MINISTRY OF EDUCATION

MANUFACTURING ENGINEERING

for Senior High Schools

TEACHER MANUAL



YEAR THREE

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MINISTRY OF EDUCATION

REPUBLIC OF GHANA

MANUFACTURING ENGINEERING

For Senior High Schools

Teacher Manual

Year Three

NATIONAL COUNCIL FOR CURRICULUM & ASSESSMENT OF MINISTRY OF EDUCATION

MANUFACTURING ENGINEERING TEACHER MANUAL

Enquiries and comments on this manual should be addressed to:

The Director-General

National Council for Curriculum and Assessment (NaCCA)

Ministry of Education

P.O. Box CT PMB 77

Cantonments Accra

Telephone: 0302909071, 0302909862

Email: info@nacca.gov.gh

website: www.nacca.gov.gh

©2026 Ministry of Education

This publication is not for sale. All rights reserved. No part of this publication may be reproduced without prior written permission from the Ministry of Education, Ghana.

Contents

Introduction vii

Acknowledgements ix

SECTION 1: CLASSIFICATION AND APPLICATION OF ADVANCED MATERIALS 1

STRAND: MANUFACTURING MATERIALS AND TECHNOLOGIES 1

Sub-Strand: Classification of materials 1

WEEK 1 4

Focal Area 1: Classification of advanced materials 4

Focal Area 2: Importance of advanced materials in manufacturing 7

WEEK 2 13

Focal Area 3: The structure of semiconductors 13

WEEK 3 21

Focal Area: Applications of advanced materials 21

WEEK 4 28

Focal Area: Structure, physical properties and processing of bamboo 28

SECTION 2: UNDERSTANDING MECHANICAL PROPERTIES AND FAILURE OF MATERIALS 47

STRAND: MANUFACTURING MATERIALS AND TECHNOLOGIES 47

Sub-Strand: Properties of materials 47

WEEK 5 50

Focal Area: Mechanical properties of Bamboo as a sustainable material 50

WEEK 6 60

Focal Area: Tensile strength of bamboo 60

WEEK 7 69

Focal Area: Failure of materials 69

WEEK 8 80

Focal Area: Concepts of creep, fatigue or fracture in failure of materials 80

SECTION 3: DRAWING PRINCIPLES FOR MANUFACTURING 106

STRAND: DESIGN AND PROTOTYPING 106

Sub-Strand: Design and Drawing for Manufacture 106

WEEK 9 109

Focal Area: Importance of conventions of materials and machine components in production drawing 109

WEEK 10 121

Focal Area: Applications of limits and fits in production drawing 121

WEEK 11 131

Focal Area: Application of detailed drawing in production drawing 131

WEEK 12 136

Focal Area: Part drawing 136

SECTION 4: RAPID PROTOTYPING TECHNOLOGIES AND APPLICATIONS 166

STRAND: DESIGN AND PROTOTYPING 166

Sub-Strand: Rapid Prototyping 166

WEEK 13 169

Focal Area: Importance of rapid prototyping technologies 169

WEEK 14 174

Focal Area: Concepts of solid-based and liquid-based rapid prototyping technologies 174

WEEK 15 186

Focal Area: Concept of powder-based prototyping technology in manufacturing 186

WEEK 16 194

Focal Area: Building of Prototypes using rapid prototyping 194

SECTION 5: APPLICATIONS OF MACHINE TOOLS AND COMPUTER NUMERICALLY CONTROLLED MACHINES (CNC) 214

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES 214

SUB-STRAND: MANUFACTURING TOOLS AND EQUIPMENT 214

WEEK 17 217

Focal Area: Identification and classification of cutting tools used in manufacturing 217

WEEK 18 228

Focal Area: Application of cutting tools 228

WEEK 19 240

Focal Area: Computer numerically controlled (CNC) machine 240

WEEK 20 255

Focal Area: Operation and application of CNC machine 255

SECTION 6: PRINCIPLES OF MATERIAL REMOVAL PROCESSES AND APPLICATIONS OF THE CENTRE-LATHE MACHINE 261

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES 261

Sub-Strand: Manufacturing Processes 261

WEEK 21 264

Focal Area 1: Fundamentals of material removal processes 264

Focal Area 2: Principles of operation of the centre-lathe machine 265

Focal Area 3: Turning, drilling and milling operations using centre-lathe machine 268

WEEK 22 275

Focal Area 1: Understanding grinding operations 275

Focal Area 2: Perform a material removal process using a lathe machine 276

SECTION 7: SAFETY AND QUALITY MANAGEMENT IN MANUFACTURING300

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES 300

Sub-Strand: Safety, Quality and the Environment 300

WEEK 23 304

Focal Area 1: Safety tests based on National and International guidelines and principles 304

Focal Area 2: Penalty and criteria for corrective actions 307

WEEK 24 313

Focal Area 1: Role of quality control in manufacturing 313

Focal Area 2: Functions of quality control and quality assurance in manufacturing 314

Focal Area 3: Decision making with quality control data 317

FOCAL AREA 1 326

FOCAL AREA 2 328

Introduction

The National Council for Curriculum and Assessment (NaCCA) has developed the third and final set of curriculum materials to support the implementation of the new Senior High School curriculum.

This Year Three Teacher Manual for Manufacturing Engineering covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively support learners in their final year of Senior High School. All the necessary information for the Student Assessment Portal has been included in the Year Three Teacher Manual to simplify the development of weekly learning plans, meaning that teachers have a single reference document.

The Year Three Teacher Manual has two main objectives:

- To support learners to consolidate and deepen their understanding of the content, pedagogy, and assessment across all three years of the new Senior High School curriculum in preparation for the West Africa Senior Secondary Certificate Examination (WASSCE).
- To equip teachers with the tools and resources needed to deliver revision-focused, assessment-led lessons that build on the knowledge learners have acquired from Year One to Year Three.

In this third year, teachers will be supporting learners to prepare for the WASSCE. Each section of the Teacher Manual is therefore structured around the highest Depth of Knowledge (DoK) levels, allowing learners to build progressively on knowledge acquired from Year One to Year Three. For each week, learning tasks and pedagogy are built around the assessment, ensuring that classroom activities directly prepare learners for the demands of the examination. Two sets of sample examination papers are also provided; one administered by Week 12 as a first semester practice examination, and one by Week 20 as a mock examination, to gauge learners' competencies and identify areas requiring remediation.

To further support teachers in delivering Year Three, NaCCA, working with the Ghana Education Service, has developed a subject specific App for each subject.

The Year Three PLC sessions have been revised in response to findings from the 2025 annual evaluation survey. The survey confirmed that teachers have made strong progress in lesson planning, use of varied instructional methods, ICT integration and modes of assessment. To address the identified gap in explaining concepts clearly using examples familiar to learners, each PLC

session now includes a dedicated Content Exploration segment. This ten-minute segment brings the subject group together to work through one challenging problem or concept from the week's Teacher Manual content, not to plan how to teach it, but to ensure that every teacher in the group fully understands it.

The PLC sessions in Year Three also place particular emphasis on connecting the week's content to equivalent topics taught in Years One and Two. Teachers are encouraged to note the recap weeks signposted throughout the Teacher Manual and to use the App to explore how content across all three years links together.

As in previous years, teachers are expected to integrate National Values, Gender Equality and Social Inclusion (GESI), Social and Emotional Learning (SEL), and 21st-century skills into their learning activities, assessment tasks, and rubrics and mark schemes. The subject-specific App will support teachers in doing this throughout the year.

Ghana Education Service acknowledges the dedication of the teachers who have implemented the new curriculum across Years One and Two and recognises that Year Three represents both the culmination of that effort and a critical moment for learners. The Year Three Teacher Manual and its accompanying resources have been developed to ensure that every learner, regardless of background, ability, or school context, is fully prepared to demonstrate what they know and can do in the WASSCE and to progress confidently to further studies, the world of work, and adult life.

Acknowledgements

Special thanks to Professor Samuel Ofori Bekoe, Director-General of the National Council for Curriculum and Assessment (NaCCA) and all who contributed to the successful writing of the Teacher Manuals for the new Senior High School (SHS) curriculum.

The writing team was made up of the following members:

National Council for Curriculum and Assessment	
Name of Staff	**Designation**
Reginald Quartey	Ag. Director, Curriculum Development Directorate
Anita Cordei Collison	Ag. Director, Standards, Assessment and Quality Assurance Directorate
Dr. Mercy Nyamekye	Ag. Director, Research, Planning, Monitoring, and Evaluation
Joana Adua Vanderpuije	Ag. Director, Instructional Resources Directorate
Rebecca Abu Gariba	Ag. Director, Corporate Affairs
Nii Boye Tagoe	Senior Curriculum Development Officer
Juliet Owusu-Ansah	Principal Curriculum Development Officer
Samuel Owusu Ansah	Principal Curriculum Development Officer
Godwin Mawunyo Kofi Senanu	Assistant Curriculum Development Officer
Stephen Acquah	Principal Curriculum Development Officer
Thomas Kumah Osei	Principal Curriculum Development Officer
Ayuuba Sullivan	Principal Curriculum Development Officer
Dr.Jephtar Adu-Mensah	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Richard Teye	Principal Standards, Assessment and Quality Assurance Officer (SAQA)
Nancy Asieduwaa Gyapong	Assistant Standards, Assessment and Quality Assurance Officer (SAQA)
Bridget Aku Anku	Principal, Standards, Assessment and Quality Assurance Officer (SAQA)
Francis Agbalenyo	Principal Research, Planning, Monitoring and Evaluation Officer
Joseph Barwuah	Senior Instructional Resource Officer

National Council for Curriculum and Assessment	
Name of Staff	**Designation**
Samuel Amankwa Ogyampo	Senior Corporate Affairs Officer
Seth Nii Nartey	Corporate Affairs Officer

Name	Name of Institution	Subject
Bernard Adobaw	West African Examinations Council	Accounting
Emmanuel Kodwo Arthur	Institute of Charted Accountants, Ghana	
Benedicta Ama Yekua Etuaful	Ogyeedom SHTS	Additional Mathematics
Innocent Nunana Duncan	KNUST SHS	
Benedicta Carbilba Foli	Pope Johns SHS & Minor Seminary, Koforidua	Agricultural Science
David Esela Zigah	Achimota School	
Prof. Jakpasu Victor Kofi Afun	Kwame Nkrumah University of Science and Technology	
Eric Morgan Asante	St. Peter's Boys SHS	Agriculture
Prof. Frederick Adzitey	University for Development Studies, Tamale	
Akuffo Twumhene Frederick	Koforidua SHTS	Applied Technology
Emmanuel Korletey	Benso SHTS	
Firmin Anewuoh	Presbyterian College of Education, Akropong	
Isaac Buckman	Armed Forces SHTS	
Kunkyuuri Philip	Kumasi Senior High Technical School	
Lavoe Daniel Kwaku	Sokode SHTS	
Philip Turkson	St Joseph's SHTS, Bekwai	
Dr. Sherry Kwabla Amedorme	Univ. of Skills Training and Entrepreneurial Development	

Name	Name of Institution	Subject
Walter Banuenumah	Univ. of Skills Training and Entrepreneurial Development	
Wisdom Dzidzienyo Adzraku	Univ. of Skills Training and Entrepreneurial Development	
Abass Umar Mohammed	University of Ghana, Legon	Arabic
Mohammed Mahey Ibrahim	Tijjaniya Senior High School, Kumasi	
Dr. Ebenezer Acquah	University of Education, Winneba	Art and Design Studio and Foundation
Dr. Mantey Jectey-Nyarko	Kwame Nkrumah University of Science and Technology	
Kwame Opoku-Bonsu	Kwame Nkrumah University of Science and Technology	
Seyram kojo Adipah	GES- Ga East	
David Kofi Oppong	Kwame Nkrumah University of Science and Technology	Aviation and Aerospace
Obed Frimpong	Zipline International	
Jo Ann Naa Dei Neequaye	Nyakrom SHTS	Biology
Paul Beeton Damoah	Prempeh College, Kumasi	
Dr. Daniel Akwei Addo	Kwame Nkrumah University of Science and Technology	Biomedical Science
Dr. Mrs. Dorothy Araba Yakoba Agyapong	Kwame Nkrumah University of Science and Technology	
Avole Baba Ansbert	Bolga SHS	Business Management
Emmanuel Caesar Ayamba	Bolgatanga Technical University	
Faustina Graham	GES HQ	
Bismark Kwame Tunu	Opoku Ware School, Kumasi	Chemistry
Patrick Nsobila Awumbire	Bolgatanga S.H.S.	
Francis Normanyo	Mt Mary College of Education	Christian Religious Studies & Islamic Religious Studies
Francis Opoku	Valley View University	
Haruna Zagoon-Sayeed	University of Ghana	

Name	Name of Institution	Subject
Kabiru Soumana	GES HQ	
Richardson Addai-Mununkum	University of Education, Winneba	
Seth Tweneboah	University of Education, Winneba	
Jusinta Kwakyewaa (Rev.Sr.)	St Francis SHTS, Akim Oda	Clothing and Textiles
Rahimatu Yakubu	Potsin T.I Ahmadiyya SHS	
Dordoe Raphael Senyo	Ziavi SHTS	Computing and ICT
Gaddafi Abdul-salaam	Kwame Nkrumah University of Science and Technology	
Kwasi Abankwa Anokye	Ghana Education Service	
Gabriel Boafo	Kwabeng Anglican Senior High Technical School	Design and Communication Technology
Mensah Henry Angmor	Anglican Senior High School, Kumasi	
Phyllis Mensah	University of Skills Training and Entrepreneurial Development (	
Charlotte Kpogli	Ho Technical University	Economics
Salitsi Freeman Etornam	Anlo SHS, Anloga	
Daniel Kwesi Agbogbo	Kwabeng Anglican Senior High Tech School	Engineering
Dr Valentina Osei-Himah	Atebubu College of Education	
Benjamin Orrison Akrono	Islamic Girls' SHS	English Language
Esther Okaitsoe Armah	Mangoase SHS	
Kukua Andoh Robertson	Breman Asikuma SHS	
Perfect Quarshie	Mawuko Girls SHS, Ho	
Ama Achiaa - Afriyie	St. Louis SHS, Kumasi	Food and Nutrition
Lily-Versta Nyarko	Mancell Girls SHTS, Kumasi	
Osmanu Ibrahim	Mount Mary College of Education, Somanya	French
Mawufemor Kwame Agorgli	Akim Asafo SHS	

Name	Name of Institution	Subject
Comfort Korkor Sam	University for Development Studies, Tamale	General Science
Robert Arhin	S.D.A SHS, Akim Sekyere	
Ishmael Yaw Dadson	University of Education, Winneba	Geography
Prof Ebenezer Owusu -Sekyere	University for Development Studies, Tamale	
Raymond Nsiah-Asare	Methodist Girls' SHS, Mamfe	
Catherine Ekua Mensah	University of Cape Cape	Ghanaian Language
David Sarpei Nunoo	University of Education, Winneba	
Prof Kwasi Adomako	University of Education, Winneba	
Arko Blay Augustine	University of Education, Winneba	Government
Josephine Akosua Gbagbo	Ngleshie Amanfro SHS	
Anitha Oforiwah Adu-Boahen	University of Education, Winneba	History
Prince Essiaw	Enchi College of Education	
Blessington Dzah	Ziavi SHTS	Literature-in-English
Juliana Akomea	Mangoase SHS	
Dorcas Akosua Opoku	Winneba SHS	Management in Living
Grace Annagmeng Mwini	Tumu College of Education	
Eric Abban	Mt. Marys College of Education, Somanya	Mathematics
Isaac Buabeng	Mamprobi Sempe 2 JHS	
Benjamin Ofori	Cocoa Research Institute of Ghana Primary School	Music
Cosmas W. K. Mereku	University of Education, Winneba	
Davies Obiri Danso	New Juaben SHS	
Prof. Joshua Alfred Amuah	University of Ghana, Legon	
Evans Kofi Mati	GES HQ	

Name	Name of Institution	Subject
Wilson Klebi	GES HQ	
Professor Emmanuel Obed Acquah	University of Education, Winneba	
Chris Ampomah Mensah	Bolgatanga S.H.S	Performing Arts
Doreen Deedee Quarcoo	University of Education, Winneba	
Dr. Latipher Osei Appiah-Agyei	University of Education, Winneba	
Albert Sackey	KNUST SHS	Physical Education and Health (Core and Elective)
Ebenezer Ewiah-Quarm	Nkroful Agric SHS	
Evans Asare Yeboah	Adisadel College	
John Benedict Nyarko	Adisadel College	
Mary Aku Ogum	University of Cape Coast	
Dr Linus Kweku Labik	KNUST	Physics
Sylvester Affram	Kwabeng Anglican SHTS	
Anthony Mensah	Abetifi Presbyterian College of Education	RME
Clement Nsorwineh Atigah	Tamale SHS	
Eliel Keelson	Kwame Nkrumah University of Science and Technology	Robotics
Isaac Nzoley	Wesley Girls High School	
Jemima Ayensu	Holy Child Girls SHS, Cape Coast	Social Studies
Mohammed Adam, Ph.D.	University of Education, Winneba	
Simon Tengan	Wa Senior High Technical School	
Franklina Kabio-Danlebo	University of Ghana	Spanish
Mishael Annoh-Achampong	University of Media, Art and Communication	

Name	Name of Institution	Subject
Augustina Gloria Henyo	West African Examinations Council	Inclusive Education
Dr. Gideon Kwesi Obosu	University of Cape Coast	
Dr. Daniel Fobi	University of Education, Winneba	
Dr. Martha-Pearl Okai	University of Cape Coast	
Francis Kweku Essel	Ashesi University	
Richard Doku	Mampong/Akw SHTS For The Deaf	
Yao Mati Abotsi	Ghana Blind Union	
Seth Kwame Ativor	Okuapemman SHS, Akropong	
Bernard Duorinaah	Presbyterian College of Education	
Evans Odei	Achimota Senior High School	

Subject	Name of Reviewer	Institution
Accounting	Ms. Ivy Eklemet	Univ. of Professional Studies, Accra
Additional Mathematics	Francis Tornyenor	Pope John SHS & Minor Seminary, Koforidua
Agricultural Science	Selina Acheampong	Univ. College of Agriculture and Environmental
Agriculture	Mr. Godwin B. K. Doli	Municipal Educ. Office, Amasaman
Arabic	Abdullah Musah Abdullah	Univ. of Media Arts & Communication, UniMAC
Art and Design Studio	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
Art and Design Foundation	Ernest Kwasi Elelakpodia	Hope College, Gomoa Fetteh
Automotive & Metal Technology	Okyere Kojo Alex	Ada College of Education
Aviation & Aerospace Engineering	Dr. Augustine Akuoko Kwarteng	Univ. of Mines and Technology
Biology	Rev. Joseph Kweku Delanyo	formerly of Hope College, Gomoa Fetteh
Biomedical Science	Dr. Irene Adzo Agbo	Univ. of Professional Studies, Accra

Building Construction & Woodwork Technology	Mr. Alex A. Appah	Christ Calvary Prep. Sch.
Business Management	Mr. Emmanuel Boakye	Ghana Employers Association
Chemistry	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
Clothing and Textiles	Rosemary Quarcoo	Department of Clothing and Textiles, UEW
Design & Communication Technology	Esme Serwaa Boateng	Ghana National College, Cape Coast
Economics	Dr. Kofi Kamasa	Department of Management Studies, UMaT
Electrical & Electronics Technology	Dr. Emmanuel Ampoma Affum	Telecom Engineering Department, KNUST
Engineering	Dr. Albert Kotawoke Awopone	Univ. of Skills Training & Entreprenuerial Development
English Language	Prof. Philip Gborsong	University of Cape Coast
Food and Nutrition	Sylvia Baaba Yankey	
French	Gregory Nana Kobina Nketsia Mensah	Mfantsipim School, Cape Coast
General Science	Joyce Okreyewa Odei	Hope College, Gomoa Fetteh
Geography	Prof Kofi Adu Boahen	University of Education, Winneba
Ghanaian Languages	Prof. Regina Caesar	University of Education, Winneba
Government	Clement Adu Acheampong	Prempeh College SHS, Kumasi
History	Prof Wilson Yayoh	Univertsity of Cape Coast
Information Communication Technology	Felicia Archeresuah	Nkoronza Technical Institute
Manufacturing Engineering	Dr. Frank Kwabena Nyarko	Kwame Nkrumah Univ. of Science and Technology
Mathematics	Ezekiel Osei Bonsu	Bono East Regional Education Office, Nkoranza
Management in Living	Ms. Anna Holdbrooke	Swedru Senior High School
Music	Prof Mark-Millas Fish	University of Education, Winneba
Physical Education and Health Core	Francis Maxwell Ayamba	Atebubu College of Education

Physical Education and Health Elective	Sulemana Ahmed Tijani	Atebubu College of Education
Performing Arts	Dr. Godfred Asare Yeboah	University of Education, Winneba
Physics	Peter Bekoe	Our Lady of Mount Carmel Girls SHS, Techiman
Religious and Moral Education	Christain Kwarteng Mensah Oppong	Prempeh College, Kumasi
Robotics	Dr. Yaw Okraku-Yirenki	Kofi-Annan Centre of Exellence in ICT
Social Studies	Samuel Larbi	St Louis Girls SHS, Kumasi
Spanish	Prof. Jonson Asunka	University of Ghana Legon

SECTION 1: CLASSIFICATION AND APPLICATION OF ADVANCED MATERIALS

STRAND: MANUFACTURING MATERIALS AND TECHNOLOGIES

Sub-Strand: Classification of materials

Learning Outcome: Group and identify materials as advanced materials and discuss their applications in the manufacturing industry.

