MINISTRY OF EDUCATION

Manufacturing Engineering

TEACHER MANUAL

YEAR 1 - BOOK 1

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

Manufacturing Engineering

Teacher Manual

Year One - Book One

NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION

MANUFACTURING ENGINEERING TEACHER MANUAL

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CONTENTS

INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS), Senior High Technical School (SHTS) and Science, Technology, Engineering and Mathematics (STEM) Curriculum. It aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

This Teacher Manual for Manufacturing covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year One of the new curriculum. It contains this information for the first 12 weeks of Year One, with the remaining 12 weeks contained within Book Two. Teachers are therefore to use this Teacher Manual to develop their weekly Learning Plans as required by Ghana Education Service.

Some of the key features of the new curriculum are set out below.

Learner-Centred Curriculum

The SHS, SHTS, and STEM curriculum places the learner at the center of teaching and learning by building on their existing life experiences, knowledge and understanding. Learners are actively involved in the knowledge-creation process, with the teacher acting as a facilitator. This involves using interactive and practical teaching and learning methods, as well as the learner's environment to make learning exciting and relatable. As an example, the new curriculum focuses on Ghanaian culture, Ghanaian history, and Ghanaian geography so that learners first understand their home and surroundings before extending their knowledge globally.

Promoting Ghanaian Values

Shared Ghanaian values have been integrated into the curriculum to ensure that all young people understand what it means to be a responsible Ghanaian citizen. These values include truth, integrity, diversity, equity, self-directed learning, self-confidence, adaptability and resourcefulness, leadership and responsible citizenship.

Integrating 21st Century Skills and Competencies

The SHS, SHTS, and STEM curriculum integrates 21st Century skills and competencies. These are:

- **Foundational Knowledge:** Literacy, Numeracy, Scientific Literacy, Information Communication and Digital Literacy, Financial Literacy and Entrepreneurship, Cultural Identity, Civic Literacy and Global Citizenship
- **Competencies:** Critical Thinking and Problem Solving, Innovation and Creativity, Collaboration and Communication
- **Character Qualities:** Discipline and Integrity, Self-Directed Learning, Self-Confidence, Adaptability and Resourcefulness, Leadership and Responsible Citizenship

Balanced Approach to Assessment - not just Final External Examinations

The SHS, SHTS, and STEM curriculum promotes a balanced approach to assessment. It encourages varied and differentiated assessments such as project work, practical demonstration, performance assessment, skills-based assessment, class exercises, portfolios as well as end-of-term examinations and final external assessment examinations. Two levels of assessment are used. These are:

- o Internal Assessment (30%) – Comprises formative (portfolios, performance and project work) and summative (end-of-term examinations) which will be recorded in a school-based transcript.
- o External Assessment (70%) – Comprehensive summative assessment will be conducted by the West African Examinations Council (WAEC) through the WASSCE. The questions posed by WAEC will test critical thinking, communication and problem solving as well as knowledge, understanding and factual recall.

The split of external and internal assessment will remain at 70/30 as is currently the case. However, there will be far greater transparency and quality assurance of the 30% of marks which are school-based. This will be achieved through the introduction of a school-based transcript, setting out all marks which learners achieve from SHS 1 to SHS 3. This transcript will be presented to universities alongside the WASSCE certificate for tertiary admissions.

An Inclusive and Responsive Curriculum

The SHS, SHTS, and STEM curriculum ensures no learner is left behind, and this is achieved through the following:

- Addressing the needs of all learners, including those requiring additional support or with special needs. The SHS, SHTS, and STEM curriculum includes learners with disabilities by adapting teaching and learning materials into accessible formats through technology and other measures to meet the needs of learners with disabilities.
- Incorporating strategies and measures, such as differentiation and adaptative pedagogies ensuring equitable access to resources and opportunities for all learners.
- Challenging traditional gender, cultural, or social stereotypes and encouraging all learners to achieve their true potential.
- Making provision for the needs of gifted and talented learners in schools.

Social and Emotional Learning

Social and emotional learning skills have also been integrated into the curriculum to help learners to develop and acquire skills, attitudes, and knowledge essential for understanding and managing their emotions, building healthy relationships and making responsible decisions.

Philosophy and vision for each subject

Each subject now has its own philosophy and vision, which sets out why the subject is being taught and how it will contribute to national development. The Philosophy and Vision for Manufacturing is:

Philosophy: An effective education in Manufacturing Engineering needed for sustainable industrialisation and economic growth should provide learners with opportunities and hands-on experiences to expand, change, enhance and modify the ways in which they view the world. This can be achieved when skilled facilitators provide the enabling environment that promotes the construction of learners' own knowledge, based on their prior experiences leading to the development of critical thinkers, problem solvers and innovators equipped with 21st century skills and competencies.

Vision: Equip graduates with the relevant knowledge and skills to design, analyse and control local and global manufacturing processes.

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SCOPE AND SEQUENCE

Manufacturing Engineering Summary

S/N	STRAND	SUB-STRAND	YEAR 1			YEAR 2			YEAR 3		
			CS	LO	LI	CS	LO	LI	CS	LO	LI
1	Materials for Manufacturing	Classification of Materials	2	1	4	2	1	6	2	1	5
		Properties of Materials	2	1	4	2	1	4	2	1	4
2	Design and Prototyping	Design and Drawing for Manufacturing	2	1	4	3	1	6	2	1	4
		Rapid Prototyping	2	1	4	1	1	2	2	1	4
3	Manufacturing Tools, Equipment and Processes	Manufacturing Tools and Equipment	2	1	4	2	2	4	2	2	4
		Manufacturing Processes	2	1	2	2	1	4	2	1	4
		Safety, Quality and the Environment	2	2	2	2	1	5	2	2	5
Total			**14**	**8**	**24**	**14**	**8**	**31**	**14**	**9**	**30**

Overall Totals (SHS 1 – 3)

Content Standards	**42**
Learning Outcomes	**25**
Learning Indicators	**85**

SECTION 1: UNDERSTANDING MATERIALS

Strand: **Materials for Manufacturing**

Sub-Strand: Classification of Materials

Learning Outcome: *Demonstrate understanding of the performance of materials*

Content Standard: Understand and classify engineering materials according to their use

INTRODUCTION AND SECTION SUMMARY

In this section, learners will be introduced to the relationship between materials science and engineering and its relevance to technological advancement. They will understand how the structure, processing and properties of materials and their use influence the manufacturing of products. Furthermore, learners will be able to classify engineering materials according to their use and link their relevance to the development of products aimed at solving societal problems and improving the quality of life of mankind.

The section covers the following weeks:

- **Week 1**: Relationship between materials science and engineering
- **Week 2**: Structure, processing, properties and performance of engineering
- **Week 3**: Classification of engineering materials according to their use
- **Week 4**: Industrial applications of engineering materials

SUMMARY OF PEDAGOGICAL EXEMPLARS

Given the diversity in learners' backgrounds, learning capacities, and learning styles, it is crucial to employ a broad spectrum of pedagogical approaches that cater for students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as the experiential learning/nature walk, collaborative learning and talk for learning. In this section, consider providing learners the opportunity to view a video detailing the historical progression of materials and the processing thereof and initiating a field trip to local materials processing sites within the community. Allow learners to articulate their experiences through collaborative discourse to identify and classify the materials available in their community into metals and non-metals, and to explain how the processing of these materials affects their structures, properties, performances and use. In mixed ability groupings, learners should be given the opportunity to outline the relevance of material science and engineering in solving societal problems. Finally, a research project can be considered so learners can classify materials according to their industrial applications.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions following a visit to a materials processing company; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to explain the difference and relationship between materials science and engineering and classify materials into metals and non-metals and according to their industrial applications. These should contribute to learners' formative assessment.

Week 1

Learning Indicator: *Explain the relationship between materials science and engineering*

Theme or Focal Area: The relationship between materials science and engineering

Introduction

Materials Science involves investigating the relationships between the structures and properties of materials. Materials Engineering, on the other hand, deals with designing or engineering the structure of a material to produce a predetermined set of properties.

Historical Background of Materials

The development and advancement of societies are linked to the ability of humans to produce materials to satisfy their needs. Civilisations have been designated by the materials developed, such as the Stone Age, Bronze Age, Iron Age, Steel Age, Space Age and Electronic Age. The earliest humans had access to only naturally occurring materials such as stone, wood, clay, skins, etc. Various techniques for developing materials that had improved and better properties than the naturally occurring materials were discovered. This led to pottery and various metals. Afterwards, the change in the properties of materials according to heat treatment and alloying became paramount. This discovery increased the range of available materials. In recent times, scientists have developed materials with specialised properties that meet the needs of the modern age. These include metals, plastics, glasses, and fibres that have led to the development of many technologies that make our existence so comfortable. Today, semiconductor materials are used to develop components for electronic devices such as phones and computers. The discovery and development of advanced materials, biomaterials, and smart materials have revolutionised all industrial sectors in the world. These materials respond to the exact needs of humans and produce efficient responses based on their structure and properties.

Materials Science

Materials science is an interdisciplinary field that involves the investigation and innovation of materials. It includes the study of the relationships that exist between the structures and properties of materials and how to use this knowledge to create new products or enhance the properties of existing ones. From the desks used in the classroom to the aeroplanes that fly, materials science plays a crucial role in promoting technological advancement to meet the needs of mankind. A world without materials science can be likened to a world without innovations.

People who work in the field of materials science are called Materials Scientists. They engage in research and development to discover new materials and improve existing ones. They also perform scientific tests to analyse and understand the properties of materials, and they design materials with specific properties to be used for special applications such as in high-speed electronics, advanced medical devices, sustainable buildings and many more.

Materials science contributes greatly to making society and the environment a better place. For instance, the development of lightweight materials for use by vehicles can lead to fuel efficiency and reduce greenhouse gas emissions. Global plastic waste problems can be addressed by developing and using biodegradable materials. Biomaterials have great prospects in changing the phase of medical science by providing safe and compatible materials to replace worn-out tissues and organs. Flexible and wearable electronics are fast replacing transparent conductive materials in the electronics industry.

Materials Engineering

Materials Engineering deals with designing and developing materials to produce a predetermined set of properties and products. It is focused on ensuring that the properties of materials are tailored towards meeting specific human needs to solve real-life problems by making materials stronger, lighter, durable, or environmentally friendly.

Materials Engineers play major roles in the development of products. Their main roles involve designing and manufacturing new materials, using new or improved materials to develop new products or improve upon existing ones, testing the properties of materials under different conditions to ensure they meet required product specifications or scaling up the production of materials for industrial and commercial use. In most cases, designing new or improved materials stems from understanding the material's structure and manipulating it to achieve a specific property.

Materials Engineers play a critical role in technological advancement and improving the quality of life. They design and develop materials that have unique properties to meet human needs. For instance, the development of materials to improve the safety and performance of vehicles, the development of sustainable and environmentally friendly materials, the development of materials for medical implants and devices that improve health care, the development of flexible electronic materials and the development of materials that improve the efficiency of energy production and storage systems are all possible by the help of by the Materials Engineer.

Relationship between Material Science and Engineering

Materials Science and Engineering are characterised by four main components: processing, structure, properties and performance. These four components are interrelated. Thus, the structure of a material depends on how it is processed, whereas a material's performance is a function of its properties. This relationship is demonstrated in Fig. 1.1.

Why study Materials Science and Engineering?

A design problem involving materials is one of selecting the right materials from the thousands that are available. The final decision is normally based on several criteria, including in-service conditions, material properties and cost. The study of Materials Science and Engineering will help you to:

1. Select a material for a given use, based on cost and performance considerations.
2. Understand the limits of materials and the change of their properties with use.
3. Be able to create a new material that will have some desirable properties.
4. Be able to use the material for different applications.

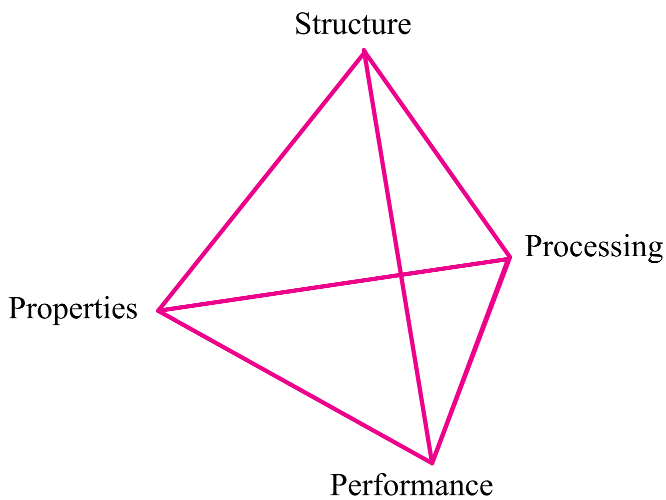

Fig. 1.1: *The Materials Science tetrahedron (Source: Donahue, 2019)*

Learning tasks

1. Learners collect materials from the community and group them into raw and processed materials.
2. Learners use mind maps and webbings to relate historical ages to their respective materials.
3. Learners make presentations on the relationship between materials science and engineering, considering the four components of materials science and engineering, i.e. processing, structure, properties and performance of materials.

Pedagogical exemplars

1. **Experiential learning/Nature walk**

   Let learners go round their community and bring to the classroom different materials available in their communities and group materials, such as stone, wood, clay, skin, plastics and household items into raw and processed materials. Encourage all learners to participate in the activity.

2. **Collaborative Learning**

   a. Introduce learners to the historical evolution of materials from charts, videos and textbooks. Let learners in think-ink-pair-share use mind maps and webbing to relate the historical ages to their respective materials. Be intentional when pairing learners to ensure that learners with difficulties in understanding the concept get help from peers while providing leading tasks to learners who easily understand the concept.

   b. In mixed-ability groups, let learners discuss the relationship between material science and engineering and present findings to the class for feedback. Make room for learners who may want to write their views to also do so.

Note: Encourage learners with physical and health challenges to participate in the lessons.

Key assessment

1. **Assessment Level 1**

   1. Which of the following is not a raw material?

      a) Leather b) wool c) steel d) stone

   2. Which of the following materials is characteristic of the electronic age?

      a) Copper b) stone c) semi-conductors d) smart materials

   3. How does materials engineering differ from materials science?

      a. Materials engineering is theory based.
      b. Materials engineering deals with application of materials to solve real-life problems.
      c. Materials engineering is focuses on the aesthetics of materials.
      d. There is no difference.

