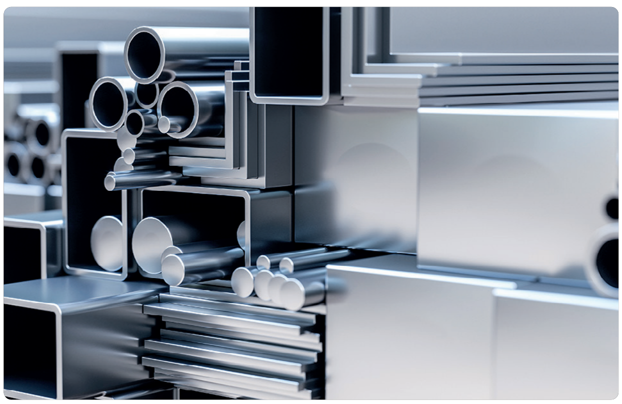
Properties	Description
Magnetization	The ability of a material to become magnetized when exposed to a magnetic field.
Magnetic susceptibility	The ratio of the magnetization of a material to the magnetic field strength.
Magnetic permeability	The ratio of the magnetic field strength within a material to the magnetic field strength outside of the material.
Curie temperature	The temperature at which a material loses its permanent magnetic properties.

These properties are considered in applications where materials will be used in magnetic fields or electromagnetic devices such as motors, generators, and transformers. Magnetization properties, magnetic susceptibility, magnetic permeability, and electrical conductivity are important in determining the magnetic performance of a material. The Curie temperature is important in determining a material's suitability for high-temperature applications.

Materials Used in Engineering Design

Materials can be broadly grouped into several categories: metals, polymers, ceramics, composites, and natural materials. Each category has its own unique set of properties, advantages, and limitations that must be considered when selecting a material for a specific application. For example, metals are known for their high strength and durability, while polymers are known for their flexibility and ease of molding. Ceramics are known for their high hardness and thermal resistance, while natural materials are known for their natural look and feel.

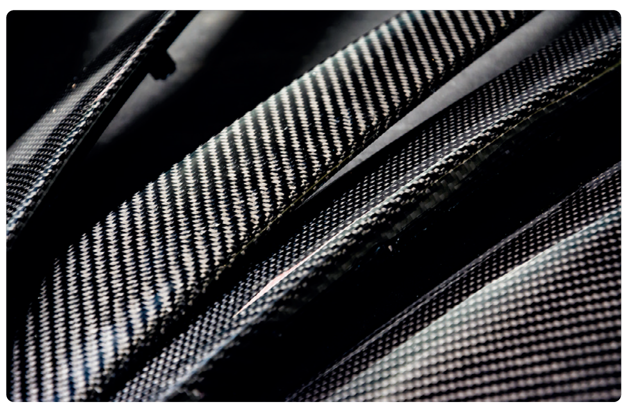
Selecting a material for a specific application is a critical step in engineering design. It requires a thorough understanding of the properties and behavior of different materials. To make an informed decision, engineers must consider the environmental, safety, and performance requirements of the product or structure and the cost and availability of materials. The table below illustrates the categories of materials that are used in engineering design.



Metals

Polymers

Ceramics



Composites

Materials in engineering design

Description	Example materials	Example applications
Metals		
A class of materials characterized by their metallic bonding, high thermal and electrical conductivity, and ability to be shaped.	Iron, steel, aluminum, copper, and titanium.	Construction, automotive, aerospace, machinery, medical devices, and implants.
Polymers		
A class of materials characterized by their long chain-like molecular structure and ability to be molded or shaped.	Polyethylene, polypropylene, PVC, nylon, and rubber.	Packaging, consumer goods, automotive, medical devices, and electrical and electronic components.
Ceramics		
A class of materials characterized by their high hardness, strength, and electrical and thermal resistance.	Alumina, silicon carbide, silicon nitride, and zirconia.	Cutting tools, automotive parts, advanced ceramics, and electrical and electronic components.
Composites		
A class of materials composed of two or more different materials combined to create a new material with improved properties.	Fiberglass, carbon fiber, and Kevlar.	Aerospace, automotive, sports equipment, construction materials, and wind turbine blades.