Content Standards

1. *Demonstrate understanding of the use of advanced materials. (Week 1,2 & 3)*
2. *Demonstrate knowledge of bamboo as a manufacturing material. (Week 4)*

INTRODUCTION AND SECTION SUMMARY

This section builds on Year 1 and 2 content by extending learners' understanding of conventional materials (e.g., metals, ceramics, polymers) into the realm of advanced materials, emphasising critical thinking, applied knowledge, and real-world relevance. The section introduces learners to a diverse and transformative class of materials known as advanced materials, which are engineered to meet the demands of modern industries. Key ideas include:

- Classification of Advanced Materials: Learners explore semiconductors, nanomaterials, smart material and biomaterials, learning to differentiate them from conventional materials based on structure, function, and industrial relevance.
- Semiconductor Structure and Conductivity: Learners analyse the crystal and atomic structure of semiconductors, understand the concept of doping and band theory, and explain how these materials form the foundation of modern electronics and energy devices.
- Industrial Applications of Advanced Materials: The section emphasises how materials such as shape memory alloys, piezoelectric ceramics, and biodegradable polymers are transforming sectors like automotive, healthcare, aerospace, and electronics through their unique responsive behaviours.
- Bamboo as a Sustainable Engineering Material: Learners investigate the structural, mechanical, and ecological properties of bamboo. They explore traditional and modern processing methods and their potential for green manufacturing in local contexts.
- Real-world applications: Through projects, discussions, and critical reflection tasks, learners apply their knowledge to evaluate and propose solutions using advanced materials for pressing local or global problems, such as sustainable packaging or renewable energy systems.

At the end of this section, learners should be able to:

- Identify and classify advanced materials based on their structure, properties, and real-world applications in modern manufacturing.
- Explain how the unique properties of semiconductors, smart materials, biomaterials, and nanomaterials contribute to innovation, cost-efficiency, and sustainability in engineering processes.
- Understand the internal structure of semiconductors and the physical principles that enable their use in electronics and energy systems.
- Apply knowledge of material properties to analyse and evaluate the role of advanced materials in solving local and global industrial challenges.

The weeks and the indicators covered by the section are:

Week 1: Outline the importance of advanced materials such as semiconductors, biomaterials, and smart materials and nanomaterials.

Week 2: Explain the structure of semiconductors as engineering materials.

Week 3: State the applications of semiconductors, biomaterials, smart materials and nanomaterials.

Week 4:

a. Classify bamboo based on its structure, physical properties and processing.

b. State the application of bamboo in manufacturing.

SUMMARY OF PEDAGOGICAL EXEMPLARS

In this section, teachers are expected to apply a combination of experiential, research-based, and talk-for-learning pedagogies to guide learners through the study of advanced materials in manufacturing. Instruction should begin by connecting learners' prior knowledge of basic materials to the concept of advanced materials, using real-life applications, multimedia demonstrations, and case-based discussions to deepen engagement. Teachers must create active learning environments that support hands-on investigations, group projects, and demonstrations of materials that highlight their structure, function, and applications. Learners are required to explore the atomic and crystal structures of semiconductors, understand the principles of band theory and doping, and assess how material innovation drives cost savings, sustainability, and technological advancements. They must also develop the ability to analyse local materials, such as bamboo, using scientific reasoning and apply engineering knowledge to solve context-specific manufacturing problems. At the end of the section, learners should demonstrate the ability to evaluate, explain, and present arguments regarding material choices in modern engineering contexts.

ASSESSMENT SUMMARY

To effectively evaluate learners' understanding of the principal concepts in this section, a variety of assessment modes is employed to accommodate different learning styles and levels of proficiency. Oral assessments are conducted through interactive class discussions and presentations, enabling learners to classify advanced materials, explain their characteristics, and discuss their applications in modern manufacturing. These activities also provide opportunities for learners to communicate ideas confidently and engage in collaborative learning.

Written assessments, including structured questions, short essays, and application-based tasks, are used to evaluate learners' knowledge of the properties, classification, and industrial uses of advanced materials. Learners are also assessed on their understanding of bamboo as a sustainable manufacturing material by identifying its characteristics, discussing its advantages and limitations, and explaining its applications in manufacturing processes.

Research activities, practical investigations, and case studies further enable learners to explore real-world applications of advanced materials and bamboo in the manufacturing industry. These experiential learning activities promote critical thinking, problem-solving, and informed decision-making regarding material selection for different manufacturing purposes. This comprehensive assessment approach ensures that learners not only acquire sound theoretical knowledge but also develop the practical skills required to evaluate and apply advanced materials appropriately in manufacturing contexts. Table 1 is the assessment summary for Section 1.

Table 1 Assessment summary for Section 1

Indicators	DOK Level	Assessment Strategy and/or Mode
Leaners outline the importance of advanced materials such as semiconductors, biomaterials, and smart and nanomaterials.	Level 2	Learners analyse and compare advanced materials with conventional ones through structured written reports and presentations. They justify the application of selected advanced materials in specific industrial processes.
Learners explain the structure of semiconductors as engineering materials	Level 4	Learners construct models or detailed diagrams of the atomic and band structures of semiconductors, incorporating explanations of conductivity and doping, supported by peer-reviewed sources or group presentations.
Learners explain the applications of advanced materials	Level 4	Learners conduct a mini-research project or case study analysis comparing two types of smart materials, presenting their properties, applications, and impact on cost and performance in industry.
Learners classify bamboo based on its structure, physical properties and processing, and its application in manufacturing	Level 4	Learners assess the potential of bamboo as a sustainable material by investigating and reporting on its processing techniques, mechanical properties, and suitability for specific engineering applications.

WEEK 1

Learning Indicator: Outline the importance of advanced materials such as semiconductors, biomaterials, smart materials and nanomaterials

Recap weeks

Year 1	Week 3: Distinguish between different kinds of materials. Week 4: Group materials based on their industrial applications.
Year 2	Week 1: Group materials as metals, ceramics and polymers based on their chemical properties Week 3: Classify materials as metals, ceramics and polymers according to their processing methods.

Focal Area 1: Classification of advanced materials

1.1 Introduction to Advanced Materials (Refer back to Year 1, Section 1, Week 3 Distinguish between different kinds of materials; Year 2, Section 1, Week 1 Group materials as metals, ceramics and polymers based on their chemical properties; Year 2, Section 1, Week 3 Classify materials as metals, ceramics and polymers according to their processing methods)

Advanced materials are specially engineered to possess enhanced or entirely new properties compared with traditional materials, such as steel, wood, or plastic. These materials are developed to address modern challenges such as reducing energy consumption, improving durability, and enabling cutting-edge technologies. For instance, advanced materials make smartphones lighter, medical implants safer, and renewable energy systems more efficient. Their importance lies in three key areas: sustainability, innovation, and economic growth. Some common advanced materials include semiconductors, nanomaterials, smart material and biomaterials.

1.1.1 Activity linking conventional and advanced materials

a. Ask the class: What can conventional materials not do well? List on the board:
   - Metals rust, are heavy.
   - Ceramics break easily.
   - Polymers melt at low temperatures, are not strong.

b. Pose a challenge: “Imagine you need a material that is as strong as steel but as light as plastic, and it must change shape when heated. Can we find that in nature?” (No – we must engineer it.)

c. Introduce the term “advanced materials” as materials designed to solve specific problems that conventional materials cannot.

d. Connect properties directly: For each advanced material type (semiconductor, nanomaterial, etc.), explicitly state which conventional limitation it overcomes. Example: “Semiconductors overcome the limitation that metals cannot switch between conducting and insulating – they give us *controllable* conductivity.”

1.2 Semiconductors

Semiconductors are materials, such as silicon or gallium arsenide, that have electrical conductivity between conductors (like copper) and insulators (like rubber). They form the foundation of modern electronics, enabling devices like computers, solar panels, and LED lighting. For instance, microchips made from semiconductors power everything from smartphones to satellites, while solar cells efficiently convert sunlight into electricity. Semiconductors also enable technology to become smaller and more energy-efficient; tiny chips in smartwatches or medical devices are made possible by their unique properties. Additionally, they reduce energy consumption in devices that use semiconductors, last longer and consume less power than traditional incandescent bulbs. Figure 1 shows a schematic diagram of inorganic semiconductors and amorphous oxide semiconductors.

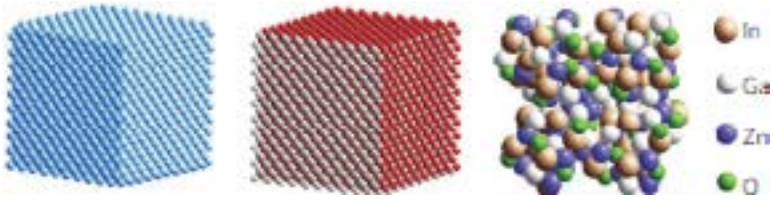


Figure 1: *Schematic diagram of inorganic semiconductors and amorphous oxide (Jariwala et al., 2017)*

1.3 Nanomaterials (Refer back to Year 2, Section 1, Week 4 Grouping of materials according to their synthesis.)

Nanomaterials are substances with at least one dimension smaller than 100 nanometres (about 1/1000th the width of a human hair). At this microscopic scale, materials exhibit extraordinary properties. Carbon nanotubes, for example, are 10 times stronger than steel and are used in lightweight sports equipment and aerospace components. Nanocoating's on phone screens make them scratch-resistant, while nanoparticles in medicine can deliver drugs directly to cancer cells, minimising side effects. These materials revolutionise industries by making products lighter, stronger, and more efficient (Pacheco-Torgal et al., 2013). Figure 2 shows examples of carbon-based nanomaterials.

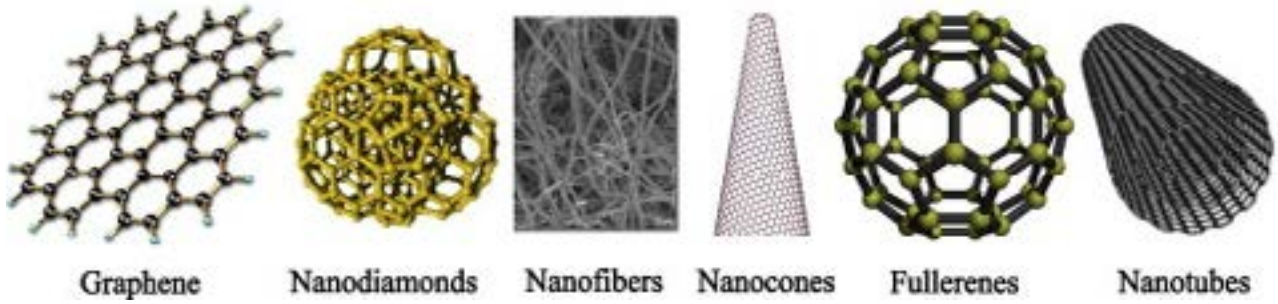


Figure 2: *Carbon-based nanomaterials (Zhang et al., 2013)*

1.4 Smart Materials

Smart materials respond dynamically to external stimuli, such as temperature, light, or pressure. Shape-memory alloys, used in eyeglass frames or dental braces, return to their original shape when heated. Piezoelectric materials generate electricity when bent or pressed, powering sensors in devices such as lighters, shoes, and touchscreens, as shown in Figure 3. Electrochromic windows, which automatically tint to block sunlight, reduce cooling costs in buildings. These materials enhance safety and efficiency; for example, self-healing concrete repairs its cracks, extending the lifespan of bridges and roads. Smart materials also enable futuristic applications, like clothing that adapts to weather changes (Casini, 2016).

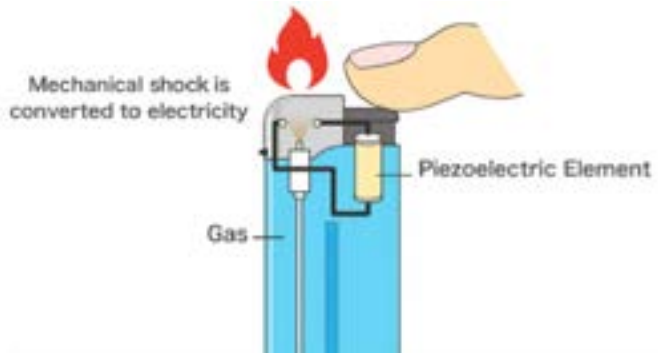


Figure 3: *Piezoelectric element in a lighter (ElProCus, 2019)*

1.5 Biomaterials

Biomaterials are designed to interact with living systems for medical or environmental purposes. Titanium hip implants and polymer-based artificial heart valves replace damaged body parts, improving patients' quality of life. Bioresorbable stitches dissolve after wounds heal, eliminating the need for removal surgeries. Biodegradable plastics made from plant-based materials reduce pollution, while nanoparticles can target diseased cells without harming healthy tissue. These advancements not only save lives but also promote sustainability (European Commission, 2023). Figure 4 illustrates various biomaterials utilised in the medical industry.

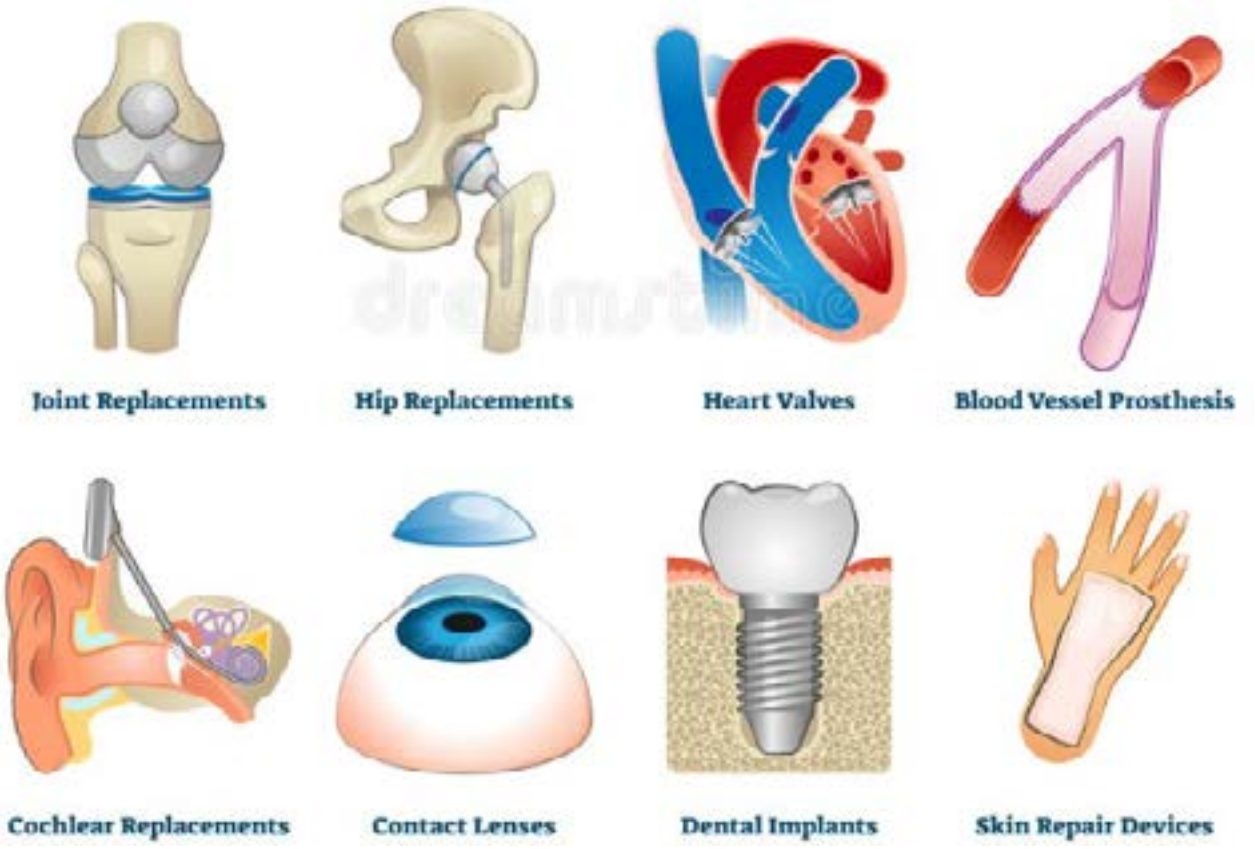


Figure 4: *Sample biomaterials used in the medical industry (Neupane, 2022).*

Focal Area 2: Importance of advanced materials in manufacturing

1.6 Introduction

(Refer back to Year 1, Section 1, Week 4 Group materials based on their industrial applications)

In the rapidly evolving world of manufacturing, advanced materials are becoming increasingly essential due to their transformative impact in various industries. These materials enhance the performance and functionality of products, allowing for innovations that were previously unattainable. By exploring the importance of advanced materials, learners can gain insights into how materials such as semiconductors, composites, and smart materials are driving technological advancements through improved efficiencies across sectors, weight reduction, cost savings, innovation, environmental sustainability, and global competitiveness. Understanding these aspects not only highlights the pivotal role advanced materials play in modern manufacturing but also inspires future engineers to explore the potential these materials hold in shaping sustainable and efficient industrial practices. Through this exploration, Learners are encouraged to think critically about how these materials are applied in real-world scenarios, fostering a deeper appreciation for the innovations that fuel our global economy, as discussed in the sections that follow (Manufacturing-Engineering-Curriculum, 2023; Callister & Rethwisch, 2020; Groover, 2012).

1.7 Enhanced performance and functionality

Advanced materials play a crucial role in enhancing the performance and functionality of products. These materials, such as semiconductors and smart materials, allow for the creation of products that are more efficient, responsive, and capable of performing complex tasks. For example, semiconductors are essential in the electronics industry, enabling the development of faster and more reliable devices. Advanced materials also contribute to weight reduction and efficiency. By utilising materials such as carbon fibre and composites, manufacturers can produce lighter products that require less energy to operate, which is particularly beneficial in the automotive and aerospace industries.

1.8 Cost savings and resource efficiency

Cost savings and resource efficiency are significant benefits of advanced materials. By utilising materials that offer superior properties, manufacturers can reduce waste and lower production costs. For instance, advanced alloys and ceramics can withstand higher temperatures and pressures, resulting in longer-lasting components and reduced maintenance requirements. Advanced materials also drive innovation and product differentiation. Manufacturers can create unique products that stand out in the market by incorporating new materials that offer distinct advantages, such as enhanced aesthetics or improved functionality.

1.9 Environmental sustainability

Environmental sustainability is a growing concern in manufacturing, and the use of advanced materials can contribute to more sustainable practices. Materials such as biodegradable polymers and recycled composites help reduce the environmental impact of production processes and products. These materials not only minimise waste but also decrease the carbon footprint of manufacturing activities. Durability and longevity are key attributes of advanced materials. Products made from these materials tend to have longer lifespans and better resistance to wear and tear, which reduces the need for frequent replacements and conserves resources.

1.10 Technological advancements

Technological advancements are closely linked to the development of advanced materials. As new materials are discovered and improved, they open up possibilities for cutting-edge technologies and applications. This progress is crucial for maintaining global competitiveness and capitalising on market opportunities. Countries that invest in advanced materials research and development can lead in high-tech industries and export innovative products worldwide.

1.11 Durability and longevity

Durability and longevity are key attributes of advanced materials, ensuring products have longer lifespans and better resistance to wear and tear. This reduces the need for frequent replacements and conserves resources. Technological advancements are closely linked to the development of advanced materials. As new materials are discovered and improved, they open up possibilities for cutting-edge technologies and applications, essential for global competitiveness and tapping into market opportunities (Groover, 2012).

1.12 Global competitiveness and market opportunities

The adoption of advanced materials in manufacturing is crucial for maintaining global competitiveness and capitalising on market opportunities. These materials, such as semiconductors and biomaterials, offer superior properties that enhance product performance and foster innovation, enabling companies to differentiate themselves and capture new market segments. As environmental sustainability becomes increasingly important, using advanced materials that support eco-friendly practices allows companies to tap into emerging eco-conscious markets. Additionally, nations investing in advanced materials research often lead in technological advancements, boosting economic growth through the export of high-tech products and fostering international collaborations. Overall, advanced materials are crucial for driving innovation and expanding market reach in today's global economy.

Notes for Facilitators

1. **Clarifying Concepts:** The term "advanced" does not mean "better" in all contexts, but rather "engineered for a specific, demanding function." Use the analogy of a traditional wooden spoon (conventional) vs. a silicone spatula (advanced) – both are for cooking, but the silicone is heat-resistant, non-stick, and durable for specific tasks. Emphasise that these materials are designed because of their special response to stimuli (heat, light, pressure). Furthermore, when teaching material properties, connect it to the business reasons. It is not just about being strong; it is about being strong and light to save fuel in transport (cost savings). It is not just about being biodegradable; it is about reducing waste disposal costs and brand reputation (sustainability).
2. **Common Misconceptions:** Students often think "nanomaterials" are just very small objects. Clarify that it is the property change at the nanoscale that matters. For example, explain that while gold is a yellow metal, gold nanoparticles can appear red or purple, which is a completely new property. Regarding the properties of materials, students might think cost savings only come from cheaper materials. Explain that while advanced materials can be expensive upfront, they save money over the lifetime of the product (e.g., a more durable car part means fewer replacements and less labour).