   4. Fill in the blank space

      a. ___________ is the branch of engineering that applies the principles of materials science to design, analyse, and manufacture new materials for various applications.

   5. List five (5) materials that can be found in the community and group them into raw and processed materials.

2. Assessment Level 2

1. List two materials each of a raw and processed material.
2. Explain how material evolution has impacted technological advancement.
3. Explain the role of materials science in the development of sustainable solutions such as building materials, solar panels etc.
4. Describe the relationship between material science and engineering.

3. Assessment Level 3

1. Suggest innovative ways to efficiently use raw materials in the local manufacturing industries.
2. What factors account for the need for new materials in different historical ages?
3. Explain the relevance of materials science and engineering in enhancing technology.
4. Discuss how materials science and engineering have contributed to the development of sustainable materials in the electronics industry.

4. Assessment Level 4

1. Discuss sustainable means to process raw materials in the community into durable materials for use.
2. How does technological advancement influence the development of new materials?
3. Consider at least two (2) products (e.g. Table, earthenware bowl, cooking pot, etc.) in the community and tabulate how materials science and engineering influenced their development.
4. Perform a critical review of available literature on the relationship between materials science and engineering, identifying trends, gaps, and future directions for research.

WEEK 2

Learning Indicator: *Explain that the structure, processing, and properties of engineering materials affect their performance and use.*

Theme or Focal Area: The Structure, Processing, and Properties of Engineering Materials Affect Their Performance and Use.

Introduction

The performance of engineering materials depends on the material's structure, properties and processing. The way a material is processed affects its structure at the microscopic and macroscopic levels. The structure of the material also affects its properties, which determines the performance and use of the material.

Structure of a Material

The structure of a material is related to the arrangement of its internal components. This may be classified into atomic, crystal, microscopic, and macroscopic structures.

Atomic Structure

It consists of the nucleus (which contains protons and neutrons) surrounded by electronic orbitals, as shown in Fig. 2.1.

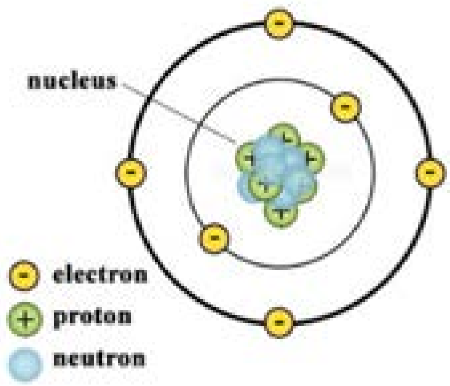

Fig. 2.1: *Atomic structure (Source: Callister and Rethwisch, 2020)*

Crystal structure

It is the arrangement of the material's atoms, ions or molecules in a regular, repeating pattern in a three-dimensional space. Figure 2.2 is a typical crystal structure of a material.

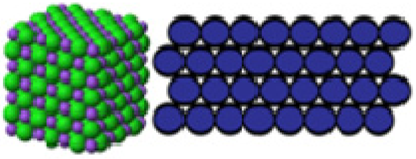

Fig. 2.2: *Crystal structure of a material (Source: Callister and Rethwisch, 2020)*

Microscopic Structure

It is the structure of the material as can be seen under the microscope. Figure 2.3 shows a typical microscopic structure of a material.

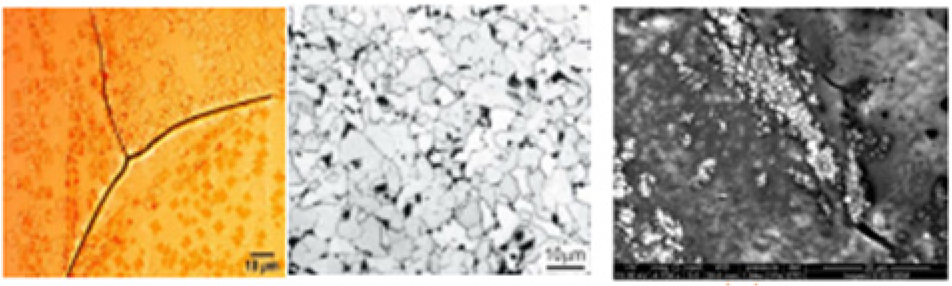

Fig. 2.3: *Microstructure of a material (Source: Callister and Rethwisch, 2020)*

Properties of the Material

The property of the material is the characteristics or attributes that describe its behaviour under certain conditions. These properties can be mechanical, chemical, physical, thermal, electrical, optical, or magnetic. For each property, there is a characteristic type of stimulus capable of provoking different responses.

- **Mechanical properties** relate deformation to an applied load or force; examples include elastic modulus (stiffness), strength, and toughness.
- **Electrical properties**, such as electrical conductivity and dielectric constant, relate to an electric field.
- **The thermal properties** of solids can be demonstrated by heat capacity and thermal conductivity.
- **Magnetic properties** demonstrate the response of a material to the application of a magnetic field.
- **Optical properties** such as index of refraction and reflectivity have stimuli as electromagnetic or light radiation.
- **Chemical properties** relate to structural features and composition of the compounds that make up the material.
- **Physical properties** relate to the colour, appearance and shape of the material.

Processing of Materials

Materials are processed by either heat or mechanical force. This may cause changes in the microstructure of the material that will directly affect the properties of the material.

Relationship between the Structure, Properties, Processing and Performance of Materials

- **The structure of the material affects its properties**: The arrangement of atoms in the structure of a material influences its properties. For example, the crystal structure can impact mechanical strength, hardness, and electrical conductivity.
- **The processing of the material affects its structure and properties**: The processing techniques used to manufacture or modify a material can change its structure, leading to changes in its properties. For example, heat treatment, forging, casting, or other processes can significantly impact a material's performance.
- **The properties of the material determine its performance**: The properties of a material dictate its behaviour and suitability for specific applications. The performance of a material is evaluated based on how well it meets the requirements of a particular use, which is directly related to its properties.

In summary, the structure and properties of a material will depend on how it is processed, while a material's performance and use are dependent on its properties. This is illustrated in Fig. 2.4.

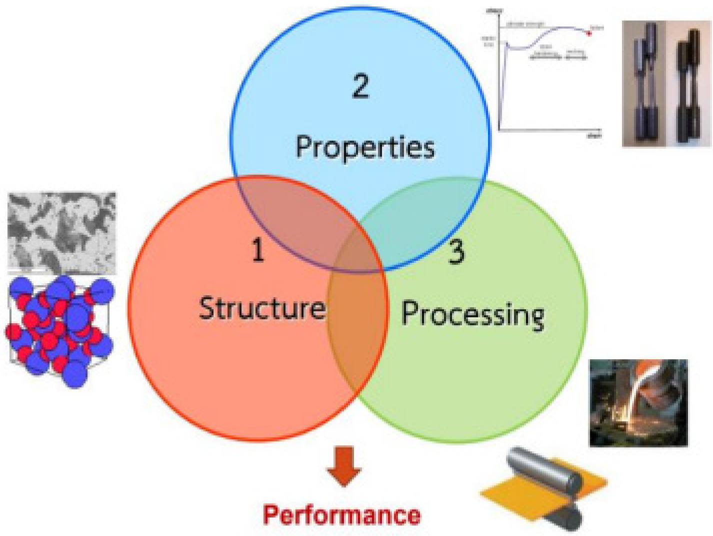

Fig. 2.4: *Relationship between the processing, structure, properties and performance of materials (Source: Callister and Rethwisch, 2020)*

Learning tasks

1. Learners make a list of appropriate materials that can be used to manufacture a product (e.g. a desk, bicycle, computer, etc.) based on their respective properties and the use of the product in everyday life.
2. Learners write a short report on how materials can be processed to enhance their performance and use.
3. Learners make presentations on how the processing of materials affects their structure, property and use.

Pedagogical exemplars

1. **Experiential learning**
   a. Take learners on a tour to any local materials manufacturing or processing site to observe the processing of materials and the anticipated performance enhancement. Let learners write a short report on how materials can be processed to enhance their performance and use. Offer additional support to learners who may not understand the concept while encouraging learners who easily understand the concept to provide more detailed report. Also, consider and make room for persons with disability during the tour.
   b. Let learners identify everyday products such as desks, bicycle, computers etc., and the materials used in manufacturing them. Let learners use flashcards to make a list of the products, the materials used to manufacture them and the reason for using those materials to manufacture the products, taking into consideration the properties of the materials and the use of the products in everyday life. Encourage more proficient learners to consider advanced products as are used in different industries.
2. **Collaborative Learning:** Let learners in mixed-ability groups read and summarise the relationship between the processing, structure, properties, and performance of materials from a chart, textbook or the internet and make a presentation of their results to the class for feedback. Be intentional in the grouping to allow learners with difficulties understanding the concept to receive help from peers, while encouraging more proficient learners to do individual and independent work.

3. **Talk for Learning:** Lead learners to discuss the effect of material processing on their structure, properties, and performance using the materials brought to class in the previous lesson as case studies. Allow learners with difficulties contributing vocally in class to contribute through writing while ensuring that a few learners do not dominate the discussions.

Note: To ensure equal participation, do not avoid learners having difficulty sharing ideas with the whole class; use strategies such as randomly selecting group members to ensure equal participation. Also provide further explanations to learners who may struggle with the concepts or task and challenge learners who give correct responses with leading questions.

Key assessment

1. **Assessment Level 1**
   1. Which of the following factors does not affect the properties of materials?

      a) Colour b) Temperature c) Pressure
      d) Chemical composition
   2. The structure of a material relates to only its physical appearance and shape.
   3. The processing of a material can change its strength and colour.
   4. The properties of all materials are the same properties regardless of their structure and processing methods.
   5. The _______ of a material refers to the arrangement of its atoms and molecules.
   6. Explain how a metal to be used along the coast can be processed to improve its corrosion resistant properties.
   7. State two (2) properties that are important for the performance of engineering materials.
2. **Assessment Level 2**
   1. Briefly describe the structure, processing, properties and performance of at least two (2) selected engineering materials from your locality.
   2. How does the structure of a metal affect its strength and hardness?
   3. A lightweight and corrosion-resistant material is needed for an aircraft component, suggest an appropriate material that can be used to manufacture this component. Explain your choice considering the structure and properties of the material.
   4. A bridge is to be constructed over a river that has some amount of salt in it. Discuss the material properties that are necessary to ensure the durability of the bridge. Suggest suitable materials that can be used for the construction of the bridge and explain how the processing and structure of the material meets the requirements of the bridge.
3. **Assessment Level 3**
   1. Evaluate the effectiveness of material processing in enhancing specific mechanical properties in engineering materials.
   2. A wooden bridge across a river leading to a senior high school collapsed one busy afternoon. How did the structure, processing, and properties of the wood contribute to the collapse of the bridge. What alternative material can be used in the reconstruction of the bridge to prevent its failure? Considering the structure, properties and processing of the alternative material in your analyses.
4. **Assessment Level 4:**
   1. How does knowledge of the structure, processing, properties and performance of materials help in the purchase and acquisition of products for everyday use.
   2. You are required to propose a material to be used in manufacturing a product that will be working in high thermal environments. Describe the desired structure and properties the material should have to ensure its effective use in the high thermal environment.

WEEK 3

Learning Indicator: *Distinguish between different kinds of materials*

Theme or Focal Area: Classification of Materials into Metals and Non-Metals.

Introduction

Different materials are used for different purposes and applications. These materials can generally be classified into metals and non-metals.

Classification of Materials

Engineering materials can be grouped into metals and non-metals. Non-metals consists of ceramics, polymers, composite materials, semiconductors and advanced materials.

Metals

Metals have high thermal and electrical conductivity and are strong yet deformable under applied mechanical loads. They are opaque to light with their atoms bound together by metallic bonds and weaker intermolecular forces. Pure metals are not good enough for many applications, especially structural applications. They are, therefore, used in the form of alloys. Examples of metals include Iron, Aluminium, Copper, Gold, Titanium, etc. Metals have numerous applications such as in nails and screws, automobile parts, utensils, machinery, hammers, etc. Examples of objects made of metals are shown in Fig.3.1.

Fig. 3.1: *Examples of objects made of metals*

Non-metals

All materials that are not metals can be placed in the larger group of non-metals. These materials include ceramics, polymers, composite materials, semiconductors and advanced materials.

Ceramics

These are inorganic compounds and are usually made either of oxides, carbides, nitrides, or silicates of metals. Ceramics are typically partly crystalline and partly amorphous. Atoms (ions often)
in ceramic materials mostly behave like positive and negative ions and are bound by very strong Coulomb forces between them. They are characterised by very high strength under compression and low ductility, usually insulators to heat and electricity. Figure 3.2 shows examples of objects made with ceramics such as glass, pottery, tiles, bricks, cookware, etc.

Fig. 3.2: *Examples of objects made of ceramics*

Polymers

Due to the kind of bonding, polymers are typically electrical and thermal insulators. Conducting polymers can be obtained by doping, and polymer-matrix composites can be obtained by the use of conducting fillers. They decompose at moderate temperatures of about 100 to 400 °C and are lightweight. Examples of objects made of polymers include plastic bottles, plastic bags, toys, PVC pipes, etc., as shown in Fig. 3.3.

Fig. 3.3: *Examples of objects made of polymers*

Composite materials

They are composed of two (or more) individual materials from metals, ceramics, and polymers. The design goal of a composite material is to achieve a combination of properties that is not displayed by any single material, and to incorporate the best characteristics of each of the component materials. There are some natural composites available, such as wood. Other examples of composite materials include fibreglass, reinforced concrete etc. Fig. 3.4 shows fibreglass and reinforced concrete.

Fig. 3.4: *Example of composite materials (Source: Callister and Rethwisch, 2020)*

Semiconductors

Semiconductors have electrical properties that are intermediate between the electrical conductors and insulators. They are an essential component of modern electronics and are used in everything from computers and smartphones to cars and medical equipment. Examples of semiconductor materials include Silicon, Germanium and Gallium Arsenide.

Advanced Materials

Advanced materials are designed to have better properties and performance compared to conventional materials. They are mostly developed through innovative research and technological advancements and often find applications in cutting-edge industries and technologies. Advanced materials play a crucial role in enhancing the capabilities of various engineering disciplines. Some examples of advanced materials include biomaterials, smart materials and nanomaterials.