1 Choose the correct answer.

1. Horsepower (hp) is a unit of measurement for:
   - **A.** Speed
   - **B.** Power
   - **C.** Force
   - **D.** Temperature

2. Thermal expansion is an important factor to consider when:
   - **A.** Testing materials at room temperature.
   - **B.** Testing materials under extreme temperature conditions.
   - **C.** Selecting materials for lightweight applications.
   - **D.** Testing materials in the absence of pressure.

3. Composites are created to:
   - **A.** Reduce the weight of materials.
   - **B.** Combine materials without changing their properties.
   - **C.** Develop materials with new and enhanced properties.
   - **D.** Maintain the original properties of the base materials.

2 Provide two units of measurement (SI and/or US) for each type of unit.

3 Explain why engineering projects do not all use the same units of measurement.

4 List three advantages of using precise measurements in engineering design projects, and three important considerations.

5 Classify the most common considerations when choosing materials for an engineering design project.

6 Specify the difference between a material's toughness and ductility.

7 Distinguish a material's toxicity and biocompatibility and explain why they are important.

8 Analyze in what circumstances dielectric strength and loss tangent are considered when choosing a material.

9 List three categories of materials, describe them, and give some examples and applications.

LESSON 3

The Product Life Cycle

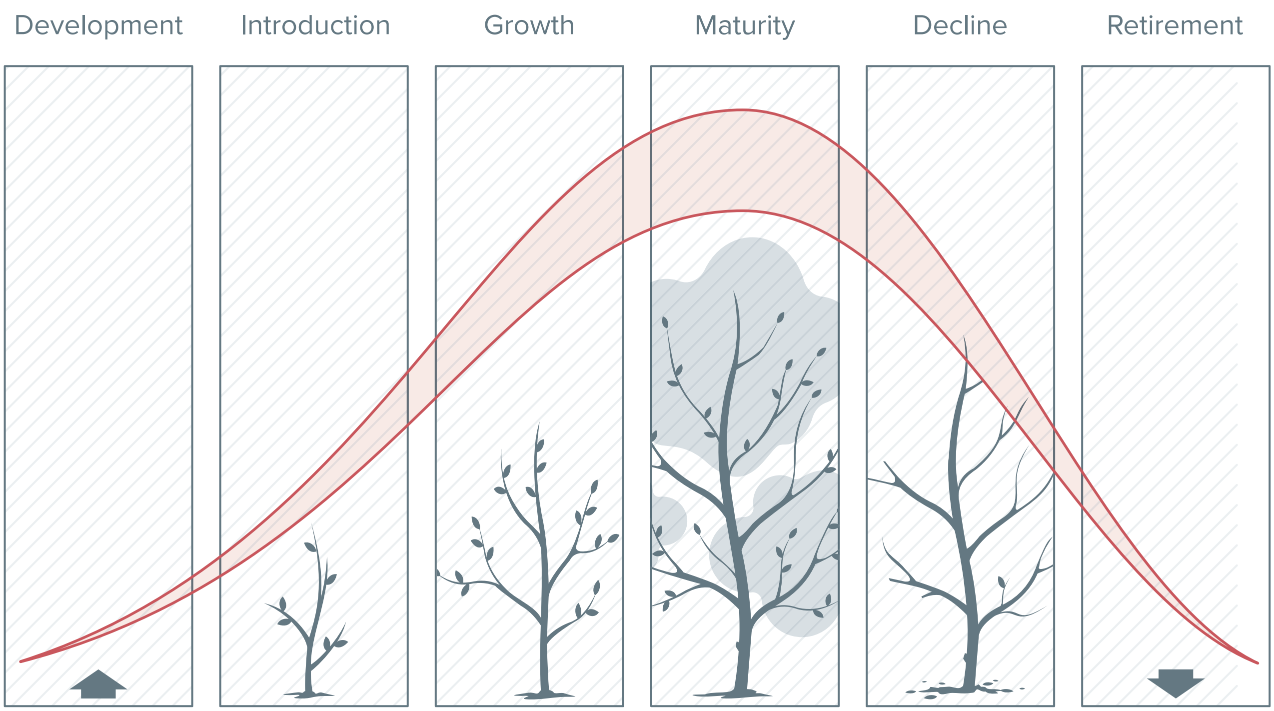
What is the Product Life Cycle?