3. **Low-Cost Demonstration and Ghanaian Examples**

   a. **Smart Material:** Bring a pair of eyeglasses with shape-memory alloy frames. If you do not have them, show a video of a Nitinol wire «remembering» its shape when heated. Ask students about dental braces in Ghana, which often use this principle.

   b. **Biomaterial:** Discuss "biodegradable" vs. "bioresorbable" using examples like Ghanaian-made "leaf bowls" (traditional) vs. modern, single-use biodegradable cutlery made from cassava starch.

   c. **Weight Reduction:** Use a concrete block and a hollow bamboo pole of similar strength. Ask students which they would rather carry up a building. Explain that bamboo is a natural "composite" giving a high strength-to-weight ratio, much like advanced composites in aircraft.

   d. **Innovation:** Discuss the Ghanaian startup that uses recycled plastic waste to produce paving stones. This is a great example of using advanced materials thinking (polymer composites) to solve a local problem (plastic waste) and create a new product (innovative paving).

Learning Tasks

1. Recap the classification of materials by drawing a tree map that indicates the type of materials, their properties, importance and real-world applications in manufacturing.
2. Identify and classify advanced materials as semiconductors, nanomaterials, smart materials and biomaterials.
3. Explain the importance of advanced materials in manufacturing.
4. Complete an example assessment question individually.

Pedagogical Exemplars

1. **Experiential Learning:** Provide learners with physical samples, images or videos of conventional materials (metals, polymers, ceramics, composites) and advanced materials (semiconductors, biomaterials, smart materials, nanomaterials) to handle or observe in groups, discuss their texture, weight, flexibility, appearance, and potential applications in manufacturing using tree maps.
2. **Talk for learning:** Learners in a think-pair-share discussion discuss the importance of advanced materials in manufacturing.
3. **Independent work** – Learners complete assessment questions individually and then mark them as a class, using the marking scheme.

Key Assessments Level 2 – Individual Class Exercise

1. Biomaterials are designed to interact with biological systems. Explain which type of material is best suited to respond to changes in external stimuli like temperature, pressure, or pH, and describe how it responds in such environments. (4 marks)

2. Describe a type of material that can return to its original shape after being deformed when exposed to a stimulus such as heat. Explain what physical property enables this behaviour and give a practical example of its use. (4 marks)
3. Compare and contrast a smart material and a nanomaterial. In your answer:
    a. Describe one unique property of each material that makes it "advanced".
    b. Explain how each property enables a specific industrial application (different from the examples given in class).
    c. State one limitation that currently prevents each material from being used more widely. (9 marks)
4. Explain three (3) reasons why advanced materials are important in modern manufacturing. (15 marks)

PLC Session 1

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is individual class exercise. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the exercise (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misc,onceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 2

Learning Indicator: Explain the structure of semiconductors as engineering materials

Recap weeks

Year 1	Week 3: Distinguish between different kinds of materials according to their use.
Year 2	Week 2: Classify materials based on their structure. Week 3: Classify materials as metals, ceramics and polymers according to their processing methods.

Focal Area 3: The structure of semiconductors

2.1 Introduction to Semiconductors (Refer to Year 1, Section 1, Week 3 Distinguish between different kinds of materials according to their use; Year 2, Section 1, Week 2 Classify materials based on their structure; Year 2, Section 1, Week 3 Classify materials as metals, ceramics and polymers according to their processing methods)

Semiconductors are materials that have an electrical conductivity value between conductors, such as metals like copper or Aluminium, and insulators, such as rubber or glass. This unique property enables them to serve as the foundation of modern electronics, including devices such as smartphones, computers, solar panels, and LED lights, as shown in Figure 5. Unlike conductors, which always allow electricity to flow freely, semiconductors can be precisely controlled to switch between conducting and insulating states. This control is achieved through methods such as adding impurities (a process called doping) or applying external stimuli, including heat, light, or voltage. Silicon is the most widely used semiconductor due to its abundance in nature, stability, and ability to form high-quality crystals. Other examples include germanium and compound semiconductors, such as gallium arsenide (GaAs), which are used in specialised applications, including high-frequency circuits and lasers. Semiconductors are essential for building components like diodes, transistors, and integrated circuits, which form the backbone of electronic systems (Neamen, 2020).



Figure 5: *Examples of everyday devices that use semiconductors (AGC, 2024)*

2.2 Atomic and Crystal Structure

The atomic structure of semiconductors plays a critical role in their electrical behaviour. Materials like silicon have a crystalline structure, meaning their atoms are arranged in a highly ordered, repeating three-dimensional pattern called a lattice. In silicon, atoms bond with four neighbouring atoms through covalent bonds, forming a diamond cubic lattice as shown in Figure 6. This structure ensures that all electrons are tightly bound at low temperatures, leaving no free charges to conduct electricity. However, when energy (such as heat) is applied, some electrons gain enough energy to break free from their bonds, creating mobile electrons and positively charged "holes" in the lattice. These free charges enable electrical conduction. The purity and regularity of the crystal structure are vital; even tiny defects, such as missing atoms or impurities, can disrupt the flow of electrons and degrade performance. Modern manufacturing techniques, such as the Czochralski process, are employed to produce near-perfect silicon crystals for industrial applications (Brennan, 2018).

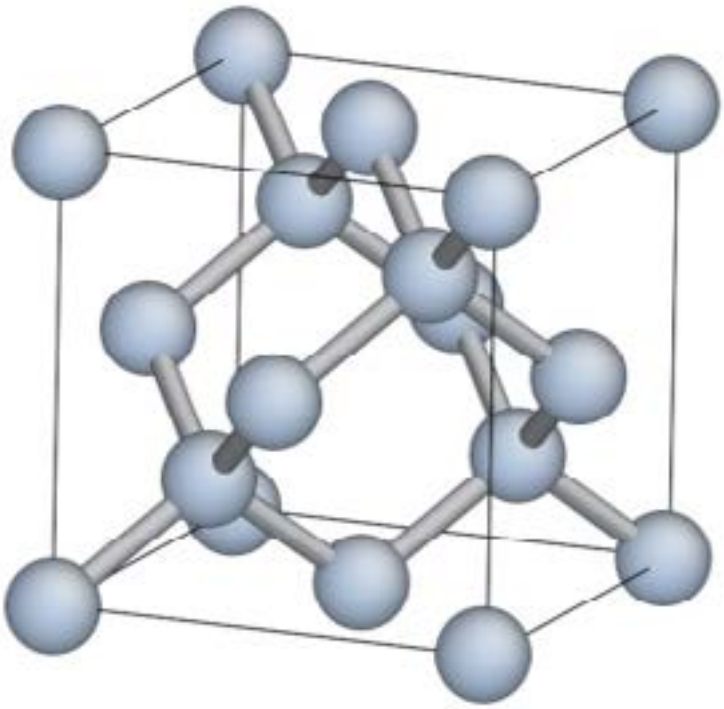


Figure 6: *Diamond cubic crystal structure of silicon with each atom bonded by four neighbouring atoms through covalent bonding*

2.3 Doping and Impurities

Doping is a process that intentionally introduces small amounts of impurities into a semiconductor to alter its electrical properties. For example, adding phosphorus (which has five valence electrons) to silicon (which has four valence electrons) creates an n-type semiconductor. The extra electron from the phosphorus atom becomes a free charge carrier, significantly increasing the material's conductivity. Conversely, adding boron (which has three valence electrons) creates a p-type semiconductor, where the absence of an electron - called a "hole" - acts as a positive charge carrier as shown in Figure 7. The interaction between n-type and p-type materials forms the basis of semiconductor devices like diodes and transistors. Lightly doped semiconductors are used in most applications, but heavy doping can create materials that behave almost like conductors. The ability to control doping levels allows engineers to design components with specific electrical characteristics, such as high-speed transistors for computers or sensitive sensors for medical devices (Hu, 2020).

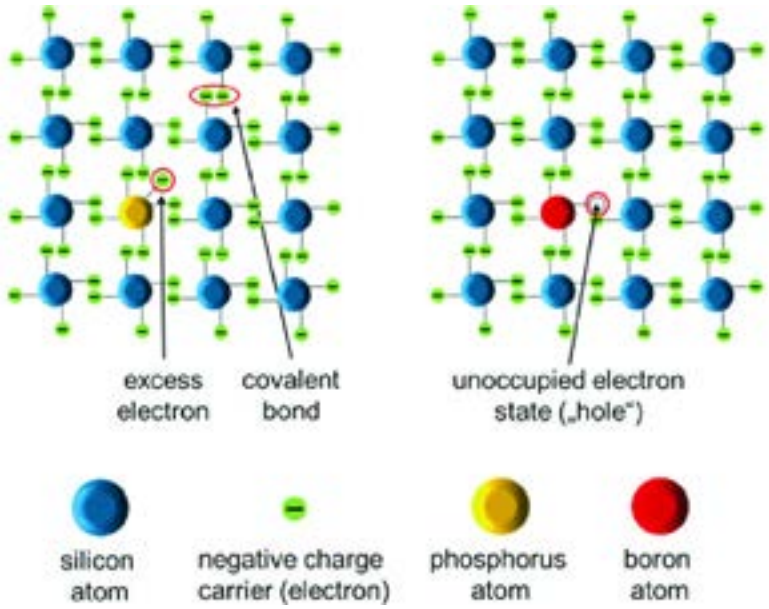


Figure 7: *n-doped silicon with phosphorus (left) and p-doped with boron (right)*

2.4. Band Theory

Band theory explains how electrons behave in solids and why semiconductors have unique conductive properties. In any material, electrons occupy energy levels called bands. The valence band contains electrons that are tightly bound to atoms, while the conduction band contains electrons that are free to move and conduct electricity. The band gap (the energy difference between these bands) determines whether a material is a conductor, semiconductor, or insulator. Semiconductors like silicon have a small band gap compared with insulators, allowing some electrons to jump from the valence band to the conduction band at room temperature as shown in Figure 8. Doping modifies the band structure by introducing additional energy levels near the conduction band (n-type) or valence band (p-type), making it easier for electrons to move. For instance, n-type doping adds donor levels just below the conduction band, reducing the energy required for electrons to become mobile. This principle is fundamental to designing efficient electronic devices (Neamen, 2020).

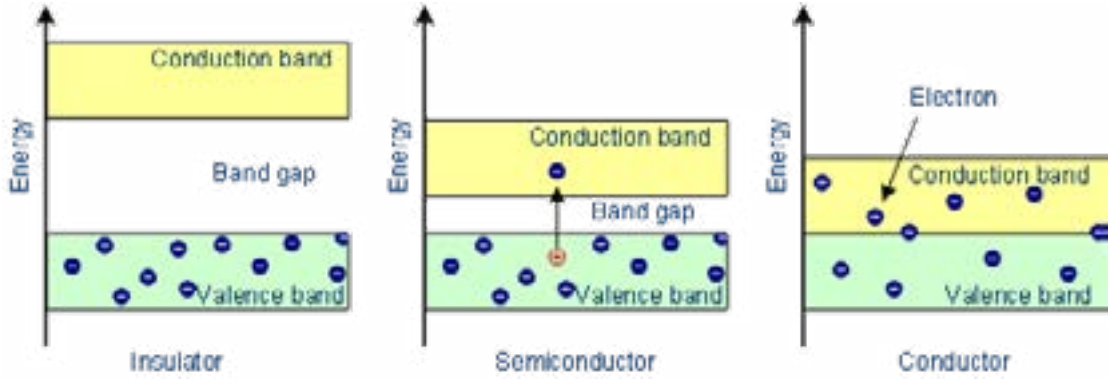


Figure 8: *The band model for an insulator, semiconductor and conductor*

2.5 Types and Properties of Semiconductors

Semiconductors can be classified into three main categories. **Intrinsic semiconductors**, such as pure silicon or germanium, have conductivity that depends heavily on temperature. As the temperature rises, more electrons gain energy to cross the band gap, increasing conductivity. **Extrinsic semiconductors** are created by doping intrinsic materials, resulting in n-type or p-type variants with enhanced and controllable conductivity. For example, n-type

silicon is used in solar cells to create electron-rich regions, while p-type silicon forms hole-rich regions. **Compound semiconductors**, like gallium arsenide (GaAs) or indium phosphide (InP), combine elements from different groups of the periodic table. These materials often have superior electron mobility compared with silicon, making them ideal for high-frequency applications like satellite communication or radar systems. Key properties of semiconductors include their sensitivity to temperature, responsiveness to light (used in photodetectors), and the ability to emit light when electrons recombine with holes (as in LEDs). However, compound semiconductors are typically more expensive and harder to manufacture than silicon (Brennan, 2018).

Notes for Facilitators

1. **Clarifying Concepts:** Use a classroom analogy. The crystal lattice is like a perfectly organised audience in a school hall, each student holding hands (covalent bonds). This is silicon at low temperatures – no one can move (no conductivity). Doping is introducing a new student. If you add a student with an extra "hand" (extra electron, like Phosphorus), that hand is free to move around the hall (n-type). If you add a student with only three "hands" (like Boron), they create a "hole" where a hand is missing; a nearby student can fill it, creating a moving vacancy (p-type).
2. Explaining the Band-Theory (The Apartment Building Analogy): Imagine a tall apartment building. Each floor is an energy level where electrons can "live."
    a. Ground floor (Valence Band): This is where most electrons live. They are comfortable, close to the nucleus, and cannot move around much – they are "bound." This means no electricity flows.
    b. Upper floors (Conduction Band): If an electron gets enough energy (from heat, light, or voltage), it can jump to an upper floor. Once there, it is free to move around the building – that means flow of electricity.
    c. The space between floors (Band Gap): There are no apartments between floors – an electron cannot stop in midair. It must jump the entire gap in one go.
    d. Different materials have different gap sizes:
        i. Insulator: Gap is like a 10storey jump – too high for most electrons to climb. No conductivity.
        ii. Semiconductor: Gap is like a 1storey jump – some electrons can make it with a little energy (room temperature, light).
        iii. Conductor: No gap at all – the ground floor and upper floors are connected by stairs. Electrons flow freely.
3. **Common Misconceptions:** Students often confuse doping with contamination. Emphasise that doping is a highly controlled, intentional process to create predictable electrical behaviour. Contamination is uncontrolled and ruins the semiconductor.
4. Low-Cost Demonstrations and Ghanaian Examples
    a. Crystal Model: Use toothpicks and small balls of clay or polystyrene to build a diamond cubic lattice model. This makes the 3D structure tangible.

b. Band Theory: Draw the band diagram on the board. Explain the band gap as a wall. In an insulator, the wall is too high for electrons to climb over. In a conductor, there is no wall. In a semiconductor (silicon), the wall is low enough that some electrons can jump over when they get "energy" from heat or light. This is why a solar panel works – light gives electrons enough energy to jump the wall and create electricity.

Learning Tasks

1. Recap the atomic structure of metals, insulators, and conductors.
2. Explain the atomic and crystal structure of semiconductors and relate it to electrical conductivity.
3. Discuss how the structure of semiconductors influences their real-world engineering applications.
4. Complete an example assessment question individually.

Pedagogical Exemplars

1. **Talk-for-Learning:** Learners engage in peer-pair activities to sketch and label basic atomic diagrams while reviewing the atomic structures of conductors and insulators. In structured group discussions, learners explore how differences in atomic arrangements affect electrical behaviour. The facilitator then guides a whole-class discussion where learners compare the atomic structures of conductors and insulators and explain why semiconductors exhibit conductivity properties that fall between those of conductors and insulators.
2. **Experiential Learning:** Learners in groups build three-dimensional models of the atomic and crystal structure of silicon using materials such as toothpicks and beads, or by using virtual simulation tools. Learners observe the formation of covalent bonds in silicon and examine how introducing dopants alters electron behaviour. Learners then prepare individual reports describing the type of bonding, crystal structure, and the impact of doping on the electrical properties of semiconductors.
3. **Talk-for-Learning:** Learners work in small groups to select common semiconductor-based devices such as solar panels, microchips, and LEDs, and discuss how the atomic and electronic structure of semiconductors enables their function. Each group then makes a short presentation summarising the structural relevance and application of semiconductors.
4. **Independent work:** Have learners complete the assessment questions individually and then mark them as a class, using the marking scheme.

Key Assessment Level 4: Design and Presentation

1. Analyse how atomic structure affects the electrical conductivity of different materials, such as metals, ceramics, semiconductors, and insulators. Select one material type and explain, using electron behaviour, why it is either a good or poor conductor. Then evaluate why this property makes it suitable or unsuitable for real-world electrical applications (e.g., wiring, insulators, microchips). (10 marks)
2. Evaluate the impact of a hypothetical failure in the doping process of silicon used to make a smartphone processor.

a. Describe what would happen to the electrical conductivity if phosphorus were accidentally omitted from an ntype wafer.

b. Predict two consequences for the processor's performance (e.g., speed, power consumption, heat).

c. Propose a quality control procedure at the wafer fabrication stage that could detect this failure before the chips are assembled.

(10 marks)

3. Explain two key properties of semiconductors that make them suitable for electronic devices. Then, analyse how each property affects the design and function of these devices (e.g., switching, miniaturisation, energy efficiency). Conclude by evaluating how these properties compare to other material types in similar roles. (10 marks)

PLC Session 2

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is design and presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

    a. transfer your chats into your learning planner template.

    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 3

Learning Indicator: State the applications of semi-conductors, biomaterials, smart materials and nanomaterials

Recap weeks

Year 1	**Week 4:** Group materials based on their industrial applications i.e., clothing, building, food, automobiles, electronics and medical.

Focal Area: Applications of advanced materials

3.1 Introduction to the Focal Area

Advanced materials are specially engineered to perform better than conventional materials. These materials often possess unique electrical, mechanical, or chemical properties that make them more suitable for modern industrial applications. In the context of manufacturing, advanced materials are transforming how products are designed, made, and used - enabling stronger, lighter, smarter, and more sustainable products. Four key categories of advanced materials widely used in manufacturing include semiconductors, smart materials, biomaterials, and nanomaterials. Each of these types has specific properties that serve different industrial applications. Understanding their applications helps Learners connect classroom knowledge with real-world manufacturing innovations.

3.2 Applications of Semiconductors in Manufacturing

(Refer to Year 1, Section 1, Week 4 Group materials based on their industrial applications i.e., clothing, building, food, automobiles, electronics and medical)

Semiconductors are materials that can behave both as conductors and insulators, depending on how they are treated. This unique electrical property makes them essential in the manufacturing of electronic components and systems. In the manufacturing industry, semiconductors are used in microcontrollers, sensors, and control circuits that regulate machinery and processes. For example, in automated manufacturing systems, semiconductors help manage inputs and outputs in robotic arms, conveyor belts, and temperature controls. They are also widely used in solar panel production, where semiconductor materials like silicon are processed into photovoltaic cells that convert sunlight into electricity. In computer numerical control (CNC) machines, semiconductors control the logic boards that govern cutting, milling, and engraving operations. The production of semiconductors involves photolithography and doping processes, which are high-precision techniques (Callister and Rethwisch, 2020). Figure 9 shows Silicon microchips on a printed circuit board.

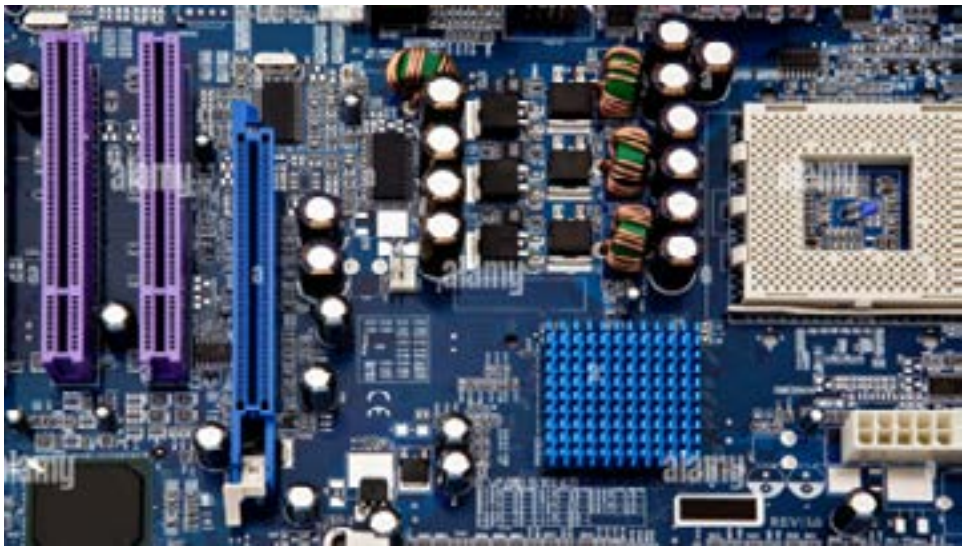


Figure 9: *Silicon microchips on a printed circuit board (Alamy, 2009)*

3.3 Applications of Smart Materials in Manufacturing

(Refer back to Year 1, Section 1, Week 4, Classification of Materials according to their Industrial Applications.)

Smart materials respond to changes in their environment, such as heat, stress, or electricity, by changing their shape, colour, or state. These materials are increasingly applied in aerospace, automotive, and robotics manufacturing. One major example is the use of shape memory alloys (SMAs) in manufacturing mechanical actuators - components that can return to a pre-set shape after deformation. This property is used in valves and couplings that need to activate automatically without human intervention. In aerospace manufacturing, smart materials help design adaptive wings and control surfaces that change shape depending on flight conditions, improving fuel efficiency and performance. Piezoelectric materials, another type of smart material, are used in precision manufacturing equipment to produce micro-vibrations for highly accurate positioning systems in 3D printers and machining tools. Piezoelectric materials are also used in vibration dampers and pressure sensors in automotive manufacturing. Thermochromic materials that change colour with temperature are applied in safety indicators on machines or packaging that show temperature exposure (Callister & Rethwisch, 2020).