Biomaterials

These are materials engineered to interact with biological systems for a medical purpose, e.g., used for the replacement of damaged or diseased human body parts. These materials must be biocompatible with body tissues and must not produce toxic substances. Other important material factors are ability to support forces; low friction, wear, density, cost; reproducibility. Typical applications involve heart valves, hip joints, dental implants, and intraocular lenses. Figure 3.5 shows contact lenses and dental implants as examples of biomaterials.

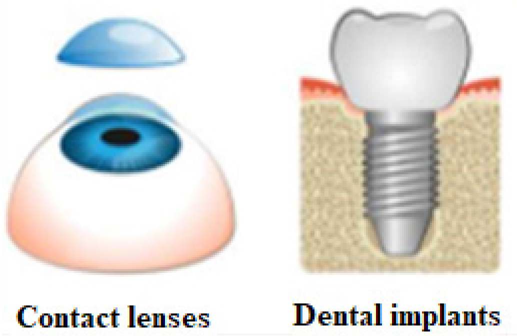

Fig. 3.5: *Examples of biomaterials (Source: Callister and Rethwisch, 2020)*

Smart Materials

Smart (or intelligent) materials are a group of new and state-of-the-art materials which are now being developed and will significantly influence many of our technologies. The adjective smart implies that these materials can sense changes in their environment and then respond to these changes in predetermined manners. In addition, this "smart" concept is being extended to rather sophisticated systems that consist of both smart and traditional materials. Examples of objects that use smart materials include thermostats, smart sensors, shape memory alloys, smart fabrics etc. Examples of smart materials are shown in Fig. 3.6.

Fig. 3.6: *Example of smart materials (Source: Callister and Rethwisch, 2020, and Author's construct)*

Nano Materials

Nanomaterials are developed at the nanoscale (typically between 1 and 100 nanometres) to exhibit unique properties; electrical, mechanical, and optical characteristics. Examples of nanomaterials include carbon nanotubes, graphene and quantum dots.

Learning tasks

1. Learners use mind-maps and webbings to classify materials as metals or non-metals.
2. Learners create a chart to compare the physical properties of metals and non-metals.
3. Learners write a report on a desk designed for their school selecting metals or non-metals based on factors such as cost, availability, functionality and environmental impact.

Pedagogical exemplars

Collaborative Learning

1. Put learners in mixed-ability groups to identify materials available in the classroom and group them into metals and non-metals, using mind-maps and webbings. Encourage all students to participate in the activities.
2. Let learners watch a demonstration video, read from a textbook or the internet on the properties of metals and non-metals. Learners in think-pair-share create a chart that compares the physical properties of metals and non-metals. Use strategies such as randomly selecting pairs to encourage equal participation.

Project-based learning

Learners in groups undertake a project to design a desk for their school. To fabricate the desk, learners are required to select metals or non-metals based on their properties, cost, availability, functionality and environmental impact. Learners should write a report on the project, indicating their justification for the choice of material selected. Groups should be formed such that learners who have difficulties understanding and performing the task will be supported by others. Further, challenge highly proficient students to perform tasks individually.

Note: Use different strategies to help provide further explanations to learners who may struggle with the concepts or task and challenge learners who give correct responses with leading questions.

Key assessment

1. **Assessment Level 1**
   1. Classify the following materials as metals or non-metals and state their use:

      a) aluminium   b) copper   c) concrete
      d) fibreglass   e) stainless steel   f) timber

   2. Which of the following is a non-metal?

      a) Iron   b) Copper   c) Carbon   d) Aluminium

   3. Metals are generally good conductors of electricity. (True/False)
   4. Non-metals can be easily shaped into wires. (True/False)
   5. Match the properties in Category A with the materials in Category B

   Category A: Malleable, Ductile, Good conductor of heat, Lustrous, Brittle, Poor conductor of electricity

Category B: Metals, Non-metals

6. _________ are typically found in the solid state at room temperature, except for mercury, which is a liquid at room temperature.
7. Non-metals are not _________, meaning they cannot be stretched into wires.
8. Name two metals and two non-metals.
9. State two (2) examples of metals commonly used in engineering fields.

2. Assessment level 2

1. Describe three (3) properties of metals and polymers
2. Explain which of the following would be the best material to use for wiring in electrical circuits. a) Rubber b) Copper c) Sulphur d) Silicon
3. Would you select a metal or a non-metal for the manufacturing of a bicycle frame? Explain your choice based on two properties of the material selected.
4. Describe what will happen if a metal and a plastic water bottle are exposed to a flame of fire.

3. Assessment Level 3

1. Evaluate the effect of using metals and non-metals in consumer products on the environment.
2. You are required to recommend a material that conducts electricity and can be easily shaped into wires for use in an engineering application. Would you recommend a metal or a non-metal? Explain your answer.
3. Assess the use of biomaterials in solving the plastic waste menace in the community.

4. Assessment Level 4

1. Given the case that you discover a new material that has a high melting point, high thermal conductivity, and high electrical conductivity in the molten state but low electrical conductivity in the solid state, and it is brittle. Would you classify this material as a metal or a non-metal? Justify your decision based on the properties provided compared to the typical properties of metals and non-metals.
2. Evaluate the impact of mining metals and non-metals on environmental degradation and human health. Propose policy solutions to ensure the sustainable mining of metals and non-metals.
3. Write a report on the role of metals and non-metals in delivering sustainable energy solutions, with a focus on their properties, applications, and implications for environmental sustainability.

WEEK 4

Learning Indicator: *Group materials based on their industrial applications i.e., clothing, building, food, automobiles, electronics and medical.*

Theme or Focal Area: Classification of Materials According To Their Industrial Applications.

Introduction

Every industry has specific materials suitable for its application. The choice of these materials is dependent on their properties (chemical, physical, and mechanical properties). This is evident in the clothing, building, food, automobile, electronic, and medical industries, etc.

Classification of Materials according to their Industrial Applications

Some materials used in various industries include:

a) **Clothing industry:** Materials commonly used in the clothing industry include cotton, wool, silk, leather, nylon, rayon and acrylic fibres. These materials can be classified under two (2) main categories, i.e. natural fibres and synthetic fibres. Natural fibres are raw materials obtained from plants and animals, while synthetic fibres are manufactured or processed materials. Natural fibres are extensively utilised in clothing industries because they are soft, comfortable, and breathable. Synthetic fibres are noted for their durability, wrinkle resistance, and ease of maintenance. However, certain materials do not fit under these categories. These materials include pigments, dyes, fillers, binders, and recycled materials. Table 4.1 shows a list of natural and synthetic fibre materials and their applications in the clothing industry.

Table 4.1: Application of Natural and synthetic fibres

Material Category	Material	Properties	Application/ Products
Natural fibres	Cotton	Soft, breathable and absorbent	T-shirts, dresses, underwear
	Wool	Warm, resilient, elastic	Sweaters, hats and other winter clothing
	Silk	Smooth, soft, natural sheen	Dresses and blouses
	Linen	Lightweight, breathable, absorbent	Summer (hot climate or weather) clothing
Synthetic (Processed) fibres	Polyester	Durable, wrinkle resistant, shape retainability	Sportswear, outdoor clothing and everyday wear.
	Nylon	High strength, elastic, resistant to abrasion	Sportswear, swimwear and hosiery
	Rayon	Soft, comfortable, highly absorbent	Dresses, blouses and linings
	Acrylic	Lightweight, warm, soft	Sweaters and fleece clothing

b) Building industry: Wood, earth, cement, steel, plastic, stone, glass, bamboo, carbon fibre, straw, amongst others, are commonly used in the building industry. These materials are divided into two categories: natural and man-made building materials. Natural building materials are materials that have undergone little to no processing while manufactured building materials are man-made or processed materials. Natural building materials are environmentally friendly and cost-effective but are not mostly durable. Nevertheless, there are different types of materials that are considered eco-friendly. These materials have a low environmental impact. Table 4.2 presents the application of natural and manufactured building materials.

Table 4.2: Application of Natural and manufactured building materials

Material Category	Material	Properties	Application/ Products
Natural building material	Wood	High strength, durable, absorbent	Structural applications, flooring and furniture
	Stone	Durable, aesthetically pleasing, high strength	Exterior and interior walls, concrete reinforcement
	Clay	Durable, good thermal properties	Bricks, tiles and ceramics
Manufactured (Processed) building materials	Cement	High binding ability, ability to harden	Concrete
	Steel	High strength, durable	Wide range structural applications
	Concrete	High strength, durable	Wide structural applications
	Bricks	Durable, good thermal properties	Walls
	Tiles	Durable, aesthetic appeal	Flooring and walls
	Paints and varnishes	Good protection, aesthetic appeal	Surface protection and decorations
Eco-friendly materials	Bamboo	High strength, light weight, renewable	Structural applications
	Recycled materials	Renewable, low energy consumption	Recycled steel, glass and plastic

c) Automobile industry: The automobile industry uses materials such as steel, rubber, plastics, and aluminium. These materials are categorised into five : metals, plastics, rubber, glass, and specialised materials for electric vehicles (EVs). Table 4.3 outlines the application of materials used in automobile.

Table 4.3: Application of materials used in automobile industries

Material Category	Material	Properties	Application/ Products
Metals	Steel	High strength, durable, heat resistant, versatility	Car bodies, engines, chassis etc
	Aluminium	Light weight, good strength	Engines, wheels and body panels

Material Category	Material	Properties	Application/ Products
Plastics	Polypropylene (PP)	Chemical resistance, highly mouldable, suitable for parts with complex and intricate designs	Bumpers, gas cans and engine covers
	Polyurethane (PUR)	High strength, resilient, highly mouldable	Seats, headrests and bumpers
	Polyvinyl Chloride (PVC)	Water resistance, chemical resistance, impact resistance, durable	Cable insulation and instrument panels
Rubber	Rubber	Flexible, durable, ability to absorb shock	Tyres, seals and hoses
Glass	Glass	Transparent, high strength, resistant to ambient weather conditions	Windows and windshields
Specialized Materials for Electric Vehicles (EVs)	Specialized Materials for Electric Vehicles (EVs)	Good electrical properties	Lithium-ion batteries

d) **Food processing industry**: The food processing industries uses raw materials (fish, nuts, fruits, vegetables, etc.), stainless steel, plastics, paper, glass, aluminium, etc. Table 4.4 describes the application of materials used in food processing industries.

Table 4.4: Application of materials used in processing industries

Material Category	Material	Properties	Application/ Products
Raw Agricultural Commodities (Foods)	Raw Agricultural Commodities (fruits, vegetables, grains, dairy products and meats)	Nutritional content, flavour	Cooking, multivitamins, flavours etc.
Processed Foods	Flour	Ability to form structure when mixed with water	Cooking, bread, cakes, cookies etc.
	Sugar	Sweetener, preservative	Cooking, cakes, jams etc.
	Oils and fats (plants and animal sources)	Texture enhancer, good thermal properties	Cooking, baking and texture enhancer
	Salt	Flavour enhancer and preservative	Cooking

Material Category	Material	Properties	Application/ Products
Additives	Preservative	Food shelf-life extension by inhibiting growth of bacteria, yeasts and molds	Can food products
	Colourings	Aesthetic enhancement	Drinks
	Flavourings	Flavour enhancer	Food products (stews, meats etc)
	Emulsifiers	Good binding and mixing enhancement ability	Foods (drinks, evaporated milk and yoghurts)
Packaging Materials	Packaging materials (plastics, metals, glass and paper)	Shelf-life extension and quality improvement ability	Tetrapaks, take away plates, bowls, carbonated drinks (minerals) and fruit juice bottles etc
Materials for Utensils, Equipment, and Machinery	Stainless Steel	High strength, durable, corrosion resistance	Cutlery, cookware, and various types of food processing equipment
	Plastics	Light weight, easy cleaning, resistance to breaking	Utensils, containers and parts of food processing machinery
	Ceramics	Heat resistant, easy cleaning	Cookware and bakeware
	Silicon	Heat resistant, flexible	Baking mats, utensils and seals for food processing machinery

e) Electronic industry: Materials used in the electronic industry include semiconductors, minerals, and non-metallic materials. Table 4.5 shows the applications of materials used in electronic industries.

Table 4.5: Application of materials used in electronic industries

Material Category	Material	Properties	Application/ Products
Semiconductors	Silicon	Semi-metal properties	Microchips, semi-conductor devices, sensors etc
	Germanium		
	Gallium Arsenide (GaAs)		

Material Category	Material	Properties	Application/ Products
Metals	Copper Nickel Chromium Aluminium Lead Silver Tin	Good electrical conductivity and malleability	Resistors, capacitors, transducers, sensors etc
Plastics and Other Petroleum Based Materials	Polystyrene, Polyethylene Terephthalate (PET), and Polyvinylchloride (PVC)	Flexible, durable, good electrical insulation	Capacitors, thermistors etc

f) **Medical industry**: Biological materials, synthetic materials, pharmaceutical raw materials, materials for medical equipment and machinery are commonly used in medical industries. Table 4.6 displays the materials and their applications in medical industries.

Table 4.6: Application of materials used in medical industries

Material Category	Material	Application/ Products
Biological Materials (Biomaterials)	Cells and Tissues	Vaccines and other cell-tissue based products
	Proteins	Various therapies including gene therapy
Synthetic Materials	Polymers, metals	Variety of medical devices, including surgical instruments, implants, and prosthetics
Pharmaceutical Raw Materials	Active pharmaceutical ingredients (APIs)	Drugs used for therapeutic effects
	Excipients	Inactive substances that serve as vehicles for APIs
Materials for Medical Equipment and Machinery	Stainless Steel	Surgical instruments and medical equipment
	Plastics	Medical equipment and devices
	Ceramics	Implants and prosthetics

Learning tasks

1. Learners match given materials to specific industries that use them.
2. Learners debate on the characteristics that make a material fit for use in an industry.
3. Learners make presentations on a proposed material that can be used across any three (3) industries and indicate the characteristics of the named material that make it fit for use in the chosen industries.

Pedagogical exemplars

1. **Collaborative learning**
   a. Provide learners with pictures of different materials and industries. Place learners in mixed-ability groups and let them use mappings and charts to classify the materials given according to their industrial applications. Let learners compare their results while discussing the properties that make the materials selected suitable for application in the respective industries.
   b. Place learners in mixed-ability groups and let them research and make presentations on a proposed material that can be used across multiple industries. In the presentation, let learners explain the characteristics of the material that make it fit for use across multiple industries. You may also allow individuals to conduct independent work.