The product life cycle is a framework that describes the stages a product goes through, from its initial concept and development to its retirement or withdrawal from the market. The product life cycle concept is commonly used in marketing and strategic management to help companies plan for the life of their product and decide when to introduce new products, when to retire older products and how to maximize profits during the different stages.

Stages of a product life cycle

The product life cycle goes through the following stages:

- **Development:** This is the stage where a product idea is researched, developed, and tested.
- **Introduction:** The product is launched into the market, and the company begins to promote and sell it.
- **Growth:** The product gains acceptance in the market, and sales increase rapidly.
- **Maturity:** The product reaches its peak in sales and profits, and the market becomes saturated with similar products.
- **Decline:** Product sales decrease as it loses market share to new products or technologies.
- **Retirement:** The product is eventually phased out and removed from the market through discontinuation or replacement with a new product.



What is Product Engineering?

Product engineering involves the process of conceptualizing and bringing a product to market through design and development. It is a multidisciplinary field that encompasses various aspects of product development, including mechanical engineering, electrical engineering, software engineering, industrial design, and materials science.

Product engineers are responsible for designing and developing products that meet customer needs and market requirements. They work closely with cross-functional teams, including designers, marketers, and manufacturing engineers, to ensure that the product is functional, reliable, and cost-effective.

Product engineering includes several key activities, such as:

- Conceptualizing and defining the product requirements.
- Designing the product and creating detailed specifications and engineering drawings.
- Conducting research and development to identify new technologies and materials.
- Creating prototypes and testing the product for functionality, performance, and reliability.
- Managing the product development process, including working with suppliers and manufacturers.
- Managing the product's life cycle, including maintenance and support.

Product engineering is a crucial part of the product development process, as it ensures that the final product meets customer needs and is manufactured cost-effectively and efficiently.

Product engineering phases

Product engineering generally includes the following phases:

1. **Concept development:** This phase includes the initial ideation and conceptualization of the product. It includes market research, customer needs analysis, and feasibility studies to determine the viability of the product and to define the product requirements.
2. **Design and development:** This phase includes the design and development of the product. It includes creating detailed specifications, engineering drawings, and prototype development.
3. **Testing and validation:** This phase includes testing and validating the product to ensure that it meets the requirements and specifications set during the concept development phase. It includes testing the product design, performance, and reliability.
4. **Manufacturing and production:** This phase includes the manufacturing and production of the product. It includes the creation of production tools and equipment and the assembly of the final product.
5. **Maintenance and support:** This phase represents maintenance and support of the product after it has been released to the market. It includes addressing customer issues, providing technical support, and releasing updates or upgrades.
6. **Retirement or phase out:** This phase includes the end of the product's life cycle, either due to it reaching its end of life or being phased out for a newer model. This includes the processes of discontinuing the product and disposing of the product safely.

Different companies or industries may have different variations of these phases and use different terminology.

Product engineering best practices

The following are some best practices for product engineering. Suppose that a car company wants to build a model. The table below shows how the company may apply product engineering best practices:

Application of engineering best practices for a car company

Best practice	Application
Understand customer needs and requirements	
Conducting market research, customer interviews, and focus groups can help product engineers understand what customers are looking for in a product.	The result of market research, customer interviews, and focus groups might conclude with the decision to build an electric car rather than a regular ICE (Internal Combustion Engine) car.
Define the product requirements	
Clearly defined requirements ensure that the product is developed to meet the target market's needs. It also helps to identify potential issues early in the development process.	The product requirements, such as the car's driving range, top speed, charging time, and expected price, are defined early in the design process.
Use a multidisciplinary approach	
Product engineering is a multidisciplinary field that requires the collaboration of various experts, such as mechanical engineers, electrical engineers, software engineers, industrial designers, and materials scientists.	A multidisciplinary approach with experts in various fields is used to design the car, optimizing components for performance, safety, durability, aesthetics, ease-of-use, cost-effectiveness, and sustainability.
Implement a robust testing and validation process	
This ensures that the product meets the requirements and specifications set during the concept development phase. It includes testing the product design, performance, and reliability.	Stringent testing is implemented to ensure that the car meets the requirements defined during concept development as well as all legal standards. Safety testing must be especially rigorous in car manufacturing.
Leverage technology and innovation	
Product engineers should stay up to date with new technologies and materials that can be used to improve product performance, reduce costs, and increase sustainability.	The latest developments in automated driver assistance, battery technology, and network connectivity are leveraged to improve the car's safety, efficiency, and user-friendliness.