3.4 Applications of Biomaterials in Manufacturing

Biomaterials are materials that are safe to use inside the human body and are usually applied in the manufacturing of medical devices and implants. In the manufacturing sector, biomaterials are used to produce surgical tools, dental implants, joint replacements, and biodegradable packaging. Titanium and its alloys are common biomaterials used in orthopaedic implants due to their strength, low weight, and biocompatibility. Biodegradable polymers, another class of biomaterials, are used in the production of single-use medical items such as sutures and tissue scaffolds. These materials degrade safely inside the body after serving their purpose, reducing the need for follow-up surgeries. Biomaterials are also used in additive manufacturing (3D printing) to create customised implants or medical devices. In Ghana and other parts of Africa, there is growing interest in developing biodegradable food packaging and sustainable cutlery made from plant-based biomaterials, which is contributing to green manufacturing.

3.5 Applications of Nanomaterials in Manufacturing

Nanomaterials are substances with structures at the nanometre scale, often between 1 and 100 nanometres. Because of their small size, nanomaterials can have very large surface areas, high strength, and unique electrical or thermal properties. In manufacturing, nanomaterials are widely used to enhance product strength, durability, and functionality. For instance, carbon nanotubes are added to metals and polymers to make lightweight but strong composite materials used in aircraft parts, sports equipment, and bicycle frames. Figure 10 is an application of nanocomposites for aerospace applications. Silver nanoparticles are used in the manufacture of antimicrobial surfaces, such as medical tools and food packaging, because they kill bacteria on contact. In electronics manufacturing, nano-coatings are applied to circuit boards to protect them from moisture and dust. Nanomaterials in paints and coatings also provide UV protection and self-cleaning properties, which are helpful in the construction and automotive industries (Ashby, 2014).

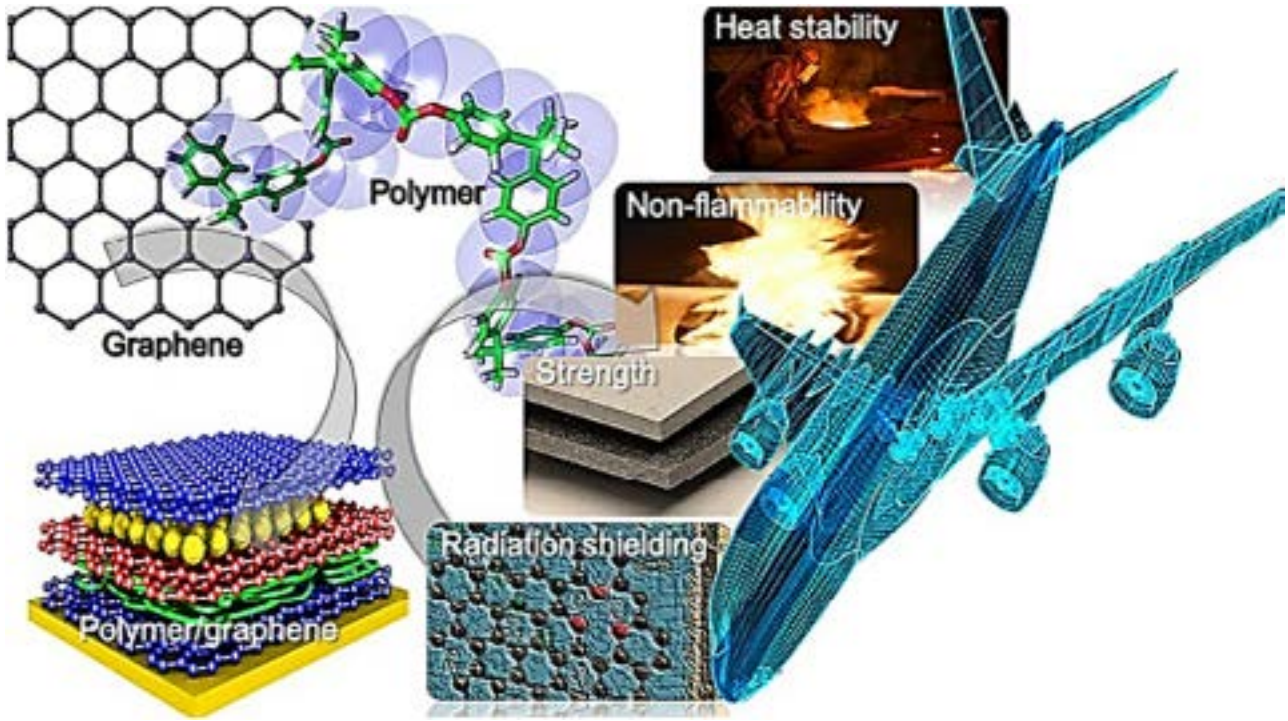


Figure 10: *Polymer nanocomposites for aerospace applications (Rashid et al., 2024)*

Notes for Facilitators

1. **Clarifying Concepts:** Structure the lesson around «problem» and «solution» to make applications more relatable. For example: «Problem: A component in a jet engine gets too hot and fails. Solution: A shape memory alloy actuator that changes shape to allow cooling air to flow.» This links the property directly to the application.
2. **Common Misconceptions:** Students may think «biomaterials» are only for high-tech medical implants. Broaden their understanding by discussing biodegradable food packaging, which is a biomaterial application becoming more common in Ghanaian markets (e.g., paper-based containers replacing plastic).
3. **Low-Cost Demonstrations and Ghanaian Examples**

    a. **Smart Material:** Show a simple piezoelectric igniter from a gas stove or lighter. This is a very common and tangible example. When you press the button, you are applying pressure, and the spark (electricity) is generated.

b. **Nanomaterials:** Discuss «nano-coatings» in the context of locally made «anti-dust» car polish or fabric sprays. Explain how the tiny particles create a surface that repels dirt and water.

c. **Biomaterials:** Discuss the growing use of bamboo (from Week 4) in Ghana as a biomaterial. Bamboo fibres are now being used to make «bamboo fabric» for clothing, an application that is both sustainable and comfortable.

Learning Tasks

1. Learners recap the applications of common materials (metals, insulators, and conductors) learnt in earlier years.
2. Learners individually research and classify different categories of advanced materials, such as semiconductors, nanomaterials, biomaterials, smart materials, and energy-efficient materials, based on their real-world manufacturing applications using mind maps.
3. Learners in mixed-ability groups develop a mini-project proposal to solve an existing local industrial or community problem using an advanced material, such as biodegradable materials for packaging, or nanomaterials for enhancing durability in road construction.
4. Complete an example assessment question individually.

Pedagogical Exemplars

1. **Group activity:** Learners work in small groups to classify given material samples according to their application in the clothing, building, food, automobile, electronics, and medical industries. Learners present their results through peer discussions and justify their classification based on material properties. The facilitator leads a debrief session to connect the recap to current studies on advanced materials.
2. **Research-based learning:** Learners conduct guided internet research or explore reading packs that present categorised real-life case studies of the industrial use of advanced materials. Using a jigsaw method, groups become 'experts' in one type of advanced material and orally share their findings with peers.
3. **Project-based learning:** Learners in mixed-ability groups identify a real-world industrial or community challenge and develop a conceptual product or material substitution solution using advanced materials, indicating their potential advantages and implications. Learners make a written report of their proposed solution.
4. **Independent work:** Have learners complete the assessment questions individually and then mark them as a class, using the marking scheme.

Key Assessment Level 4: Group Research Project

1. Why is titanium alloy commonly used in biomedical implants, and what properties make it biocompatible compared with other materials? (20 marks)
2. Evaluate how the high surface-area-to-volume ratio of nanomaterials affects their performance in a specific manufacturing process (e.g., coatings, catalysts, or drug delivery systems). Support your evaluation with data or a case study, and critically assess the limitations or trade-offs this property might introduce. (10 marks)

3. Select three distinct categories of advanced materials and evaluate how each is applied in a critical industry (e.g., aerospace, medicine, or energy). For each material, analyse how specific properties solve industry challenges, and assess any limitations or considerations that must be managed. (10 marks)
4. Design a case study comparing a smart material with a traditional material used in an automotive application (e.g., shape memory alloy vs. steel in actuators or suspension). Evaluate how each material performs under real-world operating conditions such as stress, temperature, and wear. Justify which material is more suitable depending on usage scenarios, and consider both technical and economic factors. (12 marks)

Hint



Assign Group Research Project to learners and give them reasonable time to complete it. Use the SS App to generate the project as well as the rubric. Learners' projects should be marked immediately and scores entered into the SAP.

PLC Session 3

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP)

    a. The key assessment for the week is group research project. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the project (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

    b. all teachers in the group work through the problem individually for 3–4 minutes

    c. the group then works through it together the problem, step by step

    d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

    b. After the enactment, ask for structured feedback from the group

        i. was the concept explained in a way that a learner with no prior knowledge could follow?

        ii. were the examples grounded in contexts familiar to Ghanaian learners?

        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 4

Learning Indicators

1. *Classify bamboo based on its structure, physical properties and processing*
2. *State the application of bamboo in manufacturing*

Recap weeks

Year 1	**Week 5:** Explain thermal conductivity, Specific heat capacity, thermal expansion, melting point, and thermal diffusivity as thermal properties of materials. **Week 6:** Explain electrical conductivity, electrical resistivity, dielectric strength, and temperature coefficient of resistance as electrical properties of materials. **Week 7:** Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials.
Year 2	**Week 3:** Classify materials as metals, ceramics and polymers according to their processing methods.

Focal Area: Structure, physical properties and processing of bamboo

4.1 Introduction to Bamboo

(Refer to Year 2, Section 1, Week 3 Classify materials as metals, ceramics and polymers according to their processing methods.

Bamboo is one of the fastest-growing plants on Earth and has been used for thousands of years in construction, tools, and art. Historically, it has been vital in Asian, African, and South American cultures for building homes, bridges, and even weapons due to its strength and flexibility. Unlike trees, bamboo is a type of grass with hollow, segmented stems called culms, which grow in clusters from underground rhizomes. Today, bamboo is celebrated as a sustainable material because it grows quickly (some species grow up to 1 metre per day), absorbs carbon dioxide efficiently, and requires no pesticides. Its versatility makes it a key material in modern eco-friendly manufacturing, from furniture to textiles (Gielis, 2015).

4.2 Structure of the Bamboo Plant

Bamboo has a unique structure that makes it both lightweight and strong. The plant consists of rhizomes (underground stems), culms (vertical stems), nodes (joints along the culm), and internodes (hollow sections between nodes) as shown in Figure 11. The nodes act as reinforcement points, preventing the culm from bending or breaking easily. Inside the culm, vascular bundles (tiny tubes) run vertically, transporting water and nutrients. These bundles contain fibres (for strength) and parenchyma cells (for storage). The outer layer of the culm, called the epidermis, is coated with silica, making it resistant to pests and moisture. This layered structure is similar to a natural composite material, combining flexibility and durability (Fahim et al., 2022).

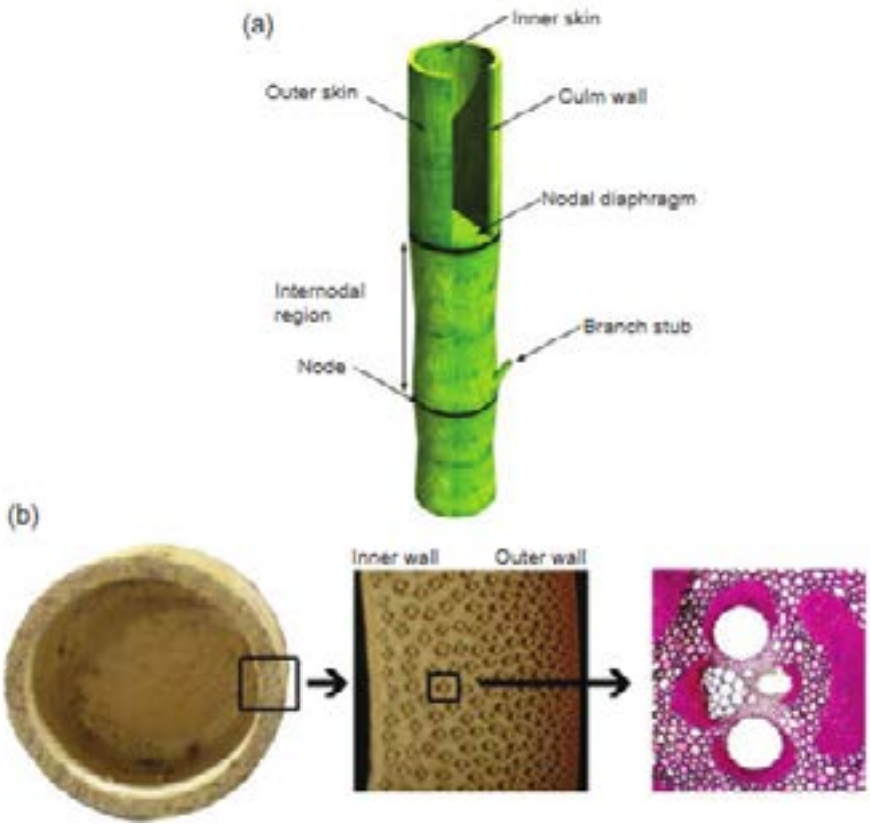


Figure 11: *Anatomy of a bamboo culm (a) Schematic view of a culm segment (b) Section of culm wall showing grading of vascular bundles (Trujilo & Lopez, 2020)*

4.3 Physical Properties of Bamboo

(Refer back to Year 1, Section 2, Week 7, Mechanical properties of engineering materials.)

The physical properties of bamboo vary by species but generally include high tensile strength (comparable with steel), low weight, and flexibility. Its density ranges between 500–800 kg/m³, making it lighter than most hardwoods. The moisture content of freshly cut bamboo is about 30–40%, but this decreases to 10–15% after drying, improving its durability. Bamboo also has excellent thermal insulation properties and can withstand temperatures up to 100°C without losing strength. However, untreated bamboo is susceptible to insects and fungi due to its starch content. These properties make it ideal for products like flooring, scaffolding, and bicycle frames. For example, bamboo's flexibility allows it to be woven into mats or bent /into curved furniture.

4.4 Processing of Bamboo

Processing bamboo involves harvesting, preservation, and shaping. Harvesting is done when the culm is 3–5 years old to ensure maximum strength. After cutting, bamboo is treated to remove starch and prevent insect damage. Common preservation methods include smoke treatment, borax soaking, or heat treatment. The culms are then split into strips, flattened, or laminated for manufacturing. Traditional techniques like hand-splitting are still used, but modern methods such as CNC machining and laser cutting enable precise shaping for products like engineered flooring or laminated beams. For example, bamboo fibres can be compressed into boards (similar to plywood) or spun into yarn for textiles. Innovations like bamboo charcoal (used for air purification) and bamboo composite materials (mixed with plastics or resins) are expanding their industrial applications.

The unique structure of bamboo, its impressive physical properties, and adaptable processing methods make it a valuable renewable resource. Classifying bamboo involves understanding its biological features, such as node distribution and fibre density, as well as its behaviour during manufacturing. By studying bamboo, Learners learn how natural materials can address modern challenges like deforestation and climate change.

Notes for Facilitators

1. **Clarifying Concepts:** Emphasise that bamboo is a natural composite material. Its strength comes from the combination of the stiff, strong fibres (like steel rebar) and the softer, flexible lignin matrix (like concrete). The hollow, cylindrical shape with nodes maximises strength while minimising weight and material use (a principle called stress optimisation).
2. **Common Misconceptions:** Students might think all bamboo is the same. Highlight that there are over 1,000 species, and their properties vary greatly. The bamboo used for weaving baskets is different from the one used for heavy construction scaffolding. Age matters too – bamboo is strongest at 3-5 years.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. Structure: Bring a fresh bamboo stalk. Have students cut it crosswise to observe the hollow internodes and solid nodes (the natural diaphragms). Slice it lengthwise to show the vertical fibre bundles.
    b. Moisture Content: Take a piece of bamboo, weigh it, and place it in the sun. Ask students to hypothesise what will happen. Re-weigh it after a few days to show weight loss due to moisture. This explains why freshly cut bamboo must be dried.
    c. Processing: Invite a local carpenter who works with bamboo to the class or visit their workshop. Have them demonstrate traditional preservation methods like smoking or borax soaking to prevent insect attack.
    d. Troubleshooting: When students process bamboo, warn that it can split easily. Demonstrate the correct technique: always drill a pilot hole for nails or screws; use a sharp blade; and cut in the direction of the grain to avoid splintering.

Learning Tasks

1. Learners in mixed-ability groups, recap the types of conventional materials, their physical properties and processing methods.
2. Learners, in mixed-ability groups, examine the cross-section of bamboo using physical samples or images, and identify its structure and physical properties.
3. Learners individually identify traditional and modern bamboo processing methods.
4. Independent work: Learners complete the assessment questions individually and then mark them as a class, using the marking scheme.

Pedagogical Exemplars

1. **Group activity:** Learners work in small groups to classify given material samples according to their structure, physical properties and processing methods. Learners present their results through peer discussions and justify their classification. Facilitator leads a debrief session to connect the recap to current studies on advanced materials.
2. Learners visit a nearby bamboo production facility, where a guide explains how raw bamboo is selected, tested, and processed into products like furniture and construction materials. Learners observe structural features, quality checks, and processing methods. Back in class, each learner writes a brief report linking their observations to classroom concepts on bamboo structure, properties, and processing techniques.
3. In pairs, learners examine bamboo sticks to identify structural parts (nodes, internodes, culms) and measure properties such as diameter, density, T/R ratio, and moisture content using basic instruments. Learners complete a classification worksheet based on their findings and connect at least one measured property (e.g., moisture content) to a relevant processing method (e.g., drying).
4. **Project-Based Group activity:** Learners process the bamboo sticks into laminated bamboo following the steps below: a) segmenting the bamboo transverse to the culm axis b) splitting the bamboo parallel to the culm axis c) planning of the bamboo culm d) treating the bamboo by bleaching and drying e) re-planning of the bamboo strips f) gluing the bamboo strips g) stacking and pressing to form a laminated material.
5. In mixed-ability groups, learners prepare a short presentation classifying their bamboo sample by structure and properties, supported by measurements taken in class. Each group demonstrates one suitable processing method (e.g., cutting or drying) on a sample and explains its purpose. Presentations are shared in a class gallery walk, with peer feedback and discussion.
6. **Independent work:** Have learners complete the assessment questions individually and then mark them as a class, using the marking scheme.

Key Assessment Level 4: Individual Assignment

1. Critically evaluate why colour is not considered a measurable physical property in bamboo analysis, unlike properties such as density, thickness, and moisture content. In your response, compare how each property contributes to material characterisation and explain the limitations of using colour as a scientific parameter in construction or engineering contexts. (5 marks)
2. Assess the role of segmentation in the bamboo processing chain for laminated board production. Analyse how omitting or altering this step could affect the mechanical properties, dimensional stability, and final performance of the laminated product. Use examples to support your explanation. (5 marks)
3. Design and evaluate a procedure to measure the moisture content of bamboo in a school or field-based lab. Include all necessary tools and variables that must be controlled to ensure reliability. Discuss how deviations in this measurement could affect downstream applications such as drying, gluing, or structural use. (7 marks)

4. In what ways does the thickness-to-radius (T/R) ratio influence the structural integrity of bamboo in construction applications? (90 marks)
5. What are two key advantages of using laminated bamboo boards in construction, and how do they improve performance compared with raw bamboo? (8 marks)

PLC Session 4

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is individual assignment. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assignment (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?s
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 1 Review

This section aims to deepen the understanding of learners in material science by transitioning from foundational knowledge of conventional materials to the more complex and innovative field of advanced materials. The learning journey began with the classification of materials, distinguishing conventional types such as metals, polymers, ceramics, and composites from advanced materials like semiconductors, nanomaterials, biomaterials, and smart materials. Learners examine the significance of these advanced materials in modern manufacturing, recognising their role in enhancing efficiency, sustainability, and technological innovation across industries such as electronics, aerospace, automotive, and healthcare.

Building on this foundation, learners delved into the structure and function of semiconductors. They studied the atomic and crystal structures that define semiconductors and analysed how these structures influence electrical conductivity. Key concepts such as band theory and doping were introduced to explain how semiconductors can be engineered for specific applications, including solar energy systems, microelectronics, and digital devices. Through diagrams, discussions, and model construction, learners gained a scientific understanding of how semiconductors bridge the gap between conductors and insulators.

The section further explores smart and advanced materials that respond to external stimuli such as heat, pressure, or electric current. Learners studied materials like shape memory alloys, piezoelectric materials, and magneto strictive compounds, learning how their unique responsive behaviours are utilised in real-world products, from wearable health devices to smart actuators in robotics. This knowledge equipped Learners to appreciate the connection between material properties and functional performance in high-tech manufacturing environments.

Finally, the section concludes with a focus on bamboo as a sustainable and locally accessible engineering material. Learners investigate its structure, physical properties, and traditional as well as modern processing methods. Bamboo was used as a case study for applying engineering principles to local resources, encouraging learners to consider ecological and economic sustainability in material selection. Throughout the unit, Learners engage in experiential activities, discussions, research projects, and critical reflections that require them to analyse material properties, justify material choices, and propose solutions to context-specific manufacturing challenges.

By the end of this section, learners are expected to have developed a solid understanding of the classification, structure, behaviour, and applications of advanced materials. They should be able to apply critical thinking to material selection decisions, communicate scientific reasoning clearly, and connect their knowledge to real-world innovation, sustainability, and local industry relevance.

MARKING SCHEME FOR THE KEY ASSESSMENTS

WEEK 1

Q1

Identification	1 mark	Identifies that smart materials are best suited for the task.
Explanation of response to stimuli	2 marks	Explains that smart materials can change shape, form, or properties in response to external changes (e.g., temperature, pressure, pH).
Application context	1 mark	Gives a relevant use-case such as in medical implants, sensors, or biomedical devices.