2. **Talk for learning**

   Put learners into mixed-ability groups with each group representing a particular industry (i.e.. clothing, building, automobile, food processing, electronic and medical industries). Let learners debate why their chosen industries require and use specific materials, considering factors such as material properties, availability, safety and cost. Encourage learners to tolerate the views of others in their debates. Also, make room for and accept both written and oral debates.

Note: To ensure equal participation do not avoid learners having difficulty sharing ideas with the whole class, use strategies such as randomly selecting pairs to ensure equal participation.

Provide further explanations to learners who may struggle with the concepts or task and challenge learners who give correct responses with leading questions.

Key assessment

1. **Assessment Level 1**
   1. Which of the following industries mostly use cotton?

      A) Clothing B) Electronics C) Automobile D) Food
   2. Which of the following materials is commonly used in the electronic industry?

      A) Steel B) Cotton C) Silicon D) Wood
   3. Which of the following materials is mostly used in building construction?

      A) Polyester B) Concrete C) Rubber D) Copper
   4. Glass is often used in the food industry for packaging (True/False)?
   5. List two materials commonly used in the automobile industry.
   6. Identify three (3) materials found in your community and classify them according to their industrial applications.
   7. In one sentence, explain why steel is the most common material used in the construction of bridges.

2. **Assessment Level 2**
   1. Match the materials in **Category A** with their primary industrial applications in **Category B**. Provide a brief justification for each match based on the characteristics of the material.

      Category A: cotton, polyester, aluminium, silicon, titanium

      Category B: clothing, automobiles, electronics, and medical industries.
   2. Explain why stainless steel is used in the food industry instead of clothing.
   3. Explain why plastics are widely used in the food industry for packaging, even though they pose serious environmental problems.

4. Compare the use of locally available materials such as bamboo, clay, plywood and veneer boards with the use of concrete in the building industry.

3. **Assessment Level 3**
   1. Discuss the properties of a semi-conductor that make it suitable for application in the electronic industry.
   2. Evaluate the importance of using polymer materials in the food industry compared to the building industry. Consider issues of health, safety and environmental impact in your evaluation.

4. **Assessment Level 4**
   1. Discuss the characteristics a material needs to have before it can be used across multiple industries.
   2. Compare and contrast the characteristics that make a material fit for use in the automobile and medical industries.
   3. You are tasked with the selection of an environmentally friendly material for the packaging of food to expand its shelf life. Propose a material and explain your choice considering the characteristics of the material.

Review of Section 1

This section introduced learners to the relationship between materials science and engineering, the structure, processing, properties and performance of engineering materials, classification of engineering materials according to their use and the industrial applications of engineering materials. The important lessons learnt from the section are summarised below:

1. Materials science and engineering involves how the processing of materials affects their structure, properties and performance for technological advancement.
2. Knowledge of materials science and engineering helps develop, select and use materials.
3. Materials are characterised by their processing method, structure, properties and performance.
4. The processing of the material affects the structure and properties, while the structure and properties of the material affect its performance and use.
5. Engineering materials can be classified as metals and non-metals.
6. Examples of metals include steel, aluminium, copper, gold, iron etc.
7. Non-metals can exist as polymers, ceramics, composite materials, biomaterials, semiconductors, smart materials, nanomaterials etc.
8. Materials are important for industries to thrive.
9. Every industry has specific materials used for their application.

Additional reading materials

1. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons.

2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). *Advanced Engineering Materials and Modeling*. John Wiley & Sons.

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SECTION 2: PROPERTIES OF MATERIALS

Strand: **Materials for Manufacturing**

Sub-Strand: Classification of Materials

Learning Outcome: *Examine the physical and mechanical properties of materials*

Content Standard: Understand the physical properties of materials

INTRODUCTION AND SECTION SUMMARY

In this section, learners will be introduced to the physical properties of materials. Learners will understand the thermal, electrical, mechanical and magnetic properties of materials and their contributions to the manufacturing of products. Learners will be able to explain different materials properties and link them to specific materials for their use in the design and manufacturing of products that solves societal problems and improving the quality of life of mankind.

The section covers the following weeks:

- **Week 5**: Thermal properties of engineering materials.
- **Week 6**: Electrical properties of engineering materials
- **Week 7**: Mechanical properties of engineering materials
- **Week 8**: Magnetic properties of engineering materials

SUMMARY OF PEDAGOGICAL EXEMPLARS

Given the diversity in learners' backgrounds, learning capacities, and learning styles, it is crucial to employ a broad spectrum of pedagogical approaches that cater for students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as the research-based learning, collaborative learning and talk for learning.

In this section, consider providing learners the opportunity to view a video demonstration of the physical properties of materials. Allow learners to articulate their experiences through collaborative discourse to define the physical properties of materials and link these properties to specific materials available in the community. In mixed ability groups, give learners the opportunity to design experiments to measure the physical properties of materials and use the knowledge gained to propose new products or suggest ways of improving the performance of existing products.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in this section. Oral responses can be elicited in class discussions after watching video demonstrations on the physical properties of materials; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to understand and explain the different properties that make up the thermal, electrical, mechanical and magnetic properties of materials, and apply the knowledge gained in the design and manufacturing of products.

WEEK 5

Learning Indicator: *Explain thermal conductivity, Specific heat capacity, thermal expansion, melting point, and thermal diffusivity as thermal properties of materials*

Theme or Focal Area: Explain The Thermal Properties of Materials.

Introduction

Thermal properties of materials are essential properties that describe a material's response to changes in temperature and heat transfer. The thermal properties of engineering materials include thermal conductivity, specific heat capacity, thermal expansion, melting point, and thermal diffusivity.

Thermal conductivity

It is a property that describes the ability of a material to conduct heat. It is a measure of the rate at which heat is transferred through a material when there is a temperature gradient. Thus, thermal conductivity quantifies how effectively a material can conduct heat from a high-temperature region to a low-temperature region.

Specific heat capacity

It is a measure of the amount of heat needed to raise the temperature of a unit mass of a substance by a given amount. It tells how much heat energy is needed to bring in 1-degree unit change. The concept of specific heat capacity is used in the design of thermal energy storage systems, refrigeration and air conditioning systems, renewable energy systems such as solar water heaters, and thermal insulators. It also has great applications in the food processing, metallurgy and materials processing, and medical industries.

Thermal expansion

The ability of a material to change its shape, area, and volume in response to a change in temperature is called thermal expansion. Thermal expansion depends on the behaviour of the interatomic forces of a material. On increasing the temperature of a material, the energy of the interatomic particles increases, resulting in the vibration of the molecules of the material. This increases the space between the molecules, causing the material to expand. The concept of thermal expansion helps in the design of structures that can accommodate temperature-related damage, for instance, sign bridges, rail tracks, pipelines, and ducts used in the oil and gas industry and many more.

Melting point

The melting point of a material is the temperature at which it changes from a solid state to a liquid. The melting point of pure metal is constant, whereas that of alloys fluctuates. The melting point of a material is dependent on the forces that hold it together. The stronger the bonding force, the greater the melting point. Thus, materials held together by covalent bonds melt at a higher temperature than those of ionic bonds. Materials of low melting point are used in the design of safety equipment such as fuse wire, fuse plugs, and boiler safety devices.

Thermal diffusivity

Thermal diffusivity is the ratio of thermal conductivity to heat capacity. It describes how soon an amount of heat supplied to a material is distributed to all parts of the material. This means that a material with higher thermal diffusivity distributes heat through it faster than one with lower thermal diffusivity. Materials with high thermal diffusivity adapt quickly to changes in the thermal environment to set up a steady-state condition and have applications in the design of heat sinks, pharmaceutical and medical equipment, thermal barrier coatings, casting and solidification, and many more.

Learning tasks

1. Learners use flashcards to define the thermal properties of materials.
2. Learners use mappings to match materials to their thermal properties.
3. Learners conduct experiments to determine the thermal properties of a metallic and wooden spoon.
4. Learners write a report and make presentations on the thermal properties of a metallic and wooden spoon.

Pedagogical exemplars

1. **Talk for Learning:** Let learners read on the thermal properties of materials from charts, textbooks or the internet and lead learners to discuss the thermal conductivity, specific heat capacity, thermal expansion, melting point and thermal diffusivity of different materials (ie. metals and non-metals). Have learners use flashcards and mappings to define and match the thermal properties of given materials. Learners may struggle to articulate their thoughts or express themselves clearly during discussions. Therefore, provide clear instructions on effective communication skills, such as active listening, paraphrasing, and using evidence to support their views. Model effective communication and provide constructive feedback to help students improve their verbal and non-verbal communication skills.
2. **Experiential Learning:** In mixed-ability groups, learners watch videos exhibiting the thermal properties of metals and non-metals and perform experiments to determine the thermal properties of a metallic and wooden spoon in the laboratory. Let learners write a report and make presentations on the experiments they conducted for feedback. Encourage all learners to fully participate in the presentations and accept criticisms and contributions made by colleagues. Performing the experiment may present classroom management challenges. Hence, set clear expectations and guidelines for behaviour and participation during the experiment. Establish clear routines and protocols to ensure a smooth experimental process. Also, maintain an active presence and provide support to learners as needed while ensuring that health and safety protocols are adhered to before, during and after the experiments.

Key assessment

1. **Assessment Level 1**
   1. Which of the following thermal properties describe how well a material transfers heat?
      a) Thermal conductivity b) Specific heat capacity
      c) Thermal expansion d) Melting point
   2. List three (3) thermal properties of materials.
   3. Simply explain the thermal conductivity of materials.
2. **Assessment Level 2**
   1. Identify two common thermal properties of materials
   2. Explain how thermal expansion affects the behaviour of railway tracks.
   3. Describe the concept specific heat capacity and how it affects the heating or cooling of objects.
   4. Explain why a metallic spoon is a better conductor of heat than a wooden spoon.

3. Assessment Level 3

1. Explain the difference between thermal conductivity and thermal diffusivity and provide two (2) materials each that exhibit them.
2. Discuss the relevance of understanding the thermal properties of materials in manufacturing.
3. Analyse the relationship between thermal conductivity, specific heat capacity, and thermal expansion in determining the overall thermal behaviour of a material.
4. Design a simple experiment to compare the thermal conductivities of a metallic spoon and a wooden spoon, outline the steps you will take in performing the experiment and how you will measure your results.

4. Assessment Level 4

1. How will the knowledge of the thermal properties of materials affect the development of a product in the community?
2. Evaluate the significant role the understanding thermal properties play in the design of metallic ladles.
3. You are required to select a material to be used to design an insulated container to keep food hot. What material will you select, and how will the thermal properties of the selected material contribute to the effectiveness of the designed container?

WEEK 6

Learning Indicator(s): *Explain electrical conductivity, electrical resistivity, dielectric strength, and temperature coefficient of resistance as electrical properties of materials.*

Theme or Focal Area: **Explain The Electrical Properties of Materials.**

Introduction

Electric properties refer to how materials behave in the presence of electric current or electric field. They are helpful in selecting materials for electrical applications. Electrical conductivity, electrical resistivity, dielectric strength and temperature coefficient of resistance are examples of electrical properties of materials.

Electrical conductivity

The electrical conductivity of a material is the measure of its ability to conduct an electric current. Materials with high electrical conductivity are good conductors of electricity, while materials with low conductivity are insulators. Examples of materials that are good electrical conductors are: copper, silver and aluminium.

Electrical resistivity

Electrical resistivity is the measure of a material's ability to resist the flow of an electric current. It is the opposite of electrical conductivity. The electrical resistivity of a material is dependent on its temperature and can be used to determine the temperature of a material. Glass, rubber and plastics have high electrical resistivities.

Dielectric strength

It is a measure of the maximum electric field a material can withstand before it breaks down and becomes a conductor. When an insulating material is subjected to an electric field that exceeds its dielectric strength, the material's electrons can gain enough energy to break free from their atomic bonds, resulting in the material becoming conductive. Therefore, dielectric strength is a measure of the insulation capability of a material under high-voltage conditions. Different materials have different dielectric strengths. The dielectric strength of a material can be influenced by factors such as temperature, humidity, and the presence of impurities. Examples of materials with high dielectric strength include glass, diamond, polyethylene, porcelain (ceramic) and mica.

Temperature coefficient of resistance

The temperature coefficient of resistance is a measure of how much the electrical resistance of a material changes with changes in temperature. It quantifies the rate at which the resistance of a material increases or decreases as the temperature changes and is expressed in terms of the percentage change in resistance per degree Celsius (or per Kelvin) of temperature change. The temperature coefficient of resistance is an important factor to consider in various electronic and electrical applications, as changes in temperature can impact the performance and accuracy of devices. For instance, in precision temperature measurement devices, materials with a low or well-controlled temperature coefficient of resistance values, such as platinum and nickel-iron alloys, are desirable to minimise errors caused by temperature variations. On the other hand, materials with a high temperature coefficient of resistance, such as tungsten and semiconductor devices, are used in components that require temperature compensation, such as resistors used in electronic circuits.

Learning tasks

1. Learners match the definitions of the electrical properties of materials using mind maps and webbings.
2. Learners write short reports on the electrical properties of materials and their relevance in manufacturing.
3. Learners perform experiments to compare the electrical conductivity of a metallic and plastic material.
4. Learners make presentations of experimental results, comparing the electrical conductivity of a metallic and plastic material to the class for feedback.

Pedagogical exemplars

1. **Research-based Learning:** Learners watch videos or read textbooks on electrical properties of materials (i.e., electrical conductivity, electrical resistivity, dielectric strength and temperature coefficient of resistance). Learners match the definitions of the electrical properties learnt using mind maps and webbings and write short reports on the electrical properties of materials indicating their importance in manufacturing. Provide extra support to learners with difficulties understanding the concept and encourage highly proficient learners write more detailed reports.
2. **Experiential Learning:** In mixed-ability groups, have learners perform experiments to compare the electrical conductivity of metals and plastics and present their results to the class for feedback. Encourage groups to accept and tolerate feedback given by peers. Ensure that health and safety protocols are adhered to before, during and after the experiments.

Key assessment

1. **Assessment Level 1**
   1. Which of the following electrical properties measures a material that opposes the flow of electric current?
      a) Electrical conductivity b) Electrical resistivity
      c) Dielectric strength d) Temperature coefficient of resistance
   2. Identify two (2) electrical properties of materials.
   3. Define thermal conductivity.
   4. Name two (2) materials that are good conductors of electricity.
2. **Assessment Level 2**
   1. Explain how the electrical conductivity of materials affects copper cables.
   2. "Copper wire has lower electrical resistivity than a rubber band." How true is this statement?
   3. Explain the difference between the electrical conductivity and electrical resistivity of materials.
   4. Describe the difference between an insulator and a conductor and give two examples each.
3. **Assessment Level 3**
   1. Analyse the relevance of understanding the electrical properties of materials in the manufacturing of electronic components.
   2. How do variations in the electrical properties of materials affect their performance and use in electronic devices?
   3. Evaluate the role electrical properties play in selecting materials for the design of power transmission lines.