Best practice	Application
Use project management methodologies	
A good project management approach will ensure that the project stays on schedule, within budget, and meets the goals set during the concept development phase.	Project management methodologies are used to balance time, cost, and quality during the car's development.
Continuously improve	
Product engineering is an iterative process. Once the product is launched, product engineers should continue gathering customer feedback, analyzing data, and improving the product.	Continuously improving the car's design, features, and performance based on customer feedback to meet evolving needs and expectations.

What is Product Life Cycle Management?

Product life cycle management (PLM) is a process used to manage the entire life cycle of a product from conception to retirement. It includes coordinating and managing all the data, documentation, and processes related to a product, including design, engineering, production, and support. PLM aims to improve efficiency and collaboration throughout product development and ensure that all stakeholders can access the most current and accurate product information.

Product life cycle management stages

Beginning Of Life (BOL)

This phase includes the product's conception, design, and development. It is the phase where the product idea is generated and evaluated for feasibility, and the product requirements are defined. The BOL stage includes the following activities:

Market research

To understand the target market's needs and identify potential opportunities for the product.

Conceptualization

Creating a preliminary concept of the product and evaluating its potential for success.

Requirements definition

Identifying and defining the functional and non-functional requirements of the product.

Design and development

Developing detailed specifications, engineering drawings, and product prototypes.

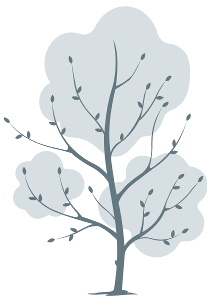
Testing and validation

Ensuring the product meets the requirements and specifications defined during the concept development phase.

Approval

Obtaining approvals from stakeholders such as customers and regulatory authorities.

This stage is critical to the product's success since it sets the foundation for the rest of the product's life cycle. A well-defined and feasible product will have a higher chance of success during the later stages of the product life cycle.



Middle of life (MOL)

The product is manufactured, produced, marketed, and launched on a commercial scale in the middle of life (MOL) stage, which includes the following activities:

Manufacturing and production

Creating the production tools and equipment and assembling the final product.

Supply chain management

Managing the flow of materials and components to support the production process.

Quality control

Ensuring that the product meets the required quality standards before it is released to the market.

Launch and commercialization

Releasing the product to the market and making it available for commercial use. This includes marketing, sales, and distribution activities.

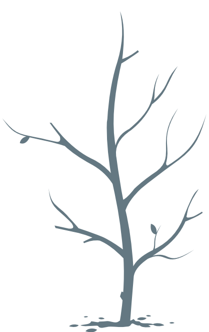
Pricing and profitability

Establishing the pricing strategy and monitoring the product's profitability.

Market analysis

Analyzing the product's market performance and identifying improvement opportunities.

In this stage, the product is already on the market, and it is important to optimize the sales, costs, and supply chain to maximize profits. The product team will focus on maintaining and improving the product's performance and addressing any issues. In this stage, it also crucial to identify potential opportunities for product enhancements or new versions and the potential to expand into new markets.



End of life (EOL)

The final phase of a product's development is when the product is phased out or reaches its end of life and production must be discontinued and existing units disposed of safely. This stage includes the following activities:

Product phase-out

Planning the phase-out of the product, including the timing and method of discontinuation.

Last-time-buy management

Managing the final orders and deliveries of the product to the customers.

Stock management

Managing the remaining product inventory and ensuring it is sold before discontinuation.