Q2

Material identified	1 mark	Identifies shape memory alloy or a specific example (e.g., Nitinol).
Explanation of the property	2 marks	Describes the shape memory effect, phase transformation, or response to heat.
Practical application	1 mark	Gives a real-world use case (e.g., stents, actuators, eyeglass frames).

Q3 Marking Scheme (9 marks)

Criteria	Marks	Description
Smart material – property	1	Correctly names one unique property (e.g., shape memory effect, piezoelectricity, thermochromism).
Smart material – application	2	Clearly explains how that property enables a specific industrial application (e.g., shape memory alloy in dental braces, piezoelectric in gas lighter). Application must differ from class examples.
Smart material – limitation	1	States a realistic limitation (e.g., high cost, low fatigue life, temperature sensitivity).
Nanomaterial – property	1	Correctly names one unique property (e.g., high surfaceareatovolume ratio, quantum effects, superstrength).
Nanomaterial – application	2	Clearly explains how that property enables a specific industrial application (e.g., carbon nanotubes in lightweight sports equipment, silver nanoparticles in antimicrobial coatings). Application must differ from class examples.
Nanomaterial – limitation	1	States a realistic limitation (e.g., difficult to disperse uniformly, health and environmental concerns, high production cost).
Clarity and comparison	1	Answer is wellstructured, uses correct terminology, and shows clear contrast between the two material types.

Sample Answer

A smart material like a shape memory alloy (SMA) has the unique property of returning to a preset shape when heated. This enables SMAs to be used as compact actuators in aerospace – for example, deploying a solar panel hinge without a motor. A limitation is that SMAs lose their effect after many cycles (fatigue).

A nanomaterial like silver nanoparticles has an extremely high surfaceareatovolume ratio, making them highly reactive. This enables their use in antimicrobial coatings on medical tools – the nanoparticles release silver ions that kill bacteria. A limitation is that manufacturing nanoparticles is expensive and their longterm environmental effects are unknown.

Q4. Importance of Advanced Materials in Modern Manufacturing Total Marks: 15

Criteria	Excellent (5 marks)	Good (4 marks)	Fair (3 marks)	Poor (1–2 marks)
1. **Explanation of Enhanced Performance and Efficiency**	Clearly explains how advanced materials improve strength, reduce weight, resist corrosion, and handle high temperatures. Includes at least two accurate examples (e.g., titanium in aircraft, ceramic brakes in cars).	Explain at least two performance benefits correctly and give one relevant example.	Mentions one or two benefits but lacks detail or gives unclear example(s).	Gives vague or incorrect explanation; no relevant example provided.
2. **Explanation of Role in Innovation and New Technologies**	Clearly describes how advanced materials enable specific modern technologies (e.g., semiconductors in electronics, biomaterials in implants). Provide at least two accurate examples.	Describes how advanced materials support innovation with one correct example.	Gives a general idea of innovation without clear links to materials or examples.	Fails to connect materials to technology or gives incorrect/ irrelevant examples.
3. **Explanation of Sustain-ability and Environmen-tal Benefits**	Accurately explains how advanced materials support sustainability (e.g., lightweight composites reduce fuel use, recyclable polymers reduce waste). Give at least two correct examples.	Gives one or two environmental benefits with limited explanation or one example.	Mentions sustainability but without clarity or supporting examples.	Fails to explain or misunderstands the environmental impact of advanced materials.

Notes for constructive feedback

1. **Always start with a positive** – even if the answer is weak, find something correct (e.g., "You correctly identified that the material is used in medicine.").
2. **Be specific, not generic** – avoid "Good try" or "Needs work". Say exactly what is missing: "You did not explain *what causes* the material to change."
3. **Provide a clear next step** – give a miniaction: "Add one sentence about the crystal structure transformation." or "Draw the before/after states."
4. **Use the rubric as a checklist** – show the student the rubric and ask them to selfassess before you mark. Then compare. This builds metacognition.
5. **Encourage resubmission** – for scores below 4/3, allow students to revise and resubmit after receiving your feedback. This turns assessment into learning, not punishment.

WEEK 2

Q1

a. Clear identification of material type (1 mark)

b. Accurate explanation of atomic structure and electron behaviour (3 marks)

c. Evaluation of material's conductivity and suitability (4 marks)

d. Use of relevant terminology and real-world examples (2 marks)

Q2: The impact of a hypothetical failure in the doping process of silicon used to

Criteria	Marks	Description
Effect of omitting phosphorus	2	Correctly states that without phosphorus (ntype dopant), the silicon remains intrinsic or ptype; conductivity drops dramatically because no free electrons are added. (1 mark for correct identification, 1 mark for explanation of charge carriers)
Consequence 1 on processor performance	2	Predicts a specific performance issue, e.g., transistors cannot switch properly, leading to slower clock speeds or logic errors. (1 mark for identification, 1 mark for causal link)
Consequence 2 on processor performance	2	Predicts another distinct issue, e.g., increased power consumption due to higher resistance, or excessive heat generation, or complete chip failure. (1 mark for identification, 1 mark for causal link)
Quality control procedure	3	Proposes a realistic, technically sound QC method, e.g., fourpoint probe resistivity measurement on test wafers before dicing; or secondary ion mass spectrometry (SIMS) to verify dopant concentration. (1 mark for naming a method, 2 marks for explaining how it detects the failure)
Overall evaluation and clarity	1	Answer is wellorganised, links causes to consequences, and demonstrates evaluation (not just description).

Sample Answer

If phosphorus is omitted during doping, the silicon remains intrinsic (no extra free electrons). Conductivity drops by many orders of magnitude.

Consequence 1: Transistors would not turn on reliably because the channel cannot form, causing logic errors and making the processor unusable.

Consequence 2: Even if some transistors work, the higher resistance would cause excessive heat, potentially melting internal connections.

QC procedure: Before wafer dicing, use a fourpoint probe to measure sheet resistance. An undoped wafer will show resistivity >1000 Ω·cm instead of the target 0.01–0.1 Ω·cm, flagging the failure immediately.

Q3

a. Identification and explanation of two properties — 4 marks (2 per property)

b. Analysis of how each property affects device function — 4 marks (2 per property)

c. Comparison with other materials (e.g., metals or insulators) — 2 marks

Sample Answer

Semiconductors are widely used in electronic devices for the following two key reasons:

1. **Ability to Control Electrical Conductivity**

   a. Explanation: Semiconductors, such as silicon and germanium, have electrical conductivity that can be precisely controlled by adding impurities (a process called *doping*). This allows them to act as insulators under some conditions and conductors under others.

   b. Usefulness in Electronics: This controllable conductivity makes semiconductors ideal for creating components like **transistors**, **diodes**, and **integrated circuits**. These components are essential for switching, amplifying, and controlling electrical signals in devices like computers, phones, and radios.

2. **Miniaturisation and Integration**

   a. **Explanation**: Semiconductors can be fabricated into extremely small components and integrated into complex circuits on a single chip (known as an **integrated circuit** or IC).

   b. **Usefulness in Electronics**: This allows electronic devices to be **compact**, **lightweight**, **energy-efficient**, and capable of performing complex functions. For example, smartphones contain powerful microprocessors made from semiconductor chips that control everything from display to wireless communication.

WEEK 3

Q1 Rubric: Why is titanium alloy commonly used in biomedical implants, and what properties make it biocompatible compared with other materials?"

Total: 20 marks

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
Biocompatibility *(2 marks)*	Clearly explains that titanium forms a TiO_2 oxide layer, making it non-toxic and allowing safe interaction with body tissues.	Mentions the oxide layer and that titanium is biocompatible, with limited explanation.	States that titanium is biocompatible, but doesn't explain why	No mention or incorrect explanation of biocompatibility
Corrosion Resistance *(2 marks)*	Explains that the oxide layer makes titanium highly resistant to corrosion in body fluids, contributing to implant durability	States that titanium resists corrosion, with a brief explanation of its benefits	Mentions corrosion resistance without detail	No mention or misunderstanding of corrosion resistance
Mechanical Properties *(2 marks)*	Clearly describes titanium's high strength-to-weight ratio, making it strong yet lightweight, ideal for implants.	States titanium is strong and/or lightweight, with some link to medical use.	Mentions strength or weight but doesn't connect to a medical purpose	No relevant description or incorrect ideas
Elastic Modulus / Stress Shielding *(2 marks)*	Explains that titanium's elasticity is closer to bone than other metals, reducing stress shielding and supporting bone health	Mentions that elasticity is similar to bone and helps avoid stress shielding	Mentions elasticity or stress shielding vaguely or incorrectly	No mention or incorrect explanation of elasticity/modulus
Additional Properties *(2 marks)*	Clearly identifies two or more: supports osseointegration, is MRI safe, and non-reactive; explains why they are important in implants.	Identifies one or two additional properties with limited explanation	Mentions one extra property with no explanation	No additional properties mentioned or explained

Sample answer

Biocompatibility: Titanium forms a stable and passive oxide layer (TiO_2) on its surface when exposed to air or body fluids. This layer prevents corrosion and makes titanium non-toxic and non-reactive, allowing it to integrate well with bone and tissue without causing an immune response.

Corrosion Resistance: The titanium oxide layer also provides exceptional resistance to corrosion in body fluids, which is essential for long-term implants (like hip joints, dental roots, and bone plates). Many other metals, like stainless steel, may corrode more easily over time.

High Strength-to-Weight Ratio: Titanium alloys (especially Ti-6Al-4V) offer high mechanical strength while being relatively lightweight, making them strong enough to bear loads without adding too much weight to the implant.

Elastic Modulus Similar to Bone: Titanium has a lower modulus of elasticity than other metals like stainless steel, meaning it is closer to that of natural bone. This helps reduce stress shielding, a phenomenon where the implant takes too much load, weakening the surrounding bone.

Osseointegration: Titanium encourages direct bonding with bone tissue (osseointegration), meaning it can be anchored securely in place without the need for adhesives or cements.

Non-Magnetic and MRI Safe: Titanium is non-ferromagnetic, so patients with titanium implants can safely undergo MRI scans—a key advantage over some other metallic materials.

Q2. Evaluate how the high surface-area-to-volume ratio of nanomaterials affects their performance in a specific manufacturing process (e.g., coatings, catalysts, or drug delivery systems). Support your evaluation with data or a case study, and critically assess the limitations or trade-offs this property might introduce. (10 marks)

Marking Scheme

Criteria	Marks
Clear explanation of surface-area-to-volume ratio and its scientific impact	2
Specific example or case study (e.g., catalysts in manufacturing, coatings)	2
Evaluation of how this property enhances effectiveness	2
Critical discussion of limitations/trade-offs (e.g., reactivity, cost)	2
Coherence and completeness of explanation	2

Sample Answer

Nanomaterials have a high surface-area-to-volume ratio, which makes them extremely reactive and effective in applications like catalysis. For example, in catalytic converters used in car manufacturing, platinum nanoparticles increase the rate of chemical reactions, making the process more efficient and reducing harmful emissions.

This high surface area allows more atoms to be exposed on the surface, improving interaction with reactants. However, this same property also makes nanoparticles more chemically reactive, which can lead to instability over time. Additionally, synthesis and handling of such materials can be costly and technically challenging.

Thus, while the high surface-area-to-volume ratio enhances performance, careful design is needed to balance performance with stability and cost.

Q3. Select three distinct categories of advanced materials and evaluate how each is applied in a critical industry (e.g., aerospace, medicine, or energy). For each material, analyse how specific properties solve industry challenges, and assess any limitations or considerations that must be managed. (10 marks)

Marking Scheme

Criteria	Marks
Identification of 3 correct advanced material categories	3 (1 per correct category)
Appropriate industrial application and justification per material	3
Analysis of how properties solve specific challenges	2
Discussion of limitations or considerations	2

Sample Answer

a. Shape Memory Alloys (SMAs): Used in aerospace for actuators. Their ability to return to original shape when heated allows them to act as compact, reliable mechanisms in space-constrained designs. Limitation: fatigue over repeated cycles.

b. Bioceramics: Used in orthopaedic implants. Their biocompatibility and hardness make them ideal for joint replacements. However, they are brittle and can fail under impact.

c. Nanocomposites: Used in sports equipment and aerospace structures. Their enhanced strength-to-weight ratio helps reduce weight while maintaining durability. However, uniform dispersion in matrices is a challenge during processing.

Q4. Design a case study comparing a smart material with a traditional material used in an automotive application (e.g., shape memory alloy vs. steel in actuators or suspension). Evaluate how each material performs under real-world operating conditions such as stress, temperature, and wear. Justify which material is more suitable depending on usage scenarios, and consider both technical and economic factors. (12 marks)

Marking Scheme (12 marks)

Criteria	Marks
Clear definition and distinction of smart and traditional materials	2
Relevant automotive application with context	2
Evaluation of performance under realistic conditions (stress, temperature, wear)	3
Economic and technical justification for the preferred material	3
Discussion of limitations and advantages (realistic)	2

Sample Answer

In automotive actuators, Shape Memory Alloys (SMAs) like Nitinol are used instead of traditional steel springs. SMAs change shape when exposed to heat, enabling compact and silent actuation systems. Steel, by contrast, relies on mechanical force and external components.

SMAs operate well in environments where space and noise constraints exist, such as adaptive seating systems. They offer precise, repeatable actuation, though at a higher cost and with limited fatigue resistance. Steel is cheaper and more durable in high-cycle operations but lacks the compact efficiency of SMAs.

In low-cycle, high-precision scenarios, SMAs are preferred. For durability and cost-critical applications, steel remains dominant. Thus, the choice depends on the performance and cost requirements of the design.

WEEK 4

Q1. Critically evaluate why colour is not considered a measurable physical property in bamboo analysis, unlike properties such as density, thickness, and moisture content. In your response, compare how each property contributes to material characterisation and explain the limitations of using colour as a scientific parameter in construction or engineering contexts. (5 marks)

Marking Scheme (5 marks)

Criteria	Marks
Clear explanation of why colour is not a quantifiable physical property	1 mark
Comparison with quantifiable properties like density, thickness, or moisture	1 mark
Explanation of the scientific relevance of measurable properties	1 mark
Analysis of why colour is not reliable or standard in engineering evaluation	1 mark
Use of real-world or technical justification (e.g., variability in bamboo colour)	1 mark

Sample Answer

Colour is not considered a measurable physical property because it is not directly quantifiable in a standardised, objective way. In contrast, density, thickness, and moisture content are quantifiable using instruments and follow defined scientific units. These properties are critical for evaluating mechanical performance and suitability for construction.

Colour varies naturally among bamboo species and can be affected by age, exposure, or treatment processes, making it unreliable as a consistent indicator. While it may have aesthetic value, it lacks engineering relevance. For example, a darker bamboo may not necessarily be stronger or drier, so colour provides no functional insight into performance, unlike moisture content, which directly affects dimensional stability.

Q2. Assess the role of segmentation in the bamboo processing chain for laminated board production. Analyse how omitting or altering this step could affect the mechanical properties, dimensional stability, and final performance of the laminated product. Use examples to support your explanation. (5 marks)

Marking Scheme (5 marks)

Criteria	Marks
Explanation of segmentation as a critical first step	1 mark
Analysis of its role in standardising size or quality	1 mark
Explanation of the consequences of omission or errors in segmentation	1 mark
Link to mechanical or dimensional outcomes	1 mark
Realistic example of effect on end-use (e.g., structural weakness, bonding flaws)	1 mark

Sample Answer

Segmentation is the process of cutting bamboo culms into uniform sections, which is essential for consistency during subsequent stages such as drying, treatment, and laminating. If this step is skipped or poorly executed, it can result in irregularly sized pieces that hinder proper bonding and lead to internal stresses or voids in the final laminated board.

For example, uneven segment lengths may dry at different rates, leading to warping or cracking. Furthermore, inconsistent sizes can cause uneven pressure distribution during pressing, weakening structural integrity. Segmentation ensures compatibility and uniformity in performance, crucial for applications like flooring or panelling where precision is vital.

Q3. Design and evaluate a procedure to measure the moisture content of bamboo in a school or field-based lab. Include all necessary tools and variables that must be controlled to ensure reliability. Discuss how deviations in this measurement could affect downstream applications such as drying, gluing, or structural use. (7 marks)

Marking Scheme (7 marks)

Criteria	Marks
Description of accurate procedure (e.g., oven-dry method)	2 marks
Identification of required tools and materials	1 mark
Mention of controlled variables (e.g., initial weight, temperature)	1 mark
Evaluation of procedure's reliability or limitations	1 mark
Discussion of consequences of inaccurate moisture readings	1 mark
Link to downstream effects (e.g., delamination, warping)	1 mark

Sample Answer

To measure bamboo's moisture content, the oven-dry method is commonly used. First, weigh a fresh bamboo sample and record its initial mass. Then place it in an oven set to 105°C for 24 hours until a constant dry weight is achieved. Moisture content is calculated as: (Initial mass – Dry mass) ÷ Dry mass × 100%

Essential tools include a precision scale, lab oven, and moisture-safe container. Variables such as oven temperature, sample size, and exposure time must be controlled to ensure consistent results.

Incorrect moisture readings can severely impact subsequent processes. For example, high moisture levels may cause delamination during pressing, while low levels can lead to brittleness. Accurate measurement ensures appropriate drying schedules and improves bonding in glue-laminated boards.

Q4. Marking Scheme: Influence of T/R Ratio on Bamboo Structural Performance

Explanation of T/R Ratio and Its Effect on Performance – 30 Marks

Sub-Point	Expectation	Marks
1.1	Defines T/R ratio as the relationship between wall thickness and culm radius of bamboo	**5**
1.2	States that the T/R ratio influences strength, stiffness, and load-bearing capacity	**10**
1.3	Explains how an optimal T/R ratio helps bamboo distribute loads and resist buckling	**10**
1.4	Links T/R ratio to specific structural performance in construction (e.g., beams, columns)	5

Identification of Structural Issues from Inappropriate T/R Ratios – 30 Marks

Sub-Point	Expectation	Marks
2.1	Explains that a low T/R ratio (thin walls) leads to bending or buckling under load	10
2.2	Explains that a high T/R ratio (excessive thickness) leads to inefficient use and increased weight	10
2.3	Describes specific consequences on structural members like beams, trusses, or columns	10

Impact on Construction Effectiveness – 30 Marks

Sub-Point	Expectation	Marks
3.1	Describes structural weaknesses such as creep, fatigue, or fracture caused by poor T/R ratios	10
3.2	Links inappropriate T/R ratios to potential safety hazards or early structural failure	10
3.3	Explains how the correct T/R ratio ensures balance between strength, flexibility, and material use	10

Sample answer

Influence of T/R Ratio on Bamboo Performance

The **thickness-to-radius (T/R) ratio** is a critical factor in determining the **mechanical properties** of bamboo, including its **strength**, **stiffness**, and **load-bearing capacity**. A proper T/R ratio allows bamboo to effectively **distribute stress**, resist **bending and buckling**, and perform reliably under various loads.

Bamboo with an **optimal T/R ratio** demonstrates higher **tensile and compressive strength**, making it well-suited for **structural applications** such as columns, beams, and trusses in construction projects.

Common Structural Issues with Inappropriate T/R Ratios

a. When the **T/R ratio is too low** (i.e., thin walls relative to the diameter), bamboo becomes **prone to buckling or deformation** under load. This compromises structural integrity, especially in vertical load-bearing elements like columns.

b. Conversely, a **very high T/R ratio** may lead to **excessive wall thickness**, which can result in **unnecessary material usage**, increased **weight**, and **inefficient structural design**. This may complicate handling or raise construction costs without proportional benefit.

Impact on Construction Effectiveness

Improper T/R ratios can cause **structural weaknesses**, increasing the risk of long-term failure due to **creep**, **fatigue**, or **fracture**. These failures could lead to **safety hazards**, increased **maintenance needs**, or premature **replacement** of bamboo components.

Ensuring an **appropriate T/R ratio** is essential to maintaining a **balance between strength, flexibility, and material efficiency**, directly contributing to the **durability**, **safety**, and **cost-effectiveness** of bamboo-based structures.

Q5. Improved Strength and Uniformity: What are two key advantages of using laminated bamboo boards in construction, and how do they improve performance compared with raw bamboo? (8 marks)

Criteria	Description	Mark(s)
Accurate Definition of Laminated Bamboo	States that laminated bamboo boards are made by glueing multiple strips or layers of processed bamboo under heat and pressure	1
Mechanical Strength Benefit	Explains that this process increases mechanical strength and removes natural variation in density and thickness found in raw bamboo	1
Predictable Structural Behaviour	Describes how the increased uniformity makes the material behave more predictably under structural loads	1
Application in Construction	States that laminated boards can be confidently used in load-bearing applications such as beams, flooring, or panels	1
	TOTAL	**4**

2. Enhanced Dimensional Stability and Durability (8 marks)

Criteria	Description	Marks
2.1 Raw Bamboo Limitation	Clearly states that raw bamboo tends to split, warp, or shrink due to moisture or environmental exposure	1
2.2 Moisture & Insect Resistance	Describes how laminated boards are processed and treated to resist moisture, insects, and dimensional changes	1
2.3 Performance Improvement	States that this increases long-term durability and reduces failure risks	1
2.4 Broader Application	Explains that laminated bamboo can be used in more environmental conditions (e.g., outdoor or humid environments) and requires less maintenance	1
	TOTAL	**4**

Sample answer

Laminated bamboo boards are generally a **more reliable, long-lasting, and versatile material** than raw bamboo in modern construction. They are mostly of:

1. **Improved Strength and Uniformity**

Laminated bamboo boards are engineered by gluing multiple strips or layers of processed bamboo together under heat and pressure. This process improves the **mechanical strength** and creates a more **uniform material** compared with raw bamboo, which naturally varies in thickness, density, and strength along its length.

a. Performance Benefit: This uniformity and added strength make laminated boards more predictable in structural behaviour, reducing the risk of failure due to natural defects like knots or cracks found in raw bamboo.

b. Application Advantage: Builders can use laminated bamboo in load-bearing applications (e.g., beams, flooring, wall panels) with greater confidence, ensuring safety and consistency across different parts of a structure.