4. Assessment Level 4

1. How will the knowledge of the electrical properties of materials be used in developing a product in the community?
2. Design an experiment to measure the electrical conductivity of steel.
3. You are required to design a material with high electrical conductivity and low electrical resistivity to be used for the transmission of power. Discuss the factors you will consider in the design of the material.

WEEK 7

Learning Indicator: *Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials.*

Theme or Focal Area: Mechanical Properties of Materials.

Introduction

Mechanical properties of materials refer to the physical properties that a material exhibits when subjected to an applied load or force. These properties help engineers and manufacturers to understand how a material responds to external forces, deforms, and performs in real-world applications. Mechanical properties play a crucial role in selecting materials for specific uses and designing components that can withstand an intended applied force.

Mechanical Properties

Examples of mechanical properties of materials include hardness, brittleness, ductility, strength, malleability, toughness, elasticity, and plasticity as mechanical properties of materials.

Hardness

Hardness is a measure of a material's resistance to localised plastic deformation (e.g., a small dent). During manufacturing the hardness of materials are determined to ensure that they can withstand anticipated loads to meet service conditions. Therefore, hardness is used to evaluate the ability of a material to resist local plastic deformation caused by mechanical indentation or wear. Diamond, ceramics, hardened steel, tungsten carbide etc., are some examples of materials with high hardness. Rubber, plastics, wood, foam, paper etc. have low hardness.

Brittleness

Brittleness is the tendency of a material to fracture or break upon impact. Brittle materials undergo little or no plastic deformation before fracture and have a wide range of applications. For instance, in construction, brittle materials, such as glass and ceramics, are used for their strength and durability. Understanding the brittleness of materials can help engineers design products that are strong and durable. Examples of brittle materials include glass, bricks, eggshells, graphite, and alkali metals like magnesium.

Ductility

Ductility is the ability of a material to undergo plastic deformation (permanent change in shape) without fracturing. Ductile materials can be stretched into wires or bent without fracturing. Engineering applications that require materials with high ductility include metal cables, stampings, and structural beams. Gold, copper, and steel are examples of ductile materials.

Strength

The strength of a material refers to the material's ability to withstand an applied load without failure or plastic deformation. It is one of the most important mechanical properties of materials and is often used as a measure of their quality. The strength of a material can be measured as tensile strength (resistance to pulling forces), compressive strength (resistance to crushing forces) or shear strength (resistance to sliding forces). Knowledge of the strength of materials helps in the design and manufacture of foundations, structures, load-bearing components for vehicles, power generation systems (turbines), and transmission systems.

Malleability

Malleability is the ability of a material to deform under compressive stress (pressure). It is the opposite of brittleness. Malleability is an important property for engineering applications such as shaping, bending, stamping, and rolling, where plastic deformation is necessary for shaping the material. It is used in the production of thin sheet metals for use in the electronics industry. It is also used in the manufacturing of roofing sheets, jewellery (wedding rings, chains amongst other things) and packaging foils (aluminium foils for food packaging). Examples of malleable materials include gold, copper, aluminium, silver, brass, lead etc.

Toughness

Toughness is the ability of a material to absorb energy and plastically deform without fracturing. It is an important property for engineering applications where materials are subjected to impact, shock, sudden loads, and resistance to fracture is key. For instance, in the transportation industry, toughness is an important property for materials used in the manufacture of lorries, aeroplanes, submarines, and ships. These materials must be able to withstand the impact of collisions and other sudden forces. Also, materials used in the manufacturing of machine parts such as gears, shafts, and bearings must be tough since these parts need to withstand the impact of sudden loads and high stresses without breaking. Some tough materials used in engineering are manganese steel, wrought iron, and mild steel.

Elasticity

Elasticity is the ability of a material to deform under stress and return to its original shape when the stress is removed. It is an important property for engineering applications where resistance to deformation is important and has strong application in the design of suspension systems, shock absorbers, brakes, tyres, seals, gaskets, bridges, buildings, aircraft and many more. Rubber, spring steel and silicon materials are examples of materials with high elasticity.

Plasticity

Plasticity is a material property that refers to the ability of a material to undergo permanent deformation when subjected to an applied force or load, without rupturing or breaking. Plastic deformation occurs when the applied stress exceeds a certain threshold, known as the yield strength or yield point, of the material. Beyond this point, the material begins to exhibit plastic behaviour, and further deformation can occur even if the applied stress is reduced. Unlike elasticity, where a material returns to its original shape after the force is removed, plastic deformation results in a lasting change in the material's shape. This property is commonly observed in materials like metals and some non-metallic materials under certain conditions. Plasticity has several applications in forming and shaping, machining, metalworking, etc.

Learning tasks

1. Learners define and match materials with their mechanical properties using flashcards.
2. Learners perform experiments to compare the tensile strength and hardness of metals, plastics and bamboo.
3. Learners make video presentations to compare the strength and hardness of metals, plastics and bamboo
4. Learners write a report to improve the design of a school desk using materials with better mechanical properties.

Pedagogical exemplars

1. **Research-based learning**
   a. Let learners watch a video, read from a textbook or the internet on the mechanical properties of materials (i.e. hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity) and let learners use flashcards to define the mechanical properties of materials and match them to respective materials, and share their results in class.
   b. Put learners in mixed-ability groups and let each group perform experiments to determine either the strength, malleability, hardness or brittleness of selected materials such as metals, plastics and bamboo. Have learners make video presentations of their results including the experiment and present it in class for feedback. Make room for learners who are highly proficient to perform individual experiments.

2. **Talk for learning:** Lead learners to discuss the importance of the mechanical properties of materials in developing a product. Have learners in mixed-ability groups write a report on how to improve upon the design of the school desk using materials with better mechanical properties. Control the class discussion to avoid a few learners dominating the discussions and encourage learners who may not be vocal to contribute to the discussion through writing.

Key assessment

1. **Assessment Level 1**
   1. Which of the following is largely considered as a brittle material? A) Steel B) Glass C) Wood D) Aluminium
   2. List three (3) mechanical properties of materials that are relevant to manufacturing.
   3. Name one (1) material that is known for its high hardness.
   4. What does the tensile strength of a material mean?
   5. List two (2) mechanical properties that should be considered when designing a desk for students.

2. **Assessment Level 2**
   1. Explain how the mechanical properties of desk for students can be improved.
   2. Explain the difference between the tensile strength and hardness of a material.
   3. Describe the importance of mechanical properties in the manufacturing of components.

3. **Assessment Level 3**
   1. How does knowledge of the mechanical properties of materials contribute to the effective design and manufacturing of products?
   2. Compare and contrast tensile strength and hardness as mechanical properties of materials. Provide examples of materials that exhibit each property and explain the advantages of these properties when forging metals into different shapes.
   3. Evaluate and select the mechanical properties that need to be considered when designing a school desk.

4. **Assessment Level 4**
   1. How will the understanding of the mechanical properties of materials enhance the work of local industries in the community?
   2. Design an experiment to measure the tensile strength and hardness of steel and bamboo.
   3. You are required to select either wood, metal or a combination of wood and metal to design a desk for your school based on their mechanical properties. Justify the material you will select based on factors such as strength, hardness, and toughness.
   4. You have been tasked to design a desk for your school. Explain the mechanical properties you will consider in selecting the right materials that will ensure the durability of the desk.

WEEK 8

Learning Indicator: *Explain permeability, retentivity, and reluctance as magnetic properties of materials.*

Theme or Focal Area: Properties of Materials

Introduction

Magnetic properties refer to the ability of a material to become magnetised (give magnetic properties to a material or to strongly respond) when exposed to an applied magnetic field. Magnetic properties are important for engineering applications that involve magnetic fields.

Classifications of Magnetic Materials

Magnetic materials can be classified into three categories: ferromagnetic, diamagnetic, and paramagnetic materials. Ferromagnetic materials are strongly attracted by a magnetic field and retain the magnetism even when the magnetic field is removed. Examples of ferromagnetic materials include iron, nickel, cobalt and steel. Diamagnetic materials are materials that produce negative magnetization when placed in an external magnetic field. Magnetic fields do not attract diamagnetic materials. Examples of diamagnetic materials are wood, glass, water, copper, and gold. Paramagnetic materials acquire a small net magnetic moment in the direction of the applied field, meaning they are slightly attracted by the magnetic field. Examples of paramagnetic materials include lithium, magnetic aluminium, and molybdenum. Table 8.1 shows the list of magnetic materials, their classifications and applications.

Magnetic Properties

Examples of magnetic properties of materials include permeability, retentivity and reluctance. The properties of permeability, retentivity and reluctance are not only dependent on the material but also on the specific conditions, such as temperature, the presence of an external magnetic field and the history of the material's magnetisation.

Permeability of materials

Permeability is a magnetic property of materials that describes how easily a material can be magnetised when exposed to an external magnetic field. It is a measure of the material's ability to allow magnetic lines of flux to pass through it as shown in Fig. 8.1. In other words, permeability indicates the degree to which a material can respond to and interact with an applied magnetic field by becoming magnetised itself. Different materials exhibit different permeability characteristics, which can have a significant impact on their magnetic behaviour and applications. For instance, ferromagnetic materials, such as iron, nickel, and cobalt, have relatively high absolute permeability due to the presence of magnetic domains that can align with external magnetic fields. This makes them ideal for applications in transformers, electromagnets and magnetic storage devices. Paramagnetic materials, such as copper, aluminium and oxygen gas, have lower permeability compared to ferromagnetic materials, indicating a weak attraction to magnetic fields. However, they are used in magnetic resonance imaging (MRI) machines and sensors. Diamagnetic materials, such as graphite, silver, mercury, water, have permeability lower than those of paramagnetic materials, indicating a weak repulsion from magnetic fields. Although their magnetic response is very weak, they are used in levitation applications for experimental purposes.

Table 8.1: List of magnetic materials, their classifications and applications

Magnetic Classification	Material	Permeability	Retentivity	Reluctance	Application
Ferromagnetic	Iron	High	High	Low	Used in power generation and transmission, electronic devices, and data storage
	Nickel				Used in coinage, rechargeable batteries, and electric guitar strings
	Cobalt				Used in the manufacture of magnetic, wear-resistant, and high-strength alloys
	Steel				Used in automotive applications, kitchenware, and industrial equipment
Paramagnetic	Aluminium	Low	Low	High	Used in the manufacture of aircraft, automobiles, and packaging
Diamagnetic	Copper	Low	Low	High	Used in the manufacture of aircraft, automobiles, and packaging

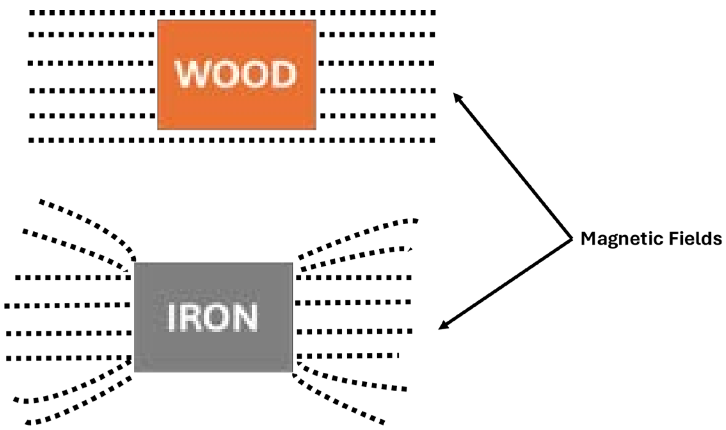

Fig. 8.1: *Magnetic lines of flux in iron and wood*

Magnetic retentivity of materials

Magnetic retentivity is a property that measures the ability of a material to retain a level of magnetisation even after the external magnetic field has been removed. Permanent magnets need to have high magnetic retentivity to ensure that the magnet retains its magnetic strength over time, making it suitable for applications in electric motors, generators, and speakers. In magnetic storage media like hard drives and magnetic tapes, magnetic retentivity allows data to be stored as magnetic patterns that persist over time, even when the external magnetic field is removed.

Magnetic reluctance of materials

Magnetic reluctance is a property of a magnetic circuit that is similar to the concept of electrical resistance in an electrical circuit. It measures the opposition offered by a material to the flow of magnetic flux through it when subjected to a magnetic field. In other words, magnetic reluctance quantifies the difficulty with which magnetic lines of flux pass through a material or magnetic circuit. Magnetic reluctance depends on the length of the path of the magnetic flux, the cross-sectional area of the material and the permeability of the material. It has applications in the design of magnetic circuits and magnetic sensors.

Learning tasks

1. Learners make flashcards that define each magnetic property with definitions and examples of materials that highly exhibit the said magnetic property.
2. Learners in mixed-ability groups perform experiments using iron filings, different shapes of magnets and non-magnetic objects, such as wood, to visually examine the concept of magnetic fields. Learners observe the alignment of the iron filings along the field lines around the different magnetic shapes and wood and make video recordings of their results for discussion in class.
3. Learners in mixed-ability groups, discuss ways to improve upon the design of a magnetic storage device considering its permeability, retentivity and reluctance. Learners write a report on their design and present to class for feedback.

Pedagogical exemplars

1. **Research-based learning**
   a. Learners read from the library and the internet on the magnetic properties of materials (i.e. permeability, retentivity, and reluctance). Learners use flashcards to define the magnetic properties of materials, with examples, and share their results in class. Encourage learners to share their findings with each other to promote collaborative learning.
   b. Let learners in mixed-ability groups perform experiments to explore the concept of magnetic fields using iron filings, different shapes of magnets and non-magnetic objects, such as wood. Have learners record video presentations of their results and present them in class for feedback. Encourage more proficient learners to perform individual experiments.
   c. Let learners watch demonstration videos of the magnetic properties of materials and let learners in mixed-ability groups, discuss and write a report on how knowledge of the magnetic properties of materials can help improve upon the design of a magnetic storage device. Allow learners who may not be vocal to contribute to the discussion through writing. Encourage all learners to contribute to the discussion while ensuring that a few learners do not dominate the discussion session. Also, make room for more proficient learners to submit individual reports. Provide learners with resources or direct them to sources where they can find more information on the magnetic properties of materials.
2. **Talk for learning:** Lead learners to discuss the importance of the magnetic properties of materials in developing a product and ways to improve upon the magnetic properties of products such as doorbells and refrigerator doors. Allow learners who may not be vocal to contribute to the discussion through writing. Encourage all learners to contribute to the discussion while ensuring that a few learners do not dominate the discussion session. Some learners may not be able to listen effectively. Develop communication and discussion skills to facilitate learning.