Retirement

Retirement of the product from the market and discontinuing its production and support.

Disposal

Disposing of the product and its components safely and in compliance with environmental regulations.

Post-retirement support

Providing support for the product for a limited time after its retirement.

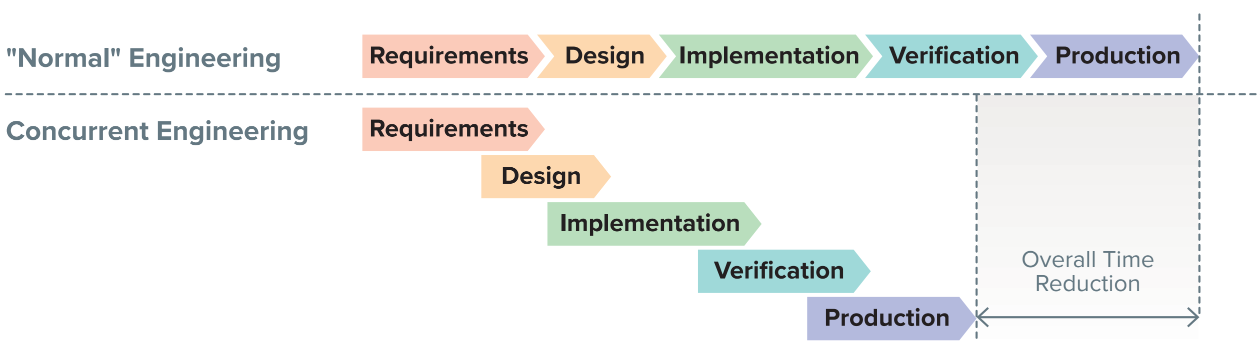
> During this stage, the product team will focus on managing the end of the product's life and ensuring a smooth transition to the next product or version. They will also work on recovering as much value as possible from the product before it is retired by selling off the remaining inventory. In this stage, it is also important to plan for the end of any services or support provided for the product.

Product life cycle management techniques

Concurrent engineering

Concurrent engineering, also known as simultaneous engineering, is a product development approach that involves multiple teams working on different aspects of a product simultaneously. This approach is intended to speed up the product development process by reducing delays caused by sequentially working on different stages of the product development process.

Concurrent engineering involves a team-based approach in which engineers, designers, and other experts work together to develop a product from concept to launch. The teams simultaneously work on different aspects of the product, such as design, manufacturing, testing, and marketing. This approach allows for quick identification of potential issues and the ability to make changes early in the development process. The figure below compares the timelines of the "Normal" Engineering Plan and the Concurrent Engineering Plan. In this figure, the overall time reduction introduced by the Concurrent Engineering technique.



Advantages of concurrent engineering include:

- Reduced product development time.
- Increased efficiency and collaboration among teams.
- Improved quality and reliability of the product.
- Reduced costs due to fewer design changes and reworkings.
- Early identification of potential issues and the ability to make changes early in the development process.

Bottom-up design

Bottom-up design is an approach to product design and development that starts with the individual components of a system and works up to the overall system. The design process starts with a detailed design of the lower-level components, such as individual parts or subassemblies, and then integrates them into larger assemblies or subsystems. This process is repeated until the entire system is designed and integrated.

> The main advantage of bottom-up design is that it allows for the design of the individual components to be completed before the overall system design is finalized. This approach allows for the optimization of individual components and can reveal any issues that may arise during the integration of the subsystems.

Top-down design

Top-down design is a product design and development approach that starts with the overall system and work down to the individual components. The design process starts with defining the overall system architecture and then breaking it into smaller subsystems and components. The design of the individual components is completed after the overall system design is finalized.

> The main advantage the top-down design is that it allows for a clear understanding of the overall system requirements before the design of the individual components begins. This approach allows for the optimization of the entire system and helps to ensure that the final product meets the needs of the customer or end user.

Both ends against the middle design

Both Ends Against the Middle (BEAM) design is a product development approach that combines top-down and bottom-up design elements. It starts with the overall system and the individual components and uses an iterative process to develop the product by working on both levels simultaneously.