2. **Enhanced Dimensional Stability and Durability**

Raw bamboo is prone to splitting, warping, and shrinking due to moisture changes or environmental exposure. Laminated bamboo boards, however, undergo treatment and controlled processing, which stabilises the material.

a. **Performance Benefit**: This increases **resistance to moisture, insects, and dimensional changes**, making laminated bamboo more durable over time.

b. **Application Advantage**: Laminated boards can be used in a wider range of environments (e.g., humid, dry, or outdoor areas), reducing maintenance needs and extending the lifespan of bamboo-based structures.

SECTION 2: UNDERSTANDING MECHANICAL PROPERTIES AND FAILURE OF MATERIALS

STRAND: MANUFACTURING MATERIALS AND TECHNOLOGIES

Sub-Strand: Properties of materials

Learning Outcome: Explain and measure the mechanical properties of bamboo and explain that materials can fail through creep, fatigue or fracture

Content Standards

1. *Demonstrate knowledge of the mechanical properties of bamboo. (Week 5 & 6)*
2. *Demonstrate understanding of the failure of materials. (Week 7 & 8)*

INTRODUCTION AND SECTION SUMMARY

This section delves into the understanding of mechanical properties and failure of materials, emphasising bamboo and its potential as a sustainable manufacturing material. Learners will explore its mechanical properties, such as tensile strength, compressive strength, and flexural strength, through experiential and research-based learning.

Again, learners will investigate the different forms of material failure, including creep, fatigue, and fracture, through collaborative research, discussions, and hands-on experiments, such as tensile testing using a Universal Testing Machine. Learners will analyse failures like creep, fatigue, and fracture through case studies and literature reviews. At the end of the section, learners will appreciate how material behaves under different conditions and why materials fail, preparing them for real-world engineering challenges and fostering a deeper appreciation for the role of materials in manufacturing. This section aligns with the curriculum's goals by preparing Learners to critically analyse and solve real-world engineering challenges, promoting extended critical thinking and strategic reasoning.

The weeks and the indicators covered by the section are:

Week 5: Explain the mechanical properties of bamboo

Week 6: Measure the tensile strength of bamboo

Week 7: Explain the term failure of materials

Week 8: Distinguish between creep, fatigue or fracture in failure of materials

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. **Think-Pair-Share:** Learners collaboratively review and discuss mechanical properties using flashcards, enhancing recall and peer teaching.
2. **Research-Based Learning**

i. Data Collection and Analysis: Groups research the mechanical properties of bamboo, comparing it with wood and steel, and present their findings.

ii. Visual Summarisation: Creation of infographics on bamboo's properties and sustainability, shared during a gallery walk for peer feedback.

iii. Material Failure Investigation and Analysis: Groups investigate and analyses different types of material failures by examining notable engineering case studies. Each group will focus on specific failure mechanisms—such as fatigue, creep, or fracture and use a variety of resources to investigate. Their findings will be presented through posters or slides, highlighting the materials involved, types of failures, root causes, and key lessons learned. As part of the project, groups will also develop a presentation and submit a summary report based on their case study analysis.

iv. Peer Review and Debrief: After presentations, peer reviews are conducted using rubrics, followed by a teacher-led debrief session to reinforce learning and address common errors, promoting a deeper understanding of the content

3. **Experiential Learning**

i. Tensile Testing: Groups develop procedures and conduct tensile tests on bamboo, documenting and presenting results.

ii. Multimedia Presentations: Use of varied resources to explore the relationship between structure and tensile strength, catering to diverse learning styles.

ASSESSMENT SUMMARY

To effectively evaluate learners' comprehension of the principal themes in this section, a diverse range of assessment modes is utilised. These modes ensure that learners across all proficiency levels have opportunities to demonstrate their understanding. Oral responses are encouraged through engaging class discussions, allowing learners to articulate their insights and participate in critical discourse. Additionally, written responses of varying difficulty levels are solicited to assess learners' understanding of major concepts.

Research and experiential learning are key components, providing learners with opportunities to explore mechanical properties and material failures comprehensively. These approaches encourage practical application and innovation, enabling learners to develop a nuanced understanding of bamboo as a manufacturing material and material failure mechanisms, illustrated by classical examples and their causes. This multidimensional assessment approach ensures that Learners not only acquire theoretical knowledge but also apply their learning to real-world scenarios, enhancing their critical thinking and problem-solving abilities. Table S2 is a summary of the assessment used against the indicator.

Table S2: Assessment summary for Section 2

Indicators	DOK Level	Assessment Strategy and/or Mode
Explain the mechanical properties of bamboo	4	Research, Presentation
Measure the tensile strength of bamboo	3	1. Group discussion, Group project

Explain the term failure of materials	4	1. Individual research project, Case study analysis with reports 2. Socratic seminar with reflective discussion
Distinguish between creep, fatigue and fracture in the failure of materials	3	Individual research and report writing, Research project 3. Think-pair-share discussion 4. Group concept mapping

WEEK 5

Learning Indicator: Explain the mechanical properties of a bamboo material

Recap weeks

Year 1	**Week 7:** Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials
Year 2	**Week 7:** Measure the tensile properties of steel using the tensile test...

Focal Area: Mechanical properties of Bamboo as a sustainable material

5.1 Introduction

Bamboos are a diverse group of woody, perennial, evergreen plants belonging to the grass family Poaceae. It is increasingly recognised as a sustainable material thanks to its remarkable mechanical properties and rapid growth rate. Structurally, it is a natural composite composed primarily of cellulose fibres embedded in a lignin matrix, which, along with its unique hollow structure, contributes to its strength and flexibility. These characteristics make bamboo both strong and lightweight, allowing it to serve as a viable alternative to traditional materials like wood, steel, and certain plastics in various applications. Understanding bamboo's tensile strength, compressive strength, and elasticity is important for evaluating its potential in sustainable manufacturing and construction, where it offers a promising alternative to traditional construction materials.

5.2 Mechanical Properties of Bamboo

(Refer back to Year 1, Section 2, Week 7, Mechanical Properties of Materials.)

Bamboo exhibits several mechanical properties that make it suitable for diverse applications. Its tensile strength is comparable to that of steel, and its compressive strength is superior to that of many hardwoods. Bamboo's elasticity allows it to bend without breaking, making it ideal for structures that need to withstand dynamic loads. Additionally, bamboo has good hardness, which contributes to its durability and resistance to wear.

Bamboo exhibits a combination of strength, flexibility, and lightness that is rarely found in other natural materials. Key mechanical properties include:

Tensile Strength: Bamboo has tensile strength up to 370 MPa, particularly along its longitudinal fibres. This is comparable to mild steel.

Compressive Strength: It typically ranges from 40 to 80 MPa, higher than many hardwoods, making bamboo effective in load-bearing vertical applications.

Flexural Strength: Due to its elasticity and fibre structure, bamboo can flex significantly without cracking.

Elastic Modulus (Stiffness): Ranges from 10 to 20 GPA depending on species and age, showing high resistance to deformation under load.

Hardness: Its surface hardness gives it durability in high-traffic and wear-prone environments.

Shear Strength: Bamboo has lower shear strength compared with its tensile and compressive strength due to its fibrous structure, and joints need reinforcement

5.3 Influence of Bamboo Morphology on Its Mechanical Properties

The unique morphology of bamboo not only contributes to its mechanical resilience but also enhances its versatility in various applications, promoting its use as a sustainable and efficient material in modern engineering and manufacturing practices. The mechanical behaviour of bamboo is directly linked to its unique morphology. Figure 12 shows the morphology of the bamboo scheme, and Figure 13 shows the structure at the macroscopic and microscopic levels of bamboo. Key aspects of the effect of bamboo morphology on its mechanical properties are below:

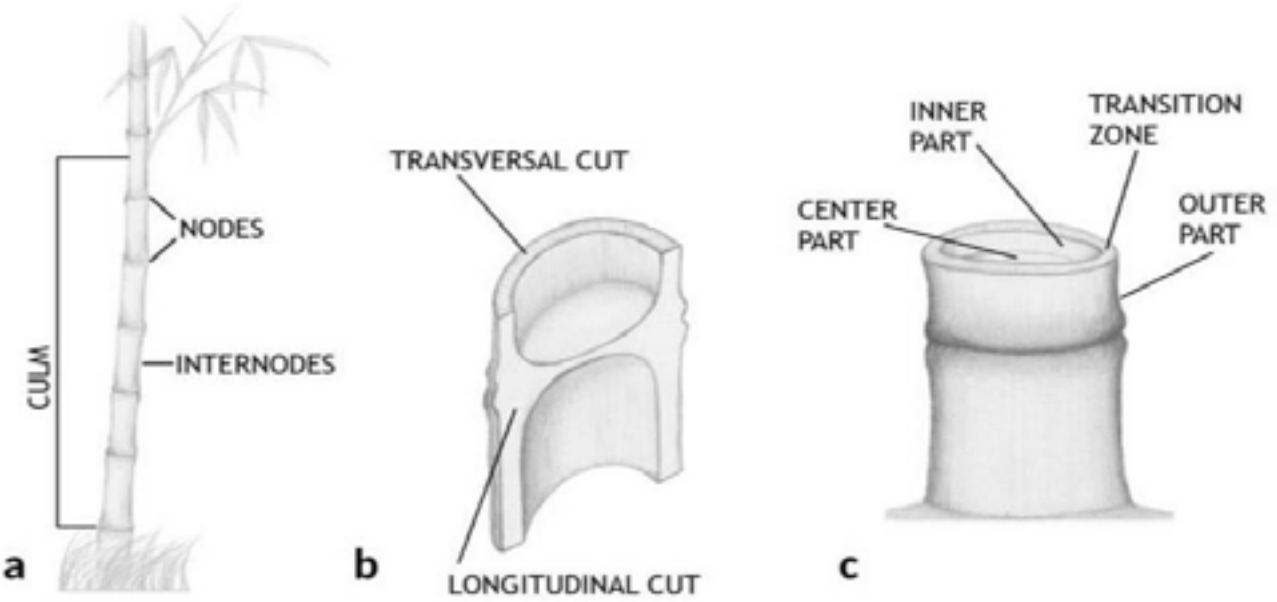


Figure 12: *Bamboo scheme: (a) view of the plant from the ground to the beginning of the branches, (b) longitudinal and transverse sectioned view and (c) circular cross section (Elejoste et al., 2021).*

Natural Composite Structure: Bamboo is made of cellulose fibres in a lignin matrix, providing strength and flexibility, ideal for construction and manufacturing.

Hollow Cylindrical Form: Its hollow structure reduces weight while maintaining strength, distributing stress evenly and enhancing load-bearing capacity.

Presence of Nodes: Nodes act as natural reinforcements, improving resistance to buckling and stability under compressive loads.

Fibre Distribution: The fibre alignment within bamboo contributes to its high tensile strength, allowing it to resist stretching and bending.

Flexibility: Bamboo's design, with flexible nodes and fibres, enhances its ability to bend without breaking, useful in dynamic applications like earthquake-resistant construction.

Moisture Management: Efficient moisture regulation is crucial as it affects strength and stiffness, requiring proper drying and treatment for longevity.

Lamination Applications: Its morphology makes bamboo suitable for lamination, forming strong panels for flooring and furniture.

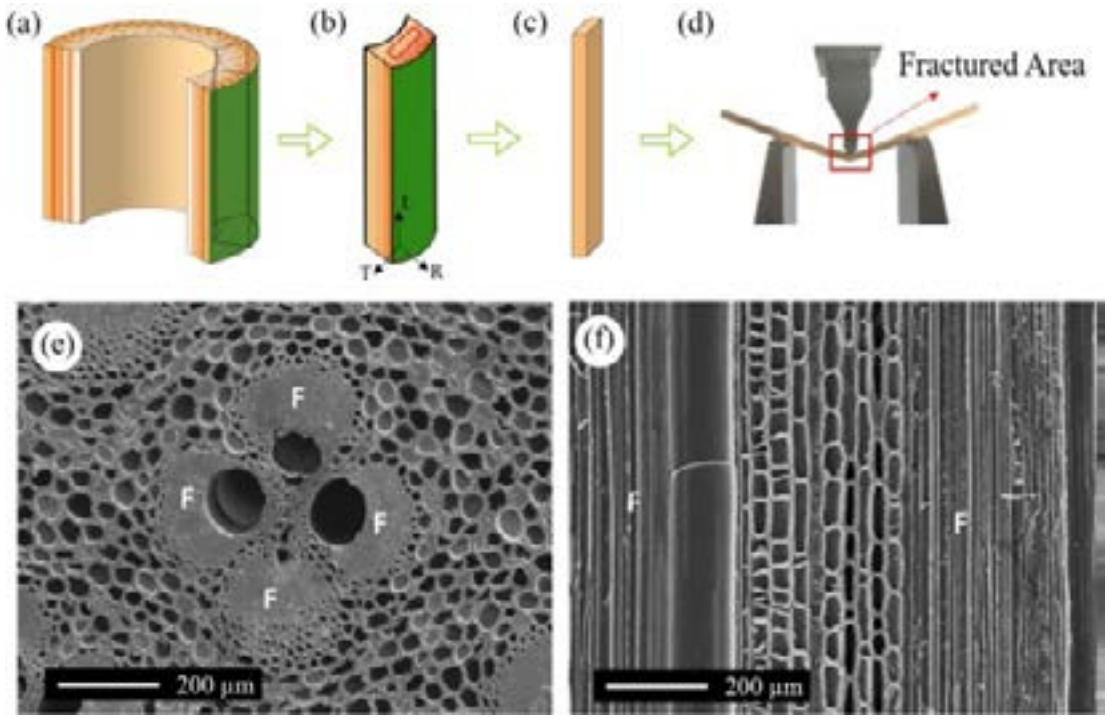


Figure 13: *Bamboo structure at macroscopic and microscopic levels (Chen et al., 2020)*

5.4 Impact of Moisture Content on Bamboo Mechanical Properties

Moisture content plays a crucial role in determining the mechanical properties of bamboo. High moisture content can reduce its strength and stiffness, making it more susceptible to deformation. Proper drying and treatment processes are essential to enhance bamboo's mechanical performance and longevity. Moisture control is vital in ensuring the structural integrity of bamboo in various applications. Moisture has a significant impact on the performance of bamboo. It reduces the strength of the bamboo, swells and shrinks the bamboo and leads to decay and mold growth. Moisture can, however, be controlled using moisture control methods such as kiln drying, chemical treatments, lamination and coating, and proper storage and usage in well-ventilated environments.

5.5 Selection of Appropriate Bamboo Species for Specific Applications

Bamboo properties can vary significantly depending on the species, age, and growing conditions. Selecting the appropriate bamboo species for specific applications is crucial to optimise its mechanical performance. For instance, species with higher density and fibre content are preferred for structural applications, while those with greater flexibility are suitable for furniture and design purposes.

The mechanical performance of bamboo varies widely depending on multiple factors such as the bamboo species, age and environmental conditions. High-strength, dense bamboo species, are, therefore, suitable for use as beams and columns, while flexible, thinner-walled species are suitable for weaving, making of furniture or crafts.

5.6 Effect of Processing and Treatment of Bamboo on Its Mechanical Properties

Processing and treatment methods can enhance or degrade the mechanical properties of bamboo. Techniques such as bleaching, drying, and lamination can improve its strength and durability. However, improper processing can lead to defects and reduced performance. It is essential to follow standardised treatment methods to maintain the quality and reliability of

bamboo products. Figure 14 shows the processing stages of bamboo, from raw material to finished product. Some bamboo processing and their effects on its mechanical properties are discussed below:

Drying: Reduces moisture, increases dimensional stability and strength.

Heat Treatment: Improves resistance to pests and fungi, and may increase surface hardness.

Chemical Treatment: Boron, copper-based solutions increase durability and resistance to biological attack.

Lamination: Engineered bamboo products (e.g., laminated bamboo lumber or scriber) have improved uniformity, strength, and load capacity.

Carbonisation: Increases resistance to decay but can lower mechanical strength if overdone.

Adhesives and Joint Reinforcement: Critical in maintaining integrity in structural bamboo components.

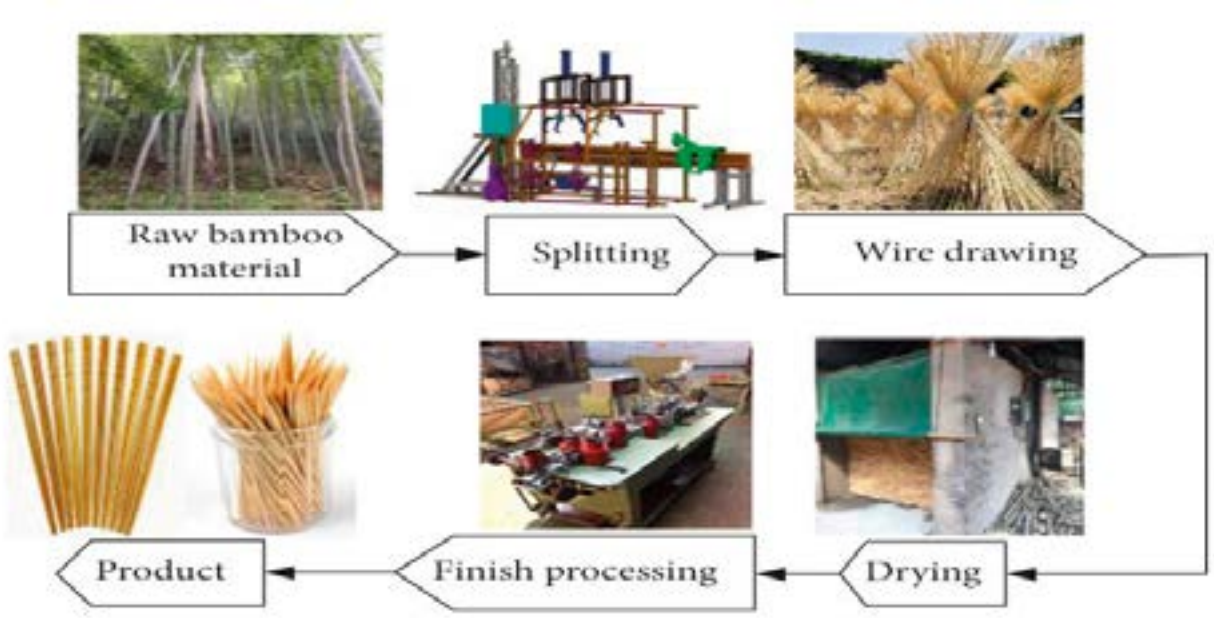


Figure 14: *Processing stages of bamboo, from raw material to finished product* (Liu et al., 2020)

5.7 Mechanical Property Testing Methods

Various testing methods are employed to assess the mechanical properties of bamboo, including tensile and compressive tests. These tests help determine the load-bearing capacity and suitability of bamboo for different applications. Accurate testing is necessary for quality assurance and ensuring that bamboo products meet industry standards. Figure 15 and Fig. 16 show the tensile and compressive testing of bamboo respectively.

5.7.1 Tensile Test

Purpose: To measure the resistance of bamboo to pulling or stretching forces.

Method: Conducted longitudinally to align with the natural fibre orientation using a universal testing machine.

Significance: Provides insights into the strength of bamboo fibres, which is vital for load-bearing applications.

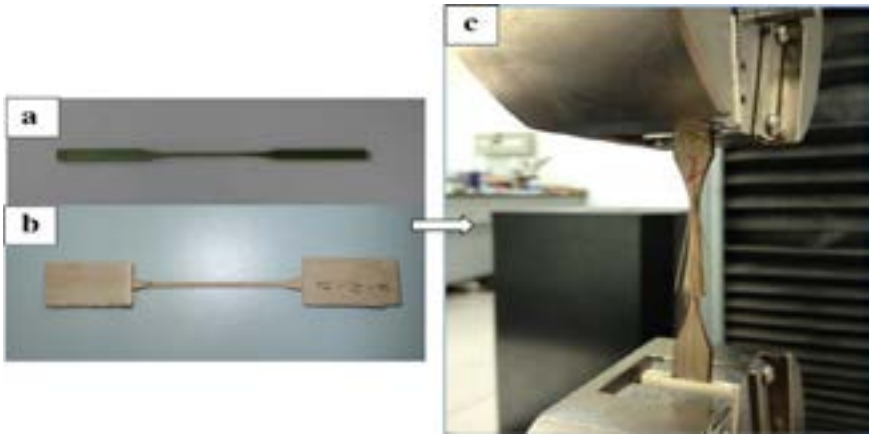


Figure 15: *The tensile property testing of bamboo strips, (a) the sample of bamboo, (b) the sample of bamboo with wood slices for protection, (c) tensile testing process (Chen et al., 2015)*

5.7.2 Compressive Test

Purpose: To evaluate bamboo's ability to withstand crushing forces.

Method: Performed on culm sections to simulate vertical loading.

Significance: Essential for bamboo used as columns or load-supporting elements.