Key assessment

1. **Assessment Level 1**
   1. Identify two (2) magnetic properties of materials.
   2. Which of the following magnetic properties describes the ability of a material to form a magnetic field within itself?

      a) Permeability b) Retentivity c) Reluctance
   3. What is permeability in terms of magnetic properties of materials?

      a) Ability of a material to conduct a magnetic field
      b) Ability of a material to retain a magnetic field
      c) Resistance of a material to a magnetic field
   4. Which of the following materials would have high retentivity?

      a) Iron b) Copper c) Aluminium d) Air
2. **Assessment Level 2**
   1. Explain why aluminium is not a good candidate for developing magnetic products.
   2. Explain the reason for the use of high permeability materials as cores in electromagnets.
   3. Explain the concept of permeability and give an example of a material with high permeability.
   4. Discuss the importance of retentivity in the design of permanent magnets.
   5. Compare the magnetic properties of permeability, retentivity, and reluctance.
3. **Assessment Level 3**
   1. Explain the importance of magnetic properties in manufacturing magnetic products.

2. Design an experiment to compare the reluctance of copper and wood. Explain the setup, and predict the results of the experiment.
3. Analyse how the magnetic properties of a material can impact its use in at least two (2) different applications.
4. Design an experiment to measure the permeability of iron, copper and wood.

4. Assessment Level 4

1. How relevant is the understanding of the magnetic properties of materials to the local industries in the community?
2. You are required to design an efficient electric motor taking advantage of the permeability, retentivity, and reluctance of selected materials. Explain the materials you will use for your design and how their magnetic properties will enhance the performance of the electric motor.
3. Identify a material with high reluctance and discuss the implications of this property on its uses.
4. Discuss how the properties of permeability, retentivity, and reluctance could be manipulated to improve the efficiency of a transformer.

REVIEW OF SECTION TWO

This section introduced learners to the properties of materials with emphasis on thermal properties, electrical properties, mechanical properties and magnetic properties. The section focused on the use of these properties in manufacturing products to improve human lives. The important lessons learnt from the section are summarised below:

1. Thermal properties of materials include thermal conductivity, specific heat capacity, thermal expansion, melting point, and thermal diffusivity. Thermal properties have wide applications in product design and material processing.

2. Electrical conductivity, electrical resistivity, dielectric strength and temperature coefficient of resistance are electrical properties of materials. These properties are helpful in selecting materials for electrical applications.

3. Mechanical properties of materials refer to the physical properties that a material exhibits when subjected to an applied load or force. They include hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity. Mechanical properties of materials are important when selecting materials for the design of components that can withstand an intended applied force.

4. The ability of a material to become magnetised when exposed to an applied magnetic field is a measure of its magnetic property. Permeability, magnetic retentivity and reluctance are examples of magnetic properties of materials. Magnetic properties have wide applications in the electronic industry.

Additional reading materials

1. **Hummel, R. E., (2011). Electronic Properties of Materials, 4th Edition, Springer.**
2. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons.
3. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). *Advanced Engineering Materials and Modeling*. John Wiley & Sons.
4. J. Pelleg, J., and Gladwell G. M. L., (2013). *Mechanical Properties of Materials*, Springer.

5. B. D. Cullity, B. D., & Graham C. G., (2008). *Introduction to magnetic materials*, Wiley-IEEE Press.

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1. **Hummel, R. E., (2011). Electronic Properties of Materials, 4th Edition, Springer.**
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SECTION 3: UNDERSTANDING MATERIALS

Strand: **Design and Prototyping**

Sub-Strand: Design and Drawing for Manufacture

Learning Outcome: *Apply Technical Drawing skills to the design of products*

Content Standard: Demonstrate knowledge and skill in the development of surfaces

INTRODUCTION AND SECTION SUMMARY

In this section, learners will be introduced to the use of drawing instruments. They will understand how to make freehand sketches and develop the surfaces of simple objects for manufacture. Additionally, learners will be equipped with skill sets that will help them design solutions for problems using the design process.

The section covers the following weeks:

Week 9: Application of drawing instruments in product design

Week 10: Development of surfaces for manufacture

Week 11: Understanding the design process

Week 12: Applications of freehand sketching and visualisation of objects in product design

SUMMARY OF PEDAGOGICAL EXEMPLARS

Learners come from different backgrounds and have varying learning capacities and learning styles. It is, therefore, crucial to use different pedagogical approaches that cater to the varied abilities of students in the classroom. Pedagogical exemplars such as project-based, experiential learning and talk for learning approaches should be adopted to meet the different learning capacities and styles of learning. In this section, consider providing learners the opportunity to practise the use of drawing instruments to make freehand sketches, draw boarder lines, title blocks and the surface development of basic shapes. In mixed-ability groups, learners should be given the opportunity to fabricate simple shapes such as squares, cones and cylinders at the workshop using boxes or metal sheets. Furthermore, provide learners with the opportunity to go out into the community to interview people to understand community problems and allow learners to articulate their experiences through collaborative discourse to understand community problems and use the design process to develop solutions accordingly. Finally, a research project should be considered to help learners use their technical drawing skills and understanding of the design process to solve a problem in the community.

ASSESSMENT SUMMARY

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Projects that allow learners to apply the principles learnt to solve problems in the community and develop surfaces of objects for manufacture should also be encouraged. At the end, learners should be able to use drawing instruments, develop the surfaces of objects for manufacture and use the design process to solve problems in the community. These should contribute to learners' formative assessment.

WEEK 9

Learning Indicator: *Demonstrate the use of drawing instruments in product design.*

Theme or Focal Area: Using Drawing Instruments in Product Design

Introduction

Drawing instruments are specialised tools that are used by engineers, architects, and other professionals to create accurate and precise drawings, diagrams, and plans. These instruments are used to create accurate and detailed drawings of designs. Examples of drawing instruments include: a drawing board, pencils, T-square, set squares, a pair of compasses etc.

Pencils

The pencils used for technical drawing differ in some ways from ordinary pencils. They are available in a range of hardness levels, from 9H (hardest) to 9B (softest). Table 9.1 shows the type of pencils used in engineering drawing and their uses. All pencil lines should be thin and clear. Pencils to be used for drawing purposes must be kept sharp to ensure clarity of drawings.

Set squares

They are triangular rulers used to draw angles and perpendicular lines. Fig. 9.1 is a picture of set squares used in engineering drawing.

Table 9.1 Type of pencils and their uses

Type of Pencil	Use
B	Soft-grade pencil used for border lines, lettering and free hand sketching
HB	Medium grade pencil used for visible outlines, visible edges and boundary lines.
H	Hard grade pencil used for construction lines, dimension lines, leader lines, extension lines, centre lines, hatching lines and hidden lines.
2H	Very hard-grade pencil used for graphic and technical drawing.

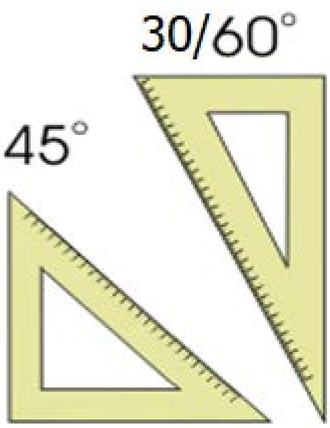

Fig. 9.1: *Set squares*

A Pair of Compasses

It is an instrument with two arms, one holding a pointed drawing tip and the other a pencil. It is used to draw circles and arcs with precise radii. Fig. 9.2 is an example of a pair of compasses.

Fig. 9.2: *A pair of compasses*

Protractor

A circular tool used to accurately measure and draw angles. Fig. 9.3 is an example of a protractor.

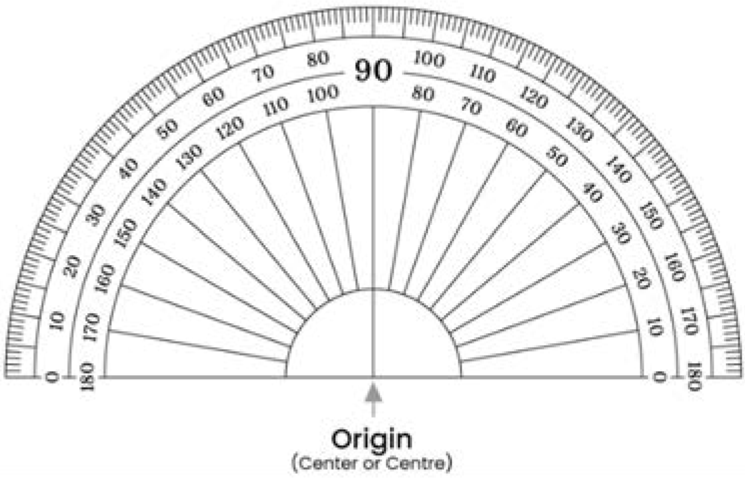

Fig. 9.3: *Protractor)*

Dividers

They are adjustable tools with two pointed legs used to measure and transfer distances, as well as to divide lines and arcs into equal parts. Fig. 9.4 is an example of a divider.

Fig. 9.4: *Divider*

Ruler

It is a basic tool used to measure and draw straight lines, dimensions, and distances accurately. It helps to ensure the precision and clarity of drawings. Fig. 9.5 is an example of a ruler.

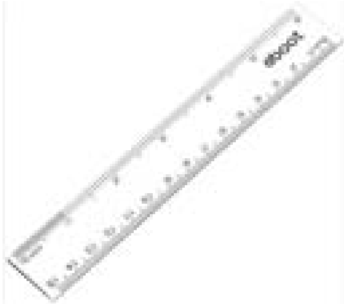

Fig. 9.5: *Ruler (*

French curves

French curves are curved templates used to draw complex curves that are challenging to create with regular drawing tools. An example of a French curve is shown in Fig. 9.6.

Fig. 9.6: *French curve*

Drawing board and T-square

A drawing board is a flat, portable surface used to support a paper or drafting sheet during the drawing process. A T-square is a T-shaped ruler used to draw horizontal lines and to align other drawing instruments on the drawing board. Fig. 9.7 shows a drawing board with a T-square. When drawing, the effective surface of the drawing board and the effective edges of the drawing board and T-square, as shown in Fig. 9.8, are used.

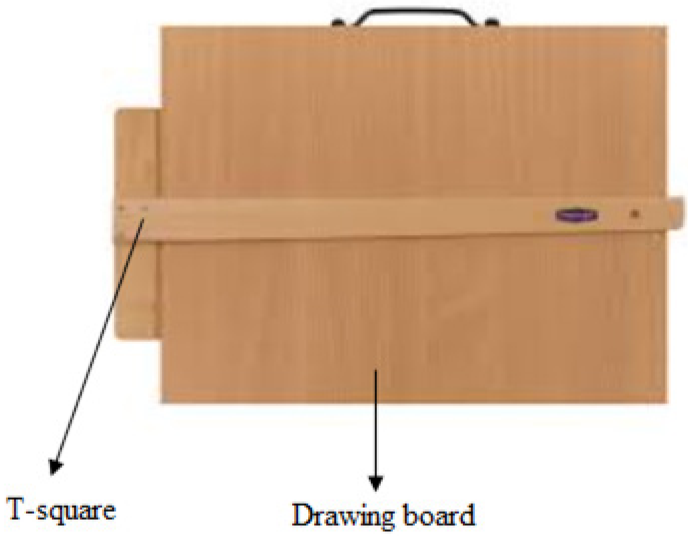

Fig. 9.7: *Drawing board with T-square*

Drawing sheets

The A series drawing sheets are mostly used in technical drawing. These drawing sheets come in different sizes as shown in Table 9.2 and Fig. 9.8. Drawing sheets can be laid out in drawing boards in landscape (viewed with the longest side horizontal) or portrait (viewed with longest side vertical) form. When using A0 to A3 drawing sheets, only landscape form of layout holds.

Table 9.2 Sizes of A-series drawing sheets

Drawing Sheet	Trimmed Sheet (mm)	Drawing Field
A0	841 × 1189	831 × 1179
A1	594 × 841	584 × 831
A2	420 × 594	410 × 584
A3	297 × 420	287 × 410
A4	210 × 297	200 × 287

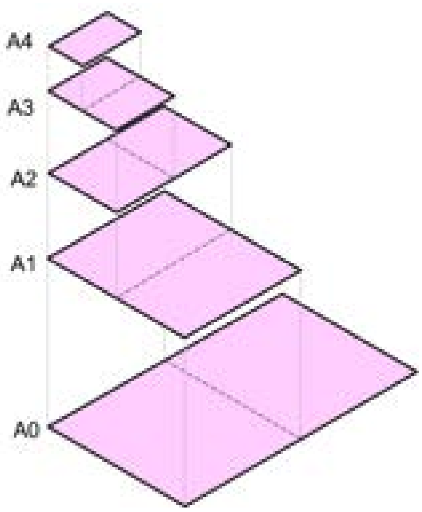

Fig. 9.8 :*Sizes of A-series drawing sheets*

Layout of drawing sheet

A blank drawing sheet to be used for any drawing contains borders enclosed by edges of trimmed drawing sheet, title block, frame limiting the drawing space and centring marks, as shown in Fig. 9.9.