> The main advantage of BEAM design is that it allows for the optimization of both the overall system and the individual components and helps to ensure that the final product meets the needs of the customer or end user while being cost-effective, reliable, and easy to manufacture.

Front-loading design and workflow

Front-loading design and workflow is an approach to product development that emphasizes the importance of early planning, design, and development in the product development process. It aims to identify and resolve potential issues early in the development process before significant resources have been invested.

The front-loading approach is based on the idea that it is much more cost-effective to identify and resolve problems early in the development process rather than later on. The front-loading design approach reduces the time, cost, and risks involved in the process of product development.

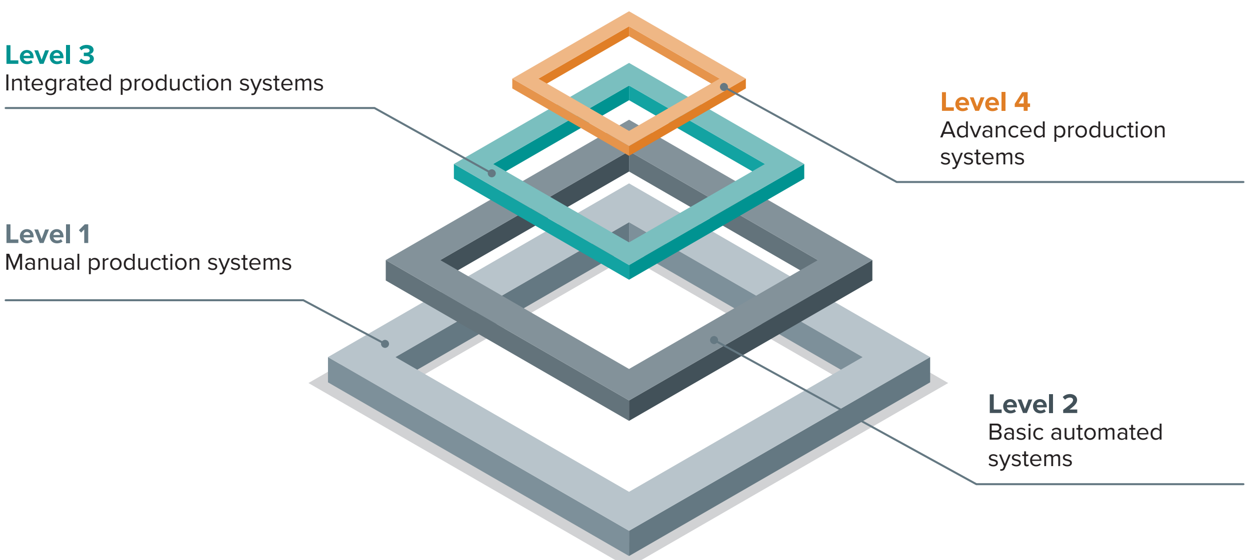
Design in context

Design in context refers to considering the context in which a product will be used when designing it. This includes considering factors such as the environment, culture, user demographics, and the intended use of the product. The goal of design in context is to create products well-suited to the specific context in which they will be used.

Design in context is important in ensuring that products are well-suited to the specific context in which they will be used and that they meet the needs of the intended users. It can lead to products that are more usable, more accessible, and more sustainable. It is widely used in product design, especially in high-tech industries such as the aerospace, automotive, electronics, medical, and environmental technology industries.

Pyramid of Production Systems

The **pyramid of production systems** is a framework used to classify and understand different levels of production systems. It is a hierarchical model representing the complexity and level of automation of production systems, starting with basic manual systems at the bottom and progressing to more advanced, automated systems at the top. The pyramid of production systems typically includes the following levels:



Level 1

Manual production systems: These systems rely on manual labor and are characterized by low automation and low productivity. They are typically used for simple and low-volume production tasks.

Level 2

Basic automated systems: These systems use basic automation techniques to automate certain aspects of the production process. They are characterized by higher levels of automation and productivity than manual systems.

Level 3

Integrated production systems: These systems use advanced automation techniques, such as computer-aided design (CAD) and computer-aided manufacturing (CAM), to integrate different aspects of the production process. They are characterized by high levels of automation and productivity.