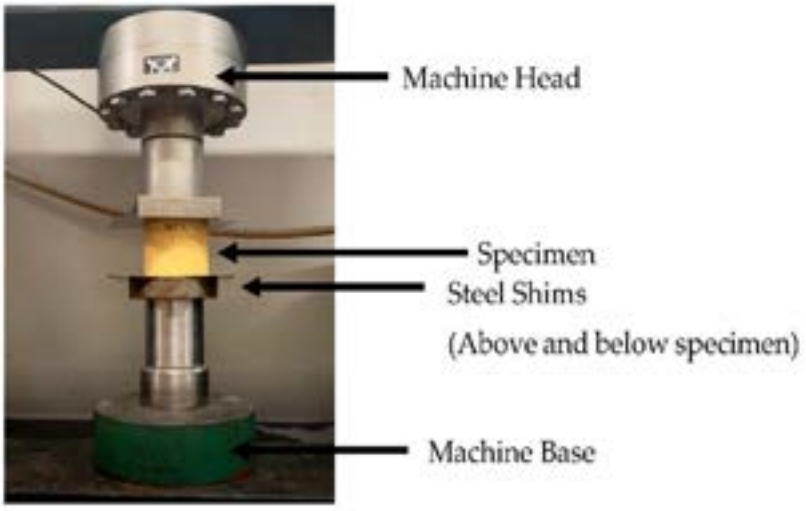


Figure 16: *The test setup used for compression testing of the bamboo specimens (Drury et al., 2023)*

5.7.3 Safety recommendations when handling Bamboo

a. Always wear safety goggles, cut-resistant gloves, closed-toe shoes, and an apron when handling bamboo samples.

b. Inspect all equipment before testing, clear bystanders at least 2 metres away, and add weights slowly.

c. Listen for cracking sounds and stop immediately if the bamboo begins to whiten or bend.

d. After failure, wait 10 seconds, then use gloves to collect all sharp fragments and dispose of them in a rigid container.

e. Any splinter in the eye requires immediate flushing and medical attention; deep cuts should be pressured and treated by a professional.

f. If any doubt about safety exists, switch to a video simulation.

5.8 Comparison of Bamboo with Traditional Materials

(Refer back to Year 2, Section S, Week 7, Tensile properties of steel)

Bamboo is often compared with traditional materials like wood and steel due to its strength-to-weight ratio and sustainability. While bamboo has comparable tensile strength to steel, it is lighter and more environmentally friendly. Compared with wood, bamboo grows faster and is more renewable, making it a more sustainable choice for many applications. Table 2 shows a comparison of the mechanical properties of bamboo against major traditional materials

Table 2 Comparison of mechanical properties of bamboo and major traditional materials

Property	Bamboo	Wood	Steel
Tensile Strength	370 MPa	100 MPa (oak)	400–550 Mpa
Renewability	High (3–5 yrs.)	Moderate (10–80 yrs.)	Non-renewable
Flexibility	High	Moderate	Low
Sustainability	Very High	Moderate	Low
Cost	Low	Moderate	High

5.9 Applications of Bamboo Based on Its Mechanical Properties

The mechanical properties of bamboo make it suitable for a wide range of applications, including construction, furniture, and textiles. Its strength and flexibility allow it to be used in building structures, while its aesthetic appeal makes it popular in furniture design. Bamboo is also used in the production of textiles, composites and engineered products, showcasing its versatility as a material.

When used for construction, bamboo is used in scaffolding, flooring and as structural frames (especially in earthquake-prone regions). As furniture, bamboo is used for making chairs, beds, tables and decorative elements. As textiles, bamboo fibres spun into yarns and fabrics. Bamboo is used as composites in bamboo-reinforced polymer composites in the automotive and sports industries, while engineered bamboo products include laminated bamboo lumber, bamboo scriber, and panels.

5.10 Challenges and Prospects of Bamboo in Manufacturing

Despite its advantages, bamboo faces challenges in manufacturing, such as variability in quality and the need for specialised processing techniques. However, ongoing research and technological advancements are addressing these challenges, paving the way for increased use of bamboo in sustainable manufacturing. The prospects for bamboo as a key material in the future of manufacturing are promising, given its environmental benefits and mechanical properties.

5.10.1 Challenges

1. Inconsistency in quality due to species and growth variability
2. Limited standardisation for mechanical grading
3. Moisture and pest sensitivity without proper treatment
4. Processing infrastructure in some regions is underdeveloped

5.10.2 Prospects

1. Engineered bamboo products are gaining popularity as eco-friendly alternatives to concrete, plastic, and steel.
2. Urban and modular construction is incorporating bamboo for both aesthetics and performance.
3. Government policies and green building standards (e.g., LEED, IGBC) are favouring sustainable materials like bamboo.
4. Innovation in treatments and adhesives is improving long-term durability and expanding its use in high-performance applications.

Notes for Facilitators

1. In the absence of a universal testing machine, use pre-recorded tests, scaled models or conduct simple comparative stress tests using basic equipment.
2. **Clarifying Concepts:** Use simple language: Tensile means pull-apart strength (like pulling a rope). Compressive means squash strength (like a pillar). Flexural = bend strength (like a diving board). Explain that bamboo is anisotropic – it is very strong along the grain (longitudinally) but much weaker across the grain.
3. **Common Misconceptions:** Students might think that because bamboo is a "grass," it is weak. Counter this with data: the tensile strength of some bamboo species (up to 370 MPa) is comparable to mild steel. Use Table 5.1 to reinforce this.
4. **Low-Cost Demonstration and Ghanaian Examples**
    a. Morphology: Get two identical bamboo poles. Mark a node on one. Ask two students to stand on each pole (with support). The pole with the node in the middle will often resist bending more, showing how the node acts as a reinforcement.
    b. Moisture: This is a critical lesson for the Ghanaian environment. Soak a piece of bamboo in water for a week. Then, try to break a dry piece and the soaked piece. The soaked piece will be much more flexible but also weaker. This demonstrates why structural bamboo in the rainy season must be properly treated.
    c. Troubleshooting: When discussing harvesting, clarify that cutting bamboo during the dry season reduces the risk of pest attack. This is a practical tip from local artisans.

Learning Tasks

1. Learners review the mechanical properties of materials such as hardness, brittleness, ductility, strength, malleability, toughness, elasticity, and plasticity to build on their previous knowledge from earlier years.
2. Learners research and explain key mechanical properties of bamboo (tensile strength, elasticity, compressive strength, hardness, and flexibility). They compare these properties with traditional materials like wood and steel
3. Learners will create presentations or infographics highlighting the advantages and limitations of bamboo as a sustainable material in manufacturing industries.

4. Learners create a presentation or infographic on the advantages and limitations of bamboo in sustainable manufacturing practices.
5. Each learner demonstrates independent understanding of the entire tensile testing process and its implications by answering a comprehensive written assessment.

Pedagogical Exemplars

Talk for Learning

Learners engage in a think-pair-share activity to review and recap the mechanical properties learned in previous years. They will use flashcards to reinforce their understanding and facilitate peer teaching by sharing findings in small groups.

Research-based learning

1. Learners in a mixed ability group, gather data on the mechanical properties of bamboo through internet research and textbooks. They will analyse their findings and compare them with the properties of wood and steel, discussing their results.
2. In mixed-ability groups or individually research scholarly articles and credible internet sources to extract data on bamboo's mechanical properties. They then create a structured summary and share findings through short group presentations.
3. Each group creates visual infographics or digital posters summarising bamboo's mechanical performance, sustainability benefits, and limitations in manufacturing. They present these in a gallery walk session for peer review and reflection.
4. After the gallery walk session, each learner receives a structured written assessment question on the learning indicator and the marked using the marking scheme to evaluate individual mastery level.

Key Assessment Level 4: Research and Presentation

1. You are a Learner in manufacturing engineering. You have been asked to help design a simple, low-cost, and eco-friendly building for a local community in a developing area. The community has access to two main building materials: **bamboo** and **steel**. Your goal is to choose the best material for parts of the structure that will be under tension (such as roof supports or braces) and create a suitable design.

    a. Research and explain how strong bamboo and steel are when they are stretched or pulled (this is called tensile strength). (3 marks)

    b. Choose the better material (bamboo or steel) for the tension parts of your structure. Compare the materials based on:

        i. Strength (which can handle more tension?)

        ii. Cost (which is more affordable for the community?)

        iii. Availability (which is easier to find locally?)

        iv. Environmental impact (which is more eco-friendly?) (9 marks)

    c. Design a simple building using the material you chose for the tension parts.

        i. Draw and label your structure (show the roof, walls, supports, etc.)

ii. Explain why you chose your design and materials. How does your design help the community and solve the problem? (DOK Level 4) (16 marks)

d. Analyse the advantages and limitations of using bamboo over traditional materials such as wood and steel in construction and manufacturing. Include specific mechanical properties in your analysis. (10 marks)

PLC Session 5

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
   a. The key assessment for the week is research and presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 6

Learning Indicator: Measure the tensile strength of bamboo

Recap weeks

Year 1	**Week 7:** Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials
Year 2	**Week 5:** a. Explain the loading, stress and strain of materials for manufacturing b. Outline the effect of loading, stress and strain in materials. **Week 6:** Explain elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials. **Week 7:** Measure the tensile properties of steel using the tensile test.

Focal Area: Tensile strength of bamboo

7.1 Introduction

Tensile strength is a fundamental property of materials that describes the maximum stress a material can withstand when being stretched before breaking. It plays a serious role in engineering and manufacturing because it determines how materials perform under tension, which is crucial for ensuring that structures and products can withstand applied forces without failure. Understanding tensile strength is essential for selecting the right materials for specific applications, thereby optimising performance and safety. In the context of bamboo, this property is especially important due to bamboo's potential as a sustainable alternative to traditional materials.

7.2 Factors Influencing the Tensile Strength of Bamboo

(Refer back to Year 1, Section 2, Week 7, Mechanical properties of materials.)

The tensile strength of bamboo is influenced by several key factors, including species, maturity, moisture content, and environmental conditions. Understanding these factors is essential for selecting bamboo for various engineering and manufacturing applications.

a. Species Differences: Different species of bamboo exhibit varying tensile strengths due to differences in fibre density and structural composition. This diversity means that some species may be more suitable for specific applications requiring high tensile strength.

b. Maturity: Mature bamboo, with fully developed fibres, generally exhibits higher tensile strength compared with younger bamboo. The maturity of the bamboo affects the density and alignment of fibres, which are critical to its mechanical performance.

c. Moisture Content: Moisture content significantly affects the tensile strength of bamboo. Dry bamboo is stronger than wet bamboo, as water can weaken the bonds between fibres, reducing the material's ability to resist tension.

d. Environmental Conditions: Conditions such as soil quality and climate during growth play a role in determining the mechanical properties of bamboo. These environmental factors

influence the development of the bamboo fibres and overall plant health, impacting tensile strength.

7.3 Comparison of Bamboo Tensile Strength with Other Materials

(Refer back to Year 2, Section 2, Week 7, Tensile properties of steel)

Bamboo is increasingly recognised for its impressive tensile strength, particularly when considering its high strength-to-weight ratio. This makes it a competitive and sustainable choice in various engineering and manufacturing applications. The tensile strength of bamboo stands out due to its lightweight nature. Table 3 shows a comparison of the mechanical properties of bamboo against major traditional materials.

While metals like steel may exhibit higher absolute tensile strengths, bamboo offers significant strength relative to its weight, making it an advantageous choice in applications where weight savings are essential. Certain species of bamboo can achieve tensile strengths ranging from 100 to 370 MPa. This range is comparable to, and sometimes exceeds, the tensile strengths of some types of wood and low-strength metals.

The renewable nature of bamboo adds to its appeal as a sustainable alternative to traditional materials like steel, wood, and concrete. Its use in structural applications aligns with modern sustainability goals, providing both environmental and functional benefits.

Table 3 Comparison of the strength of bamboo with other materials (Awaludin et al., 2017)

Materials	Compressive Strength or Yield Strength (N/mm2)	Tensile Strength (N/mm2)	Elastic Modulus (N/mm2)
Spruce wood	43	89	11000
Steel	250	410	21000
Treated bamboo (Bambusa vulgaris)	78	233	20000

7.4 Importance of Bamboo Tensile Strength in Manufacturing Applications

Bamboo's tensile strength is a critical factor in its widespread use across various manufacturing applications, including construction, furniture making, and the creation of composite materials. Its high tensile strength-to-weight ratio makes it an ideal choice for lightweight structures that demand both durability and flexibility. Figure 17 shows the processing overview of bamboo into strips.

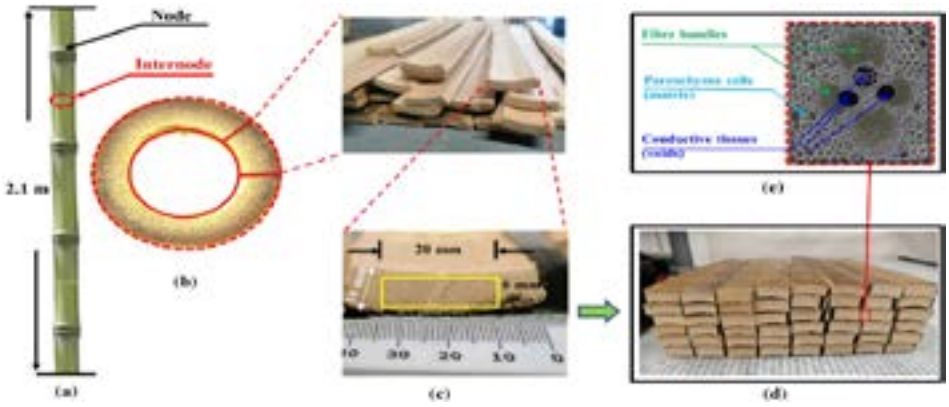


Figure 17: *Processing overview of bamboo strips with (a) bottom part of culm, (b) bamboo cross-section wall, c strips cutting, (d) short bamboo strips and (e) vascular bundles and parenchyma matrix (microscopic image) (Al-Rukaibawi and Károlyi, 2023)*

7.5 Applications in Various Industries

a. **Construction:** The tensile strength of bamboo is particularly beneficial in construction, where it is used in frameworks and scaffolding. Its ability to withstand tension while remaining lightweight makes it suitable for constructing durable and flexible structures. Figure 18 is a house made of bamboo.



Figure 18: *A housing structure made of bamboo*

https://upload.wikimedia.org/wikipedia/commons/2/25/Nipa_Hut_taken_at_Magdalena_Laguna_Philippines_on_2011_April_photo_21.jpg

b. **Furniture Making:** In the furniture industry, bamboo offers resilience and aesthetic appeal. Its natural strength allows for the creation of sturdy yet elegant furniture pieces that can withstand everyday use as shown in Figure 19.



Figure 19 Bamboo made bed and sofa

https://www.bloomingville.com/en/inspiration/guide-for-bamboo-furniture

c. **Composite Materials:** Bamboo is increasingly used in the development of composite materials, where its strength and flexibility are combined with other materials to enhance performance and sustainability. Bamboo bio-composite materials have proven quality. Medium density fibreboard, plywood and bamboo veneer, each of which has been widely used in manufacturing furniture and other products as shown in Figure 20. Distinctive properties of bamboo fibre reinforced bio composite natural increase and flexural tensile

strength, ductility and greater resistance to cracking and larger than a better impact strength and toughness of the composite



Figure 20: *Composite bamboo material (Mousavi et al., 2022)*

7.6 Measurement of the Tensile Strength of Bamboo

The tensile strength of bamboo is measured using standardised mechanical testing methods that evaluate its resistance to pulling forces along the grain. Given that bamboo is an anisotropic material, meaning its properties vary depending on the direction of the load, tensile tests are typically conducted longitudinally, aligned with the fibres, to capture its maximum tensile capacity.

7.6.1 Sample Preparation

Selection: Choose straight, defect-free culm sections, usually from mature bamboo, as these exhibit higher tensile strength due to their fully developed fibres.

Shaping: Specimens are shaped into standardised forms like dumbbell or dog-bone shapes, or clamped between metal end-tabs to prevent crushing.

Conditioning: Ensure samples are conditioned at controlled temperature and humidity to maintain consistent moisture content, which significantly affects strength.

7.6.2 Testing Procedure

Test Setup: Use a Universal Testing Machine (UTM) to apply a steadily increasing tensile load.

Alignment: Securely fix the bamboo sample to prevent slippage and misalignment, ensuring accurate results. Alternative testing test methods such as the simple deadweight test, the spring balance pulls test and simulation software or video analysis can be used aside the universal tensile test machine. Apply tensile force at a constant rate of extension until the specimen fails and record the applied force and corresponding elongation throughout the test.

7.6.3 Calculation

The tensile strength (σ) is calculated using the formula:

$$\sigma = \frac{F}{A}$$

Where:

F = Maximum load at failure (N)

A = Cross-sectional area of the specimen (mm^2)

7.6.4 Influencing Factors

Several factors including moisture content, age, species, presence of nodes or defects, specimen geometry and surface preparation can affect the measured tensile strength of bamboo. Dry bamboo generally shows higher tensile strength as moisture can weaken the fiber bonds. Different species and maturity levels of bamboo can result in varying tensile strengths. Nodes or physical imperfections can significantly impact tensile performance. Accurate shaping and preparation are critical for reliable results.

Notes for Facilitators

1. **Clarifying Concepts:** Demystify the formula ($\sigma = F/A$). Explain that F (force at failure) is like the «push» you apply, and A (cross-sectional area) is how much material is resisting that push. A thicker piece needs more force to break, but the strength (stress) is the force divided by the area.
2. **Common Misconceptions:** Students often expect a perfect, linear test. Explain that bamboo is a natural material, so results will vary even between samples from the same culm. The goal is to get an average value and understand the range.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Test Rig:** If a Universal Testing Machine (UTM) is unavailable, build a simple rig. Clamp the bamboo sample vertically. Hang a bucket from the bottom and gradually add weights (e.g., sand, rocks) until the sample fails. Calculate the force from the total weight. This is a hands-on, low-tech way to understand the principle.
    b. Troubleshooting: The biggest challenge is the sample slipping or crushing at the grips. Before the practical, show students how to wrap the ends of the bamboo sample with several layers of strong tape or use thin wooden strips as splints to distribute the gripping force. This prevents premature failure at the ends.

Learning Tasks

1. Recall key concepts on stress-strain behaviour, tensile force, and testing equipment from earlier years and link them to bamboo as a material. This includes comparing natural and engineered materials in terms of tensile properties.
2. Learners explore bamboo's structural properties and tensile characteristics using selected videos, articles, and diagrams. Discuss how bamboo's internal structure contributes to its strength and compare it to familiar materials from previous years.
3. Learners collaboratively design a standardised procedure to measure bamboo's tensile strength, considering ISO 22157 standards.
4. Learners execute the tensile testing procedure and gather force and elongation data until specimen failure.

5. Each group analyse test data, calculates tensile strength, compares results with literature, and reflects on bamboo's role in sustainable manufacturing.
6. Each learner demonstrates independent understanding of the entire tensile testing process and its implications by answering a comprehensive written assessment.

Pedagogical Exemplars

Talk for Learning

Learners engage in a **think-pair-share activity**, where they revisit Year 1 and 2 notes, then collaborate in pairs to recall definitions and testing procedures, and share examples with the class.

Experiential Learning

1. In a mixed ability group, assign a multimedia resource (video, article, infographic or diagrams) and create a short presentation highlighting the relationship between bamboo structure and tensile strength. This supports **visual, auditory, and reading/writing learners**.
2. Each group develops a **step-by-step experimental procedure** using a planning template and schematic diagrams of the UTM setup.
3. Each group performs the tensile test under supervision using a **Universal Testing Machine**. Learners log real-time data and take notes collaboratively, building observational and data handling skills.
4. Group complete **lab report** and participate in a **gallery walk**, discussing findings and sustainability reflections with peers, guided by instructor prompts.
5. After the experiment, each learner receives a structured written assessment question on the learning indicator and the marked using the marking scheme to evaluate individual mastery level.

Key Assessment: Mid-Semester Examination

1. You have the tensile strength test results for four different bamboo samples. Based on your knowledge of materials used in construction, especially for scaffolding, explain which bamboo sample would be the best choice. In your explanation, compare the importance of tensile strength to other features like moisture content and diameter, and give reasons why your chosen sample would be the safest and most effective for scaffolding. Describe the process used to measure the tensile strength of a bamboo specimen and explain one challenge encountered during the experiment. (8 marks)
2. Design and justify a tensile strength testing procedure for bamboo in a school or lab setting. Describe the specific steps, tools, and variables you would control to ensure reliable results. Then, evaluate a real or hypothetical challenge you might face during the process—such as sample preparation or measurement accuracy—and explain how it could affect your results and how you would mitigate it. (10 marks)
3. Evaluate the suitability of bamboo as a construction material in comparison to a traditional material such as steel, concrete, or wood, for a specific building application (e.g., scaffolding, low-rise housing, or roofing). Use data or specific examples to compare mechanical

properties, environmental impact, and cost. Based on your evaluation, justify which material would be more appropriate and under what conditions bamboo might be preferred. (10 marks)

Hint



*Conduct **Mid-semester Examination**. It should cover contents taught from Week 1 to 5. Refer to the **Table of Specification and Structure of the Paper**. Learners' papers should be marked immediately and scores entered into the SAP.*

Structure of the Mid-Semester

Section A: 25 Multiple choice questions

Section B: 2 Essay Questions

Table of specification for item construction for section A and B

Week	Learning Indicator	Types of questions	DoK Levels				Total
			1	2	3	4	
1	Outline the importance of advanced materials such as semiconductors, biomaterials, smart materials and nanomaterials	MCQs	2	2	-		4
		ESSAY	-	-	-		-
2	Explain the structure of semiconductors as engineering materials	MCQs	2	2	2		6
		ESSAY	-	-	1		1
3	State the applications of semi-conductors, biomaterials, smart materials and nanomaterials	MCQs	-	2	1		3
		ESSAY	-	-	-		
4	Classify bamboo based on its structure, physical properties and processing State the application of bamboo in manufacturing	MCQs	3	2	1		6
		ESSAY					
5	Explain the mechanical properties of a bamboo material	MCQs	1	3	2		6
		ESSAY			1		1
		Total	**8**	**11**	**8**		**27**

PLC Session 6

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand.

b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP)

a. The key assessment for the week is mid-semester examination. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the mid-semester examination (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through the problem individually for 3–4 minutes

c. the group then works through it together the problem, step by step

d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 7

Learning Indicator: Explain the term failure of materials

Recap weeks

Year 2	**Week 6:** Explain elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials **Week 7:** Measure the tensile properties of steel using the tensile test.