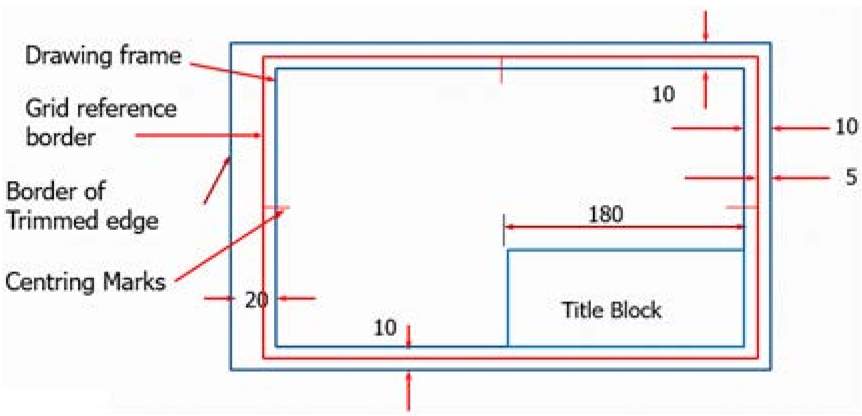

Fig. 9.9: *Layout of drawing sheet (dimensions in mm)*

Setting out a drawing sheet on a drawing board

The following techniques can be used to set out a drawing sheet on a drawing board:

- **a)** Place drawing paper on board
- **b)** Place T-square on paper
- **c)** Align herd of T-square to effective edge of board
- **d)** Align top edge of paper to horizontal effective edge of T-square
- **e)** Slide T-square slightly down and clip expose upper edge of paper to board

Title block

The title block is located at the bottom right-hand corner of the drawing space and contains basic information such as ***name of company or organisation***, ***title of drawing, drawing number, scale, date with name of staff who designed, drew and checked the drawing, method of projection.*** Fig. 9.10 is a sample Title block that can be used for drawings (all dimensions are in mm).

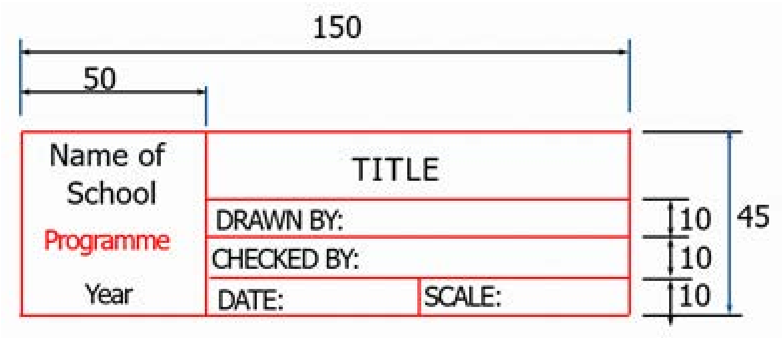

Fig. 9.10: *Sample title block*

Learning tasks

1. Learners identify drawing instruments and discuss their use.
2. Learners set out drawing sheets on a drawing board and use drawing instruments to draw boarder lines, title blocks and simple geometric shapes.
3. Learners teach a lesson on the effective use of drawing instruments in product design.

Pedagogical exemplars

1. **Talk for learning:** Ask learners to bring drawing instruments (such as pencils, protractor, compass, divider, set squares, clippers, Tee-square, drawing board, drawing sheet, eraser, French curves, scale rule, circle and ellipse templates, etc.) to class. Let learners identify the drawing instruments and discuss their uses. Furthermore, let learners in groups teach each other a lesson on the effective use of drawing instruments in product design. Ensure that every learner participates in the discussion and make room for learners who are not vocal to contribute to the discussion through writing. Also, encourage all learners to participate in the group teaching while giving greater teaching roles to learners who have very good understanding on the use of drawing instruments.
2. **Practice-based learning:** Let learners in mixed-ability groups practise the use of drawing instruments by setting out drawing sheets on the drawing board, drawing boarder lines and title blocks and drawing simple geometric shapes. Let learners display their drawings and receive

feedback. Be intentional when pairing the learners to ensure that those who have problems using the drawing instruments will receive help from others who are conversant with the use of the drawing instruments. Also, challenge learners who have very good understanding of the use of the drawing instruments with leading problems.

Key assessment

1. **Assessment Level 1**
   1. Which instrument is used to draw straight lines?
      a) Pair of compasses
      b) Protractor
      c) Ruler
      d) French curve
   2. To draw perfect circles in your product design sketches, you should use a ________.
   3. A protractor is used to measure and draw angles in product design.
   3. What is the use of a French curve in product design?
   4. Using drawing instruments, draw the border line and title block for a product to be designed.
2. **Assessment Level 2**
   1. Explain the uses of a protractor and a T-square in the drawing of a product.
   2. Compare and contrast the use of a French curve and a pair of compasses in drawing a curve and discuss the conditions within which one would be preferred over the other?
   3. You are required to draw a product that has both straight and curved shapes. Which drawing instruments will you use to draw each shape and why?
   4. Using the drawing board and other instruments, draw a circle of diameter 80 mm and a rectangle of length 70 mm and height 45 mm.
3. **Assessment Level 3**
   1. Describe the techniques for setting out a drawing sheet on a drawing board.
   2. Discuss how mastery of the use of drawing instruments can affect the accuracy of a drawing and the functionality of a product.
   3. Evaluate the importance of using the appropriate drawing instrument for a given technical drawing assignment.
   4. Investigate how professional product designers utilise drawing instruments in their work and make a presentation on how you can apply these professional practices in your drawings.
4. **Assessment Level 4**
   1. How does the use of drawing instruments contribute to precision and detail in product design?
   2. Provide a justification for mastering and using drawing instruments even in this era of highly dominated digital drawing technologies.
   3. Evaluate the advantages and disadvantages of using traditional drawing instruments compared to digital tools in product design.
   4. Develop guidelines to ensure the appropriate use of drawing instruments.

WEEK 10

Learning Indicator: *Develop the surfaces of models for manufacturing*

Theme or focal area: principles of surface development

Introduction

Surface development is a geometric concept used to transform 3D objects into 2D patterns. It involves unfolding or unrolling a complex 3D surface or object to create a flat, 2D representation that can be used as a template for manufacturing, design, or other applications. The development of an object is, therefore, the shape of a plain figure that by proper folding can be converted to the shape of the solid figure.

Importance of surface development

Surface development is an important concept in product design and manufacturing especially in sheet metal work. Products such as boilers, chemical vessels, storage vessels and chimneys are manufactured using the principle of surface development by cutting plates and bending them into their desired shapes.

Methods of surface develop ment

Parallel line development: Uses parallel lines to construct the expanded pattern of each three-dimensional shape. The method divides the surface into a series of parallel lines to determine the shape of a pattern. This method is mostly used in the development of prisms and cylinders.

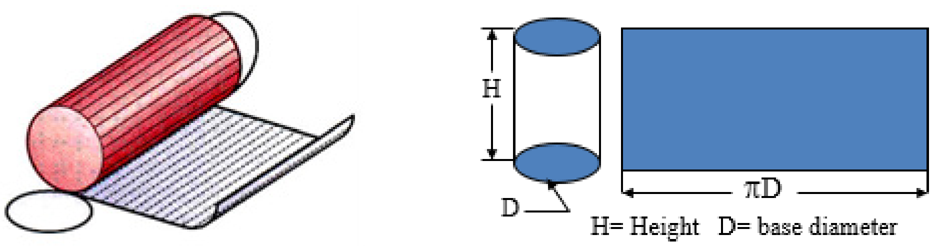

Fig. 10.1: *Development of a cylinder using parallel line method.*

Radial line development: Uses lines radiating from a central point to construct the expanded pattern of each three-dimensional shape. It is mostly used in the development of cone and pyramid.

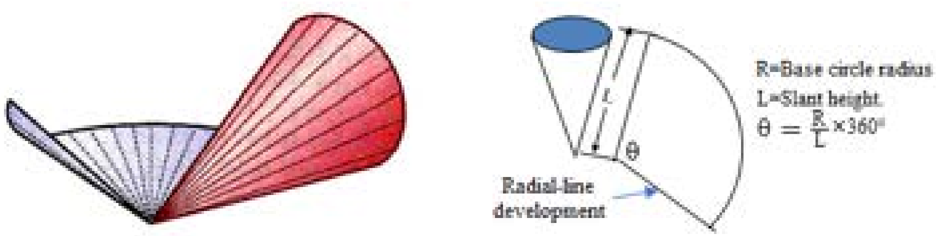

Fig. 10.2: *Development of a cone using radial line method*

Triangulation development

These developments are made from polyhedrons, single-curved surfaces and wrapped surfaces. Examples include development of tetrahedron and other polyhedrons.

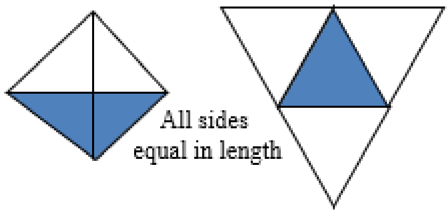

Fig. 10.3: *Development of a tetrahedron using triangulation method*

Approximate development

In this method, **t**he shape obtained is only approximate. After joining, the part is stretched or distorted to obtain the final shape. This is used in the development of spheres.

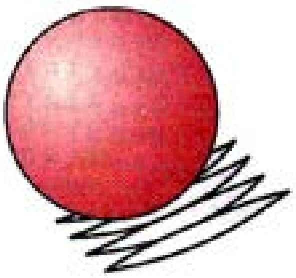

Fig. 10.4: *Development of a sphere using approximate method*

Application of Development of Surfaces

Knowledge of surface development is essential in the sheet metal, fashion, architectural, and engineering industries where products like utensils, cans, buckets, hopper, domes, aircraft fuselage, fuel tanks, clothes, furniture, packaging are made. For instance, a tailor first prepares a surface development on a cloth (pattern) to cut and stitch the correct shape and size of a shirt.

Learning tasks

1. Learners fold empty boxes along their lines to form a box and identify the method of surface development used.
2. Learners write a short report on the methods of surface development.
3. Learners fabricate cones and cylinders at the workshop using the principles of surface development.

Pedagogical exemplars

1. **Experiential learning:** Using paper boxes, let learners in mixed-ability groups unfold and fold empty boxes along their lines, and identify the method of surface development used in folding the box. To ensure that the learning needs of all learners are met, provide step-by-step instructions and demonstrations on folding techniques for learners who may require additional support, while encouraging learners who quickly understand concepts to independently explore more folding techniques. Also, ensure peer-to-peer collaboration in the mixed-ability groups to foster exchange of ideas and provision of assistance to one another. This will promote skill development and peer-to-peer learning.
2. **Talk for learning:** Let learners watch a demonstration video on the use of the principles of surface development to manufacture a product. Lead learners to discuss the methods of surface development such as parallel-line development, radial-line development, triangulation

development and approximate development and write a short report on them. Offer additional resources, such as visual aids, to learners who may have difficulties understanding the concept to reinforce understanding the principles of surface development methods. Also, encourage learners to engage in collaborative discussions, allowing for peer teaching and learning to promote deeper understanding of where they can share insights and perspectives on the various methods of surface development, allowing opportunities for peer teaching and learning, and promoting a deeper understanding of the principles of surface development.

3. **Project-based learning:** Let learners in mixed-ability groups develop cones and cylinders at the workshop using the principle of surface development and present their product in class for feedback. Ensure that all students are challenged according to their understanding and skills on surface development. Also, develop a peer mentoring system in the mixed-ability groups to encourage more advanced learners to support their colleagues in understanding and effectively applying surface development principles to develop cones and cylinders in the workshop.

Key assessment

1. **Assessment Level 1**
   1. Which of the following activities involve folding empty boxes along their lines to form a box?
   (a) Technical drawing (b) Fabrication of a cone
   (c) Surface development d) Design
   2. Surface development is only applicable in the woodworking industry. (True or False)
   3. What is surface development?
   4. Give two (2) examples of household objects that rely on surface development in their manufacturing process?
   5. Name three (3) methods used to develop surfaces onto flat planes.
   6. List three (3) geometric shapes that can be developed into flat surfaces without distortion?
   7. Briefly explain the importance of surface development in the field of manufacturing.

3. **Assessment Level 2**
   1. Define surface development as used in the field of manufacturing.
   2. What is the main reason for using surface development in product manufacturing?
   3. Demonstrate how to develop the surface of a cone using paper-folding techniques.
   4. Explain how the surface of a cone can be developed from a plain metal sheet.

3. **Assessment Level 3**
   1. What is the relationship between the dimensions of an object and its corresponding developed surface?
   2. How do changes in the dimensions of objects affect the shape and size of their developed surfaces?
   3. Apply the principles of surface development to create a flat pattern for a compound shape composed of multiple geometric solids, such as a composite cylinder with attached cones.
   4. Propose an alternative surface development method that can be used to improve the precision of the manufacturing process.

4. **Assessment Level 4**
   1. Discuss strategies that can be developed to break down complex shapes into simpler components to ensure accurate surface development.
   2. Propose two (2) innovative surface development methods that can be used to improve the efficiency of the manufacturing process.
   3. Use the principle of development of surfaces to produce a funnel.

WEEK 11

Learning Indicator: *Demonstrate understanding of the design process*

Theme or Focal Area: Understanding The Design Process.

Introduction

The design process is a systematic approach to creating products that meet specific requirements, while considering various factors such as functionality, cost, materials, and production methods. It involves a series of stages that guide the transformation of an initial concept into a tangible and marketable product.

The Design Process

The design process consists of the following steps:

1. **Defining the problem**: The design process begins with identifying and defining a problem that needs a solution.
2. **Researching/asking questions to understand the problem**: This involves understanding the problem that needs to be addressed. It is mostly done through market research and gathering input from stakeholders and end-users.
3. **Brainstorming potential solutions (conceptual designs)**: This involves the generation of ideas through brainstorming and exploring various concepts, design ideas, and different approaches to solving the problem.
4. **Deciding on a solution using an evaluation criterion essential to the solution:** This involves assessing and evaluating the generated concepts based on criteria such as functionality, manufacturability, safety, and cost, and selecting the best design concept that aligns with project objectives and constraints.
5. **Developing the solution**: This involves defining detailed specifications for the selected concept, including dimensions, materials, tolerances, performance criteria, and creating 3D computer-aided design (CAD) models and engineering drawings that depict the product's geometry and components. Design calculations are also performed at this stage to determine the right sizing of the components to select for the product.
6. **Making a prototype of the solution**: This stage involves building physical prototypes or models to validate the design and test its functionality. At this point, appropriate materials for the product are chosen based on their properties, availability, cost, and compatibility with the design. Also, decisions on the manufacturing processes required for each component are made considering factors such as precision, efficiency, and scalability.
7. **Testing the prototype**: This stage involves conducting physical testing and experimentation to validate the design's performance under different conditions.
8. **Improving the design based on results from the test:** Results from testing the prototype are used to improve upon the design.

Learning tasks

1. Learners list and explain the steps in the design process.
2. Learners write a report proposing a solution to solve solid waste disposal problems using the design process.
3. Learners make presentation of their solutions to the class for feedback.