Level 4

Advanced production systems: These systems use advanced technologies, such as robotics, artificial intelligence, and the Internet of Things, to optimize the production process. They are characterized by very high levels of automation and productivity.

For example, a furniture company produces handmade wooden chairs using manual production systems in a small workshop. As demand for their chairs grows, the company invests in a basic automated system by purchasing a machine to help cut and shape the wood more efficiently. Eventually, the company expands to an integrated production system by investing in a production line that uses advanced machinery to automate the assembly process and increase production volume. Finally, the company adopts an advanced production system by incorporating robotic systems to help with the finishing process and achieve higher levels of precision in the final product.

1 Choose the correct answer.

1. The manufacturing phase of product engineering primarily focuses on:
   A. Conducting market research.
   B. Assembling a product for mass production.
   C. Managing the end-of-life process.
   D. Creating software specifications.

2. The EOL phase in the product life cycle is concerned with:
   A. Initial research and design
   B. Quality control and assurance
   C. Marketing and sales
   D. Retirement of a product

3. Products developed with front-loading design are characterized by:
   A. Spending minimal time in the planning phase.
   B. Focusing on late-stage improvements.
   C. Spending a significant amount of time in early planning and design stages.
   D. Relying solely on software engineering.

2 Summarize what the product life cycle is.

3 List the stages of the product life cycle.

4 Analyze the stages of product engineering.

5 Compare two best practices for product engineering.

6 Define product life cycle management.

7 Classify the product life cycle management stages.

8 List the advantages of using the concurrent engineering methodology.

9 Describe how BEAM design combines bottom-up and top-down design.

10 Explain the levels of the pyramid of production systems.

PROJECT

Electric Charging Network Plan

Suppose you have been put in charge of developing the charging stations for the adoption of electric cars in a small city.

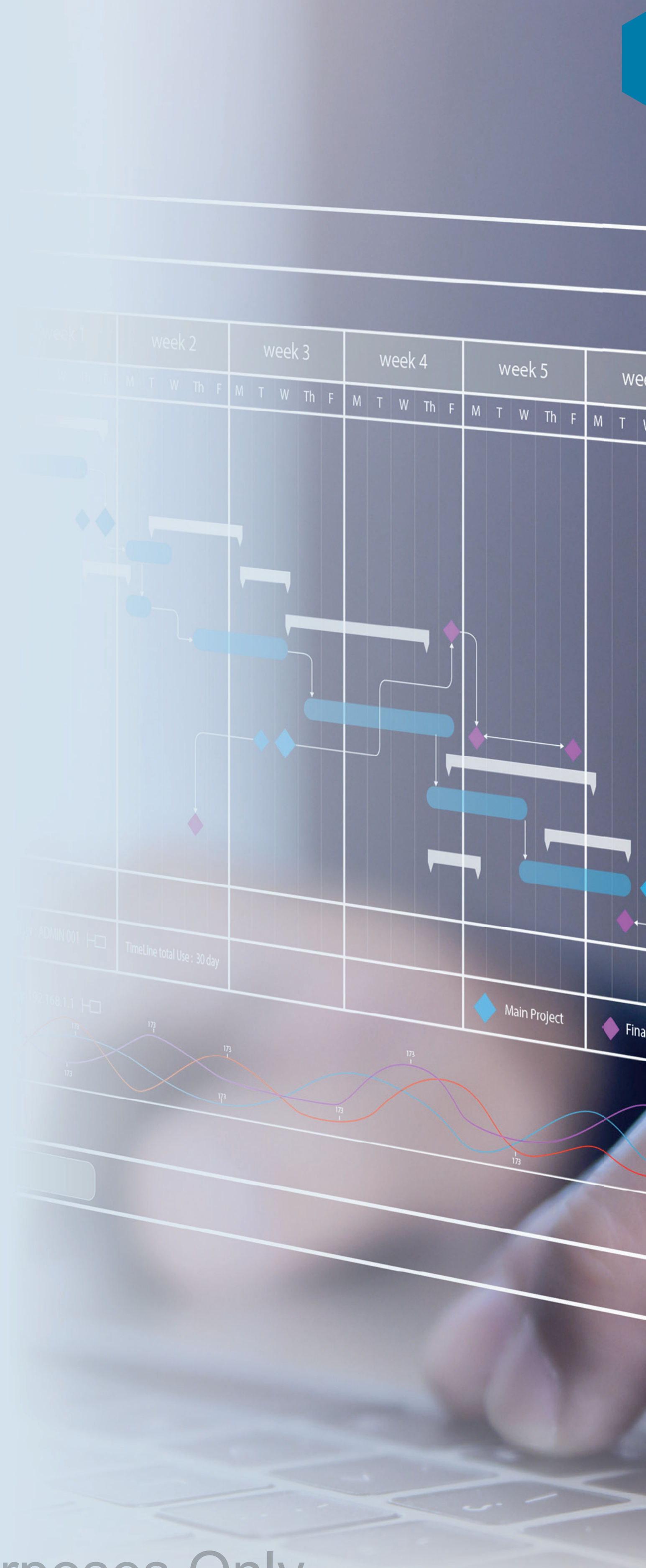
You are in charge of the development of the charging stations and their integration into the city's power grid. The project deadline is three years from now.