Focal Area: Failure of materials

7.1 Introduction

Understanding material failure is a fundamental aspect of manufacturing and engineering, as it informs the design of safe, durable, and efficient structures. Material failure occurs when a material loses its ability to perform its intended function due to structural, mechanical, or environmental breakdowns. Recognising the causes and mechanisms of failure is crucial for preventing catastrophic incidents, as seen in the tragic Melcom building collapse in Achimota, Accra, in 2012. This event highlighted the consequences of using substandard materials and inadequate construction practices.

Material failure refers to the loss of a material's ability to carry loads or perform its intended function due to structural or mechanical degradation. This phenomenon is a critical area of focus in engineering and manufacturing, where the reliability of materials directly affects the safety and longevity of structures, machines, and systems. Failures can occur due to overload, fatigue, corrosion, or long-term wear and may manifest as fractures, deformation, or surface damage. Understanding the mechanisms behind these failures enables engineers to improve material selection, optimise designs, and implement preventive measures. Real-world examples, such as the failure of metal bridges or aircraft components, highlight the importance of this knowledge in avoiding catastrophic outcomes.

7.2 Explaining the Term 'Failure of Materials'

(Refer back to Year 2, Section 2, Week 6, Elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.)

The term failure of materials refers to any instance in which a material no longer performs its intended function within a system or structure. While failure is often associated with complete breakage or fracture, it can also include less visible forms such as excessive deformation, wear, corrosion, or fatigue. These types of failures may develop gradually and still lead to serious consequences if not detected early. Material failure can significantly compromise the safety, performance, and durability of engineering components and structures. As a result, it is a critical focus in the fields of materials science and engineering, where understanding failure mechanisms helps in developing better materials, improving design, and preventing costly or hazardous incidents.

7.3 Classification/ Types of Material Failure

Material failure can be classified into several key types based on the mechanisms and conditions under which materials cease to perform their intended function. The common types of material failure include fracture, fatigue, creep, wear and corrosion.

Fracture occurs when a material separates into two or more parts under stress. It typically happens when the applied stress exceeds the material's tensile strength. Fracture can be brittle (sudden, with little deformation) or ductile (preceded by noticeable deformation) as shown in Figure 21. The type of fracture depends on the material, the type of loading, the time variation of loading, and the environment. In many cases, the final fracture is preceded by slowly occurring processes. Very often, the fracture process can be subdivided into crack initiation, subcritical and final fracture. The different steps may be accompanied by macroscopic or by microscopic plastic deformation, or may be without any plastic deformation. An example is the cracking of a concrete beam under excessive load.

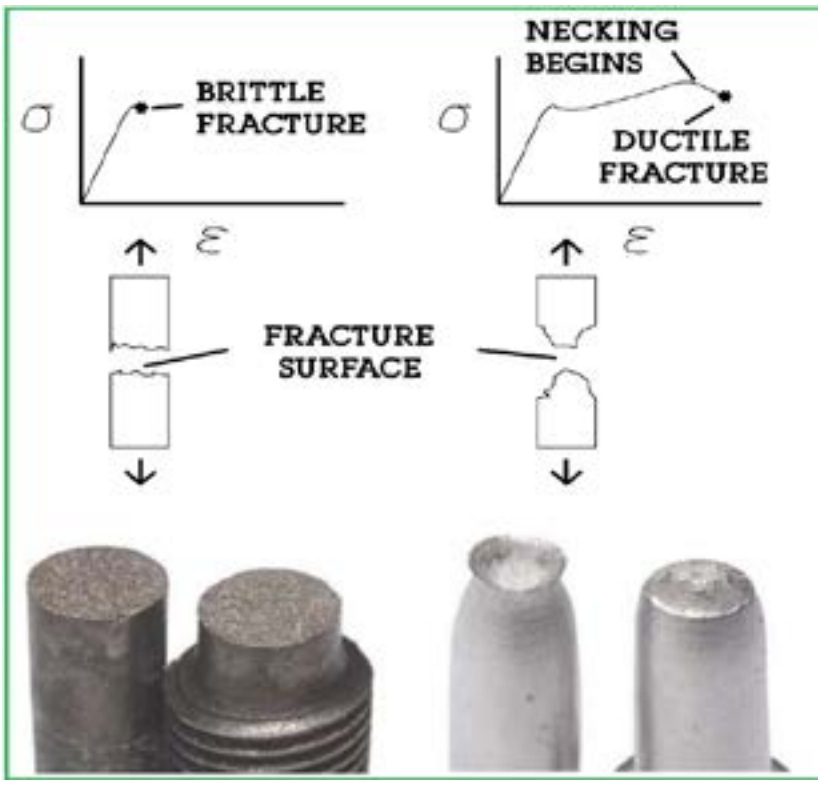


Figure 21: *Brittle and ductile fractures in materials*

https://whatispiping.com/brittle-fracture-ductile-fracture/

Fatigue failure results from repeated or cyclic loading over time. Even if the stress levels are below the material's yield strength, microscopic cracks can form and propagate, eventually leading to failure. Fatigue can be explained as the weakening of a material due to the application of fluctuating loads that result in damage to the material's structure and eventual failure. The damage starts locally and builds up over time and can end in a catastrophe. This is common in bridges, aircraft parts, and rotating machinery subjected to vibration or fluctuating forces. Figure 22 shows a material that has undergone fatigue failure.



Figure 22 Fatigue failure results from repeated or cyclic loading over time

https://fractory.com/material-fatigue-strength/

Creep is the slow, time-dependent deformation of a material under constant stress, typically at high temperatures. It is a major concern in applications such as turbine engines, boilers, and other components operating under prolonged heat and pressure. Figure 23 is a material that has undergone creep failure.



Figure 23: *Creep failure of a material under constant stress (Zhang et al., 2015)*

Wear involves the gradual loss or deformation of material on the surface due to mechanical action, such as friction or abrasion. It can lead to reduced performance or failure in components like gears, bearings, or engine parts as shown in Figure 24. The minor wear that is often neglected can be the reason that can lead to excessive wear and tear, which may also lead to intermittent issues

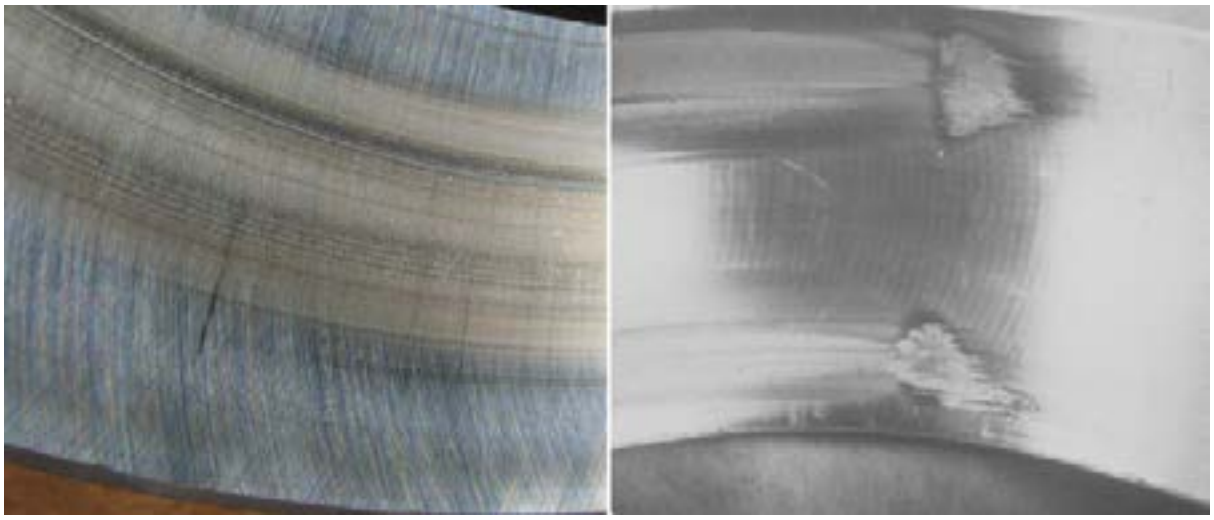


Figure 24: *Wear failure resulting from gradual loss of material on the surface due to mechanical action (Encalada-Dávila et al., 2021)*

Corrosion is the chemical or electrochemical reaction between a material (usually a metal) and its environment, leading to gradual degradation. Rusting of steel in humid conditions is a common example as shown in Figure 25. Corrosion weakens materials and structures, especially when not detected early.



Figure 25: *Failure resulted from rusting of steel in humid conditions*

https://www.dnv.com/energy/services/laboratories-test-facilities/article/preventing-external-corrosion-failures/

7.4 Causes of Material Failure

Material failure can result from a combination of factors that compromise the structural integrity and performance of materials. The most common causes include:

a. **Overloading**: When a material is subjected to forces or stresses beyond its designed strength limits, it can lead to sudden or progressive failure. Overloading is often the result of unexpected loads, misuse, or underestimation of stress during the design phase.

b. **Material Defects**: Internal flaws such as cracks, voids, inclusions, or inconsistent microstructures can significantly reduce a material's strength. These defects may originate during raw material production or later during processing, and they often serve as initiation points for failure under stress.

c. **Environmental Conditions**: Harsh environmental factors like high temperatures, moisture, chemical exposure, or UV radiation can degrade materials over time. Corrosive substances, for example, can cause rust in metals, while extreme heat can lead to creep in structural components.

d. **Improper Design**: Design flaws, such as not accounting for stress concentrations, inadequate safety factors, or misjudging load paths, can lead to premature material failure. For example, sharp corners or holes in structural components can create localised stress points that initiate cracking.

e. **Manufacturing Errors**: Mistakes during fabrication, such as incorrect heat treatment, improper welding, machining errors, or poor-quality control, can introduce weaknesses into a material. These flaws may not be visible immediately but can compromise the material's performance under load.

7.5 Consequences/Importance of Material Failure

Understanding material failure is of paramount importance in both engineering design and manufacturing. The consequences of material failure can be severe, affecting safety, functionality, and economic performance. However, by comprehensively studying and addressing material failure, engineers can prevent a range of detrimental outcomes, improve

the lifespan of products, and optimise costs. The consequences and importance of material failure are discussed below.

7.5.1 Prevention of Accidents

Material failure can lead to catastrophic events, such as structural collapses, machinery breakdowns, or transportation accidents, which often result in loss of life, injury, or environmental damage. By understanding failure mechanisms and conducting rigorous testing, engineers can design materials and structures that minimise the risk of failure, thereby safeguarding human lives and public safety.

7.5.2 Extension of Product Lifespan

Material failure is often the cause of premature product degradation. By identifying failure risks early on, engineers can design products and systems that last longer, reducing the need for frequent repairs or replacements. For instance, regular maintenance and proper material selection can increase the lifespan of infrastructure like bridges, roads, and pipelines, leading to better long-term value.

7.5.3 Cost Reduction

Material failures can result in significant financial losses due to repairs, downtime, legal liabilities, and the cost of replacing failed components. Preventing such failures by selecting durable materials, optimising design, and conducting regular inspections can help companies avoid expensive emergency repairs and warranty claims. Moreover, early detection of material issues can lead to more cost-effective solutions by addressing potential problems before they escalate.

7.5.4 Improvement in Material Design and Selection

The study of material failure contributes directly to advancements in **material science**. By analysing how and why materials fail, engineers can refine the design process, select more suitable materials for specific applications, and develop stronger, more efficient alternatives. This ongoing process of improvement leads to more resilient and innovative products that meet the growing demands of industries like aerospace, construction, and manufacturing.

7.5.5 Enhanced Safety and Efficiency in Engineering Solutions

By understanding and preventing material failure, engineers can develop safer, more reliable systems that operate at peak efficiency. This is especially important in industries like **aerospace**, **automotive**, **energy**, and **civil engineering**, where structural integrity and material performance directly impact both safety and operational efficiency.

7.6 Preventing Material Failure

Preventing material failure is essential for ensuring the longevity, safety, and performance of engineering structures and components. Various strategies can be employed to reduce the risk of failure and enhance material reliability as discussed below.

7.6.1 Proper Material Selection

Selecting the right material for specific applications is the first step in preventing failure. Materials should be chosen based on their **mechanical properties**, **environmental resistance**, and compatibility with the operational conditions (e.g., temperature, humidity, or corrosive environments). For instance, choosing **stainless steel** for structures exposed to high moisture or using **carbon fibre** for lightweight, high-strength applications can significantly reduce the risk of failure.

7.6.2 Design Optimisation

Good design practices are critical in preventing material failure. Engineers must consider **stress concentrations**, such as sharp corners or holes, which can become initiation points for cracks. Utilising **safety factors**—extra strength beyond the expected maximum load—can ensure the material performs safely under extreme conditions. Design optimisation also involves simulating potential failure modes using **Finite Element Analysis (FEA)** to predict how materials behave under different loads and conditions.

7.6.3 Quality Control

Ensuring high-quality manufacturing processes is vital to prevent defects that could lead to failure. Implementing **rigorous inspection and testing** during production, such as **Non-Destructive Testing (NDT)** methods (ultrasonic, radiographic, etc.), ensures that materials and components meet required standards. Continuous monitoring of manufacturing processes helps detect flaws early, such as cracks, voids, or inclusions, which can weaken the material.

7.6.4 Regular Maintenance

Continuous upkeep is essential for extending the life of materials and structures. Regular maintenance schedules should include visual inspections, **corrosion protection**, and structural integrity checks. For example, periodic painting of steel structures to prevent rust, or replacing worn-out components in machinery, can prevent premature material failure and reduce costly repairs or replacements.

7.7 Real-World Examples of Material Failure

Material failure has had significant consequences in infrastructure and public safety across the globe, and Ghana is no exception. These real-world examples highlight the importance of understanding and addressing material failure to prevent disasters. Some real-world examples of material failure are discussed below.

7.7.1 Bridge Collapse

In Ghana, **bridge collapses** due to **fatigue**, **corrosion**, and **overloading** are critical concerns. For example, the **Atimpoku Bridge (2018)** collapsed due to structural deterioration and corrosion, exacerbated by heavy traffic loads. This incident caused disruptions to transportation and local commerce, emphasising the urgent need for better inspection and maintenance of ageing infrastructure. With bridges in rural and peril-urban areas particularly at risk, ensuring the integrity of these structures is vital for public safety. Figure 26 shows the bridge linking Adidome, Juapong collapse.

7.7.2 Aircraft Failures

In the aviation sector, **fatigue** failure remains a significant risk. In 2015, a **Ghana Airways** aircraft experienced an engine failure attributed to **metal fatigue** in engine components. This incident underscored the importance of routine maintenance and regular inspections to detect fatigue cracks, especially in aircraft with high operational hours. Preventing such failures is crucial to maintaining the safety and reliability of air travel in Ghana and globally.



Figure 26 Collapse of the bridge linking Adidome, Juapong leaves residents stranded

https://citinewsroom.com/2024/01/collapse-of-bridge-linking-adidome-juapong-leaves-residents-stranded/

Notes for Facilitators

1. **Clarifying Concepts:** Use a clear analogy: Fracture is like a biscuit snapping (brittle) or a piece of gum stretching until it tears (ductile). Fatigue is like bending a paperclip back and forth repeatedly until it breaks. Creep is like a heavy book left on a soft shelf; over time, the shelf will sag.
2. **Common Misconceptions:** Students often think failure is only breaking. Explain that deformation (like a bent car axle), wear (a worn-out bicycle chain), and corrosion (rust) are also forms of failure because the part can no longer do its job properly.
3. **Low-Cost Demonstrations & Ghanaian Examples**
    a. **Fatigue:** This is a crucial concept. Show a photo of a collapsed bridge (like the Juapong-Adidome bridge from Figure 7.6). Discuss how repeated loading from heavy trucks (cyclical stress) can cause microscopic cracks to grow in steel beams, leading to catastrophic failure.
    b. Corrosion: Show a photo of a rusted car chassis or a corroded pipeline in the oil and gas sector. Discuss how the coastal environment of Ghana (humidity, salt) accelerates corrosion, making proper material selection (like stainless steel) and protective coatings essential.
    c. Troubleshooting: When using case studies, steer students away from simply memorising the event. Use a guided worksheet: 1) What was the material? 2) What type of failure? 3) What was the cause? 4) What could have prevented it? This develops analytical skills.

Learning Tasks

1. Review foundational concepts from Year 1 (types of materials and their properties) and Year 2 (stress-strain relationships, elastic/plastic deformation, and fracture).
2. In mixed ability, conduct guided textbook and internet research to define failure and distinguish between types: brittle, ductile, fatigue, creep, and corrosion.

3. Select one historical or industrial failure case (e.g., Tacoma Narrows Bridge, Liberty ships, metal fatigue in aircraft) and analyse what caused the material failure.
4. Selects a research topic (from a teacher-provided list), conducts a literature review using curated articles, papers, and video resources, and summarises findings in a short paper and presents their research findings to peers using posters, slides, or charts, and leads a short question and answer session.
5. Each learner demonstrates independent understanding of material failure, assessing depth of understanding and ability to apply concepts.

Pedagogical Exemplars

Talk for Learning

The teacher begins the lesson with a guided recall activity, where learners are provided with summary handouts from Years 1 and 2 covering stress-strain relationships, yield strength, and failure thresholds.

Research-Based Learning

1. In a mixed ability research group assigned specific types of material failure (e.g., fatigue, creep, brittle fracture) are assigned. Each group uses textbooks, teacher-curated online sources, and short videos to define their assigned failure type and identify real-world examples. Each ability group provides a brief summary poster or slide with definitions, causes, characteristics, and applications, which they then share during a gallery walk for peer feedback.
2. Provides a list of famous engineering failure cases with corresponding resource links (videos, articles, and failure analysis reports). Each group selects one case and conducts a guided case study analysis, using a worksheet that prompts them to identify: material used, failure type, root cause, and lessons learned. Groups present findings through a short oral presentation and submit a one-page failure summary report.
3. From a list of research topics (e.g., creep in turbine blades, corrosion in marine structures). Teacher models how to conduct a literature review, evaluate sources, and organise notes. Each group work independently to gather and synthesise content, keeping a research journal or logbook to document findings before writing a structured summary paper.
4. Use their findings from the Task, to prepare a presentation (digital or physical) with visuals. They receive a peer-review checklist and practice in pairs before presenting. Each Learner or group presents to the class, then facilitates a question-and-answer session. Peers use score sheets to give constructive feedback. The teacher closes with a debrief session to highlight key insights and common errors.

   Each learner receives a structured written assessment questions on the learning indicator after completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback

Key Assessment Level 4: Case Study

1. An engineering team is investigating why a machine part suddenly failed after operating under changing loads for several months. Analyse and explain how the team can determine whether fatigue failure caused the problem. In your response**;**
    a. Describe the specific signs or evidence the engineers should look for on the broken part.
    b. Explain how this evidence relates to fatigue failure.
    c. Propose one method they could use to prevent similar failures in future designs. (8 marks)
2. Identify two common types of material failure in engineering applications. For each type, analyse the underlying mechanisms that cause the failure, discuss how these failures can impact structural integrity, and propose engineering strategies or design considerations to prevent or mitigate these failures in real-world materials. (8 marks) (DOK Level 4)
3. Discuss the concept of material failure in manufacturing. Identify and discuss three different causes of material failure. For each cause, analyse how it affects the quality and safety of the final product, and propose specific strategies or engineering controls that manufacturers can implement to prevent such failures from occurring again. (30 marks)

PLC Session 7

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.

- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

   a. The key assessment for the week is case study. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the case study (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

   b. all teachers in the group work through a similar problem individually for 3–4 minutes

   c. the group then works through the problem together step by step

   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 8

Learning Indicator: Distinguish between creep, fatigue or fracture in failure of materials

Recap weeks

Year 2	**Week 1:** a. Explain loading, stress and strain of materials for manufacturing b. Outline the effect of loading, stress and strain in materials.

Focal Area: Concepts of creep, fatigue or fracture in failure of materials

8.1 Introduction

Understanding the mechanisms of **creep, fatigue**, and **fracture** is crucial in manufacturing engineering, as these are primary causes of material failure. These concepts form the foundation for designing and analysing engineering structures and components and are essential knowledge for Learners aiming to work in the field of manufacturing.

8.2 Definition and Explanation of Creep, Fatigue, and Fracture

a. **Creep:** Creep is a time-dependent deformation that occurs under constant stress, typically at high temperatures. It is characterised by three stages: primary creep, where the rate of deformation decreases; secondary creep, which exhibits a steady-state rate; and tertiary creep, where the rate accelerates leading to failure. Creep is commonly observed in environments like power plants and jet engines, where materials are subjected to sustained stress over long periods.

b. **Fatigue:** Fatigue refers to the process by which a material accumulates damage due to cyclic loading, eventually leading to fracture. The fatigue failure process