Pedagogical exemplars

1. **Talk for learning:** Using a typical problem in the community, lead learners to discuss the design process. The discussions should focus on identifying and defining a problem in the community, researching/asking questions to understand the problem, brainstorming potential solutions (conceptual designs), selecting a solution using evaluation criteria essential to the solution, developing the solution, making a prototype of the solution, testing the prototype and improving the design based on results from the test. Guide learners to identify simple and more common problems in the community. Use visual aids or real-life examples to help them understand what a problem is and encourage them to ask questions. Provide learners with resources or direct them to sources where they can find more information.
2. **Experiential learning:** Let learners in mixed-ability groups, use the design process to propose solutions to a typical problem in their community and present their solutions to the class. Provide learners who may have difficulty with a structured template for the design process, including specific questions to guide their thinking and encourage learners to identify simple, tangible problems in their community and brainstorm possible solutions. For proficient and highly proficient learners, encourage them to consider multiple perspectives when identifying problems in their community and to think critically about the potential impact of their solutions. These learners could be asked to present their solutions through a detailed report or presentation, explaining their design process and justifying their choices.

Key assessment

1. **Assessment Level 1**
   1. List the steps in the design process.
   2. What is the first step in the design process?
      a) Define the problem
      b) Brainstorm solutions
      c) Test the solution
      d) Implement the solution
   3. Which of the following is not a step in the design process?
      a) Define the problem
      b) Brainstorm solutions
      c) Ignore the problem
      d) Implement the solution.
   4. What is the purpose of establishing design criteria before proposing a solution?
      a) To understand the problem better
      b) To guide the design process
      c) To ignore the problem
      d) To implement the solution

5. Which of the following is not a step in the design process?
    a) Define the problem
    b) Ignore the problem
    c) Brainstorm solutions
    d) Test the solution
6. What is the main goal of the design process?
    a) To create problems
    b) To ignore problems
    c) To solve problems
    d) To design problems.

2. Assessment Level 2

1. Explain what one needs to do in each of the steps in the design process.
2. Explain the steps you would take in the design process to propose a solution to solve solid waste disposal problems in your community.

3. Assessment Level 3

1. Describe the important criteria you will use to evaluate a potential solution to a problem.
2. Explain why establishing design criteria is important when proposing solutions to community problems.
3. Analyse how effective the design process is in solving problems.

4. Assessment Level 4

1. Use the design process to develop a solution to a critical problem in the community.
2. Analyse how the design process and a chosen design criteria will aid in proposing an effective solution to a specific problem (portable water problem) in your community.

WEEK 12

Learning Indicator: *Demonstrate the importance of free hand sketching and visualisation of objects in the design of products*

Theme or Focal Area: **Importance of Freehand Sketching and Visualisation of Objects**

Introduction

Freehand sketches are a quick and easy way to capture ideas and concepts on paper and it is often used in the early stages of the design process to help engineers (designers) visualise their ideas and communicate them to others. Visualisation involves creating visual representations of ideas and concepts to help designers understand how they will look and function in the real world. Visualisation can take many forms, including sketches, diagrams, models, and prototypes. Freehand sketches and visualisation work together to help designers develop concepts that are both functional and aesthetically pleasing.

Tools Required for Freehand Sketching

Use paper, pencil, and eraser as tools for freehand sketching. Do not use straight edges, Templates, pairs of compasses, etc. They slow down the process and defeat the purpose of fast communication of ideas.

Steps for Making Freehand Sketches

(a) Visualise and plan the sketch: Think about the size of the paper and scale to use, orientation of the object, minimum detail to communicate the idea, and type of sketch to use (oblique, isometric, orthographic).

(b) Outline the sketch: Use light lines to provide an outline for the sketch.

(c) Show major edges and boundaries of the sketch

(d) Add more details.

(e) Shape the sketches: This is done by adding appropriate details and darkening object lines. The steps above are illustrated in Fig. 12.1

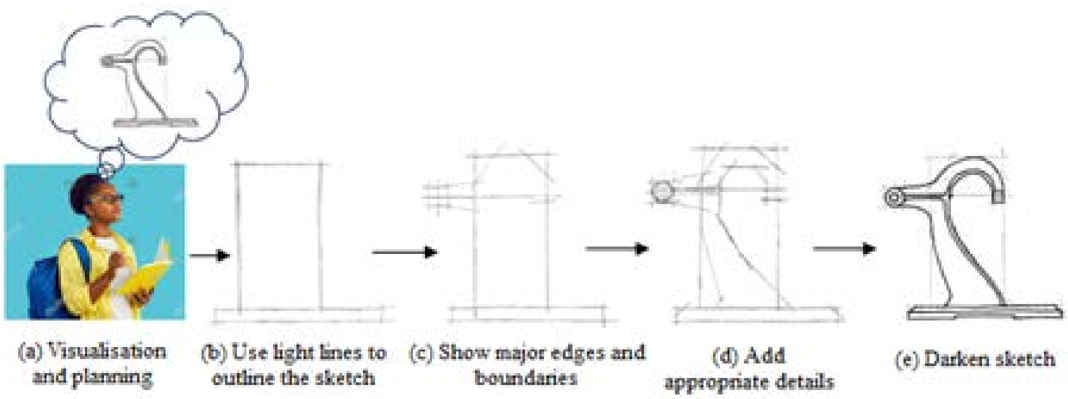

Fig. 12.1: *Steps for making freehand sketch of an idea*

Rules for Making Freehand Sketches

Drawing lines

1. Locate a start point
2. Locate an end point

3. Put pencil on start dot, look at the end dot and smoothly move pencil toward the end dot as shown in Fig. 12.2.

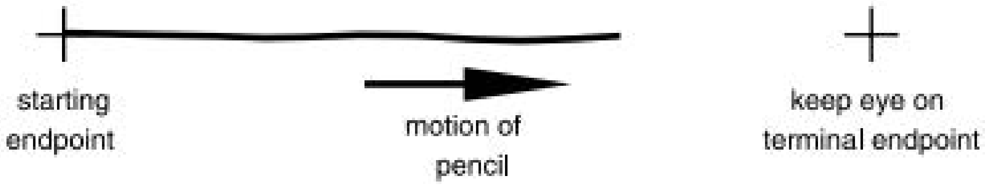

Fig. 12.2: *Sketching a line*

Drawing circles (arcs)

1. Draw light horizontal and vertical lines that intersect at the centre.
2. Lightly mark the radius on the lines.
3. Connect the radius marks with arcs to complete the circle as shown in Fig. 12.3.

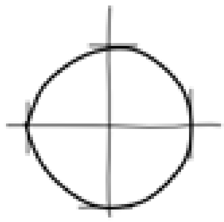

Fig. 12.3: *Sketching a circle*

Making an Oblique Sketch

1. Draw the horizontal and vertical construction lines which outline the basic shape of the main face.
2. Sketch in the face of the part.
3. Sketch receding construction lines at 30 or 45 degrees.
4. Sketch in and darken the lines outlining the part as shown in Fig. 12.4.

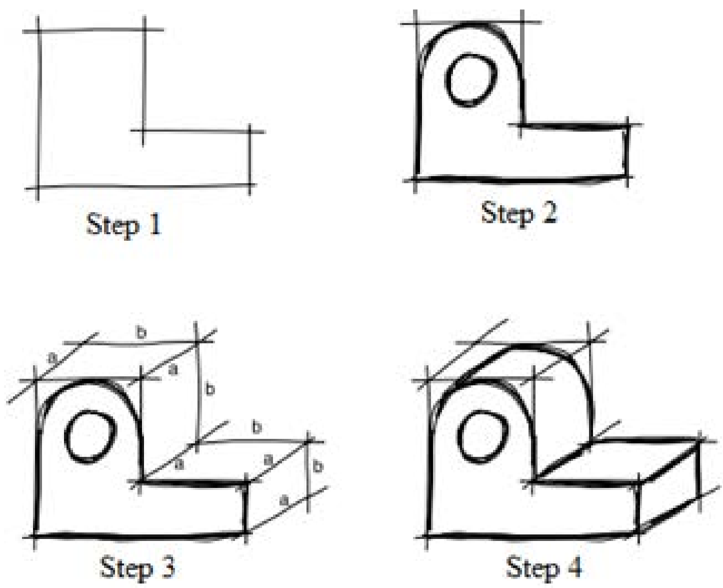

Fig. 12.4: *Making an oblique sketch*

Making an Isometric Sketch

1. Construct a horizontal line, two lines at 30 degrees above the horizontal and a vertical line through their intersection. This defines the isometric axes used to draw the sketch.
2. Sketch in a box to "block-in" the front face and the other faces follow.
3. Sketch the outline of the front face in its "block" and the other faces follow. Work parallel to the isometric axes as shown in Fig. 12.5.

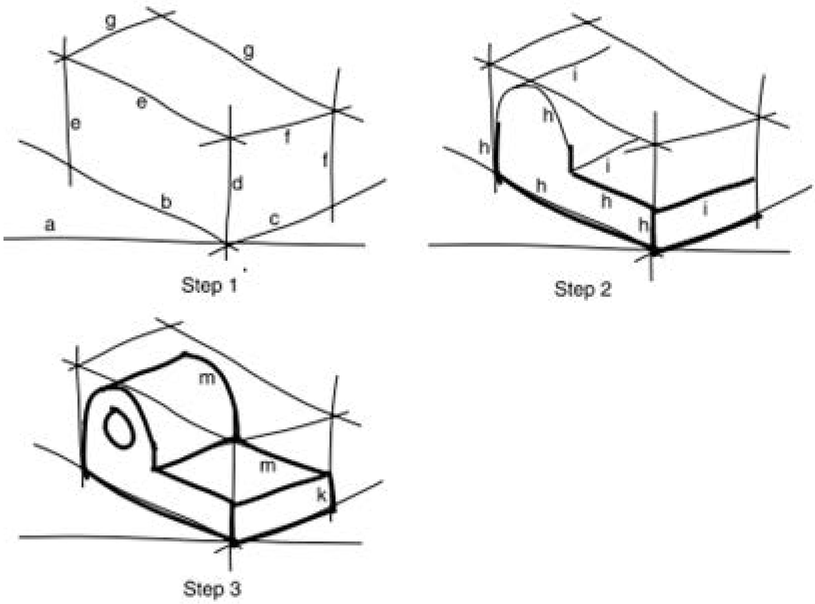

Fig. 12.5: *Making and isometric sketch*

Learning tasks

1. Learners make freehand sketch of basic geometric shapes such as circles, triangles, squares etc.
2. Learners make a freehand sketch of a product such as desk, chair, vehicle, waste bin etc.
3. Learners make a freehand sketch of a futuristic product or technology that can solve sanitation problems in the community.

Pedagogical exemplars

Project- based learning: Let learners in think-pair-share, use only pencil, paper, and eraser to sketch basic geometric shapes, common products and a futuristic idea or concept they may be used to, to solve sanitation problems in the community. Let learners discuss and revise their sketches based on peer feedback received. Provide support for learners who will be having difficulties by offering them examples and templates to guide them in sketching the basic geometric shapes and common products, while encouraging more proficient learners to independently explore futuristic ideas and concepts. Also, encourage peer collaboration such that learners of different proficiency levels can collaborate to develop futuristic ideas to solve sanitation problems in the community within a supportive learning environment.

Key assessment

1. **Assessment Level 1**
   1. What is freehand sketching?
   2. List the instruments used in free hand sketching.
   3. Identify the importance of freehand sketching in product design.
   4. Name one benefit of visualisation during freehand sketching and product design.

2. **Assessment Level 2**
   1. Describe the role of freehand sketching in communicating design ideas.
   2. Describe the role of visualisation in understanding product designs.
   3. Explain why freehand sketching is often used in the initial stages of product design.
   4. Explain how visualisation aids engineers and designers to identify potential problems of a design.

3. **Assessment Level 3**
   1. Assess the advantages and disadvantages of using freehand sketching compared to the use of drawing instruments during the design process.
   2. Analyse the role of visualisation techniques in conveying information on three-dimensional product sketches.
   3. Evaluate the impact of freehand sketching on improving the ability to effectively develop and communicate design concepts.

4. **Assessment Level 4**
   1. Create three (3) different freehand sketches of a design concept for a desk.
   2. Write a report that contains a comprehensive methodology to help young designers improve upon their freehand sketching skills.
   3. Develop a set of guidelines to integrate freehand sketching and visualisation into the product design process.
   4. Think about any product you may want to design to help your community and sketch this product using freehand.

Review of Section Three

This section introduced learners to the design process, with a focus on understanding the use of drawing instruments, the design process, surface development and the use of freehand sketching in product development. The important lessons learnt from the section are summarised below:

1. Drawing instruments are used to create accurate and detailed drawings of products.
2. Examples of drawing instruments include drawing board, pencils, T-square, set squares, a pair of compasses, divider, French curves etc.
3. Proper layout of drawing sheets, including the provision of title blocks helps create accurate and standard drawings.
4. Surface development combines creativity and geometry to bring complex 3D ideas into the tangible world of 2D patterns.
5. Surface development has applications in engineering for the manufacturing of components.
6. The design process is both a science and an art, that involves the use of creativity to solve complex problems and develop products.
7. Understanding of the design process helps to effectively develop or improve a process, product, system or solution.

8. Freehand sketching and visualisation are used in exploring design ideas.
9. Pencils, papers and erasers are the tools needed for free hand sketches.
10. The free hand can be used to sketch oblique, isometric, orthographic drawings.

Additional reading materials

1. Goetsch, D. L., Chalk, W. S., Nelson, J. A. (2015). *Technical Drawing and Engineering Communication, 7th edition*. Delmar Cengage Learning.

2. Johnson, C. M. (2016). *Technical Drawing with Engineering Graphics*. Pearson Prentice Hall.

3. Karsnitz, J. R., O'Brien, S., & Hutchinson, J. P. (2018). *Engineering design: An introduction.* CRC Press.

4. Ulrich, K. T., & Eppinger, S. D. (2015). *Product design and development*. McGraw-Hill Education.

5. Budynas, R. G., & Nisbett, K. J. (2020). *Shrigley's mechanical engineering design*. McGraw-Hill Education Top of Form

References

1. Goetsch, D. L., Chalk, W. S., Nelson, J. A. (2015). *Technical Drawing and Engineering Communication, 7th edition*. Delmar Cengage Learning.

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3. Karsnitz, J. R., O'Brien, S., & Hutchinson, J. P. (2018). *Engineering design*: An introduction. CRC Press.

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