1. Create the requirements for the project by considering what the charging stations should be able to do and how they must be placed inside the city itself. Think about what types of professionals will work on the development and then on the integration.

2. Write down the work tasks and subtasks that need to be completed for the development and integration of the charging stations. You will then create a project plan for the development and integration.

3. Create a detailed schedule for all the tasks and think about which professionals will work on each task. Setup the necessary milestones for the project. Think about the relationships between the tasks and which ones need to be completed sequentially and which ones can run concurrently.

4. Use the GanttProject tool to create the project plan with all the above properties and assign the appropriate job roles to the tasks.



Principles of Engineering Design

1

WRAP UP

THIS UNIT COVERED HOW TO:

> recognize what engineering design is.
> distinguish the job roles in an engineering design project.
> define design thinking.
> analyze the various design strategies for a project.
> recognize the importance of measurements and units.
> evaluate how materials are selected in projects.
> examine different types of material properties.
> analyze the product life cycle and its stages.
> list product engineering processes and best practices.
> identify product life cycle management processes and techniques.
> interpret the pyramid of production systems.
> provide an overview of project management.
> analyze the technical details of a project plan.
> design a detailed project plan for an engineering design project.

KEY TERMS

- Budget
- Cost Management
- Deadlines
- Design Process
- Design Strategies
- Design Thinking
- Human Resource Management
- Integration
- International System of Units (SI)
- Product Engineering
- Product Life Cycle Management (PLM)
- Project Management
- Project Milestones
- Project Planning
- Project Timeline
- Pyramid of Production Systems
- Resource Management
- Resource Mapping
- Risk Management
- Scope
- Stakeholders

Foundations of STEM

Engineering Design

Design with Purpose, Prototype with Precision

Imagine being at the intersection of creativity and technology, where your ideas evolve into real-world solutions. Picture yourself sketching designs, selecting materials, and transforming concepts into functional prototypes. With the tools and techniques of engineering design, you'll have the power to solve complex problems and bring innovative ideas to life, shaping the future of industries.

Foundations of STEM: This course introduces the core principles of engineering design, including measurements, material selection, and the product life cycle. You'll gain hands-on experience with 3D modeling and prototyping, mastering 3D printing to transform concepts into functional products. Explore the design process from start to finish, refining ideas and optimizing solutions for real-world applications.

By the end of this course, you'll confidently design, prototype, and test innovative products, transforming ideas into solutions. Whether creating complex 3D models, refining designs through testing, or mastering tools like 3D printing, you'll gain the skills to excel in engineering. This course prepares you to make an impact in industries like robotics, manufacturing, and product design, empowering you to drive progress and shape the future with creativity and expertise.

Mc Graw Hill

binarylogic

ISBN-13: 978-1-2662-4754-5
ISBN-10: 1-2662-4754-8
9 781266 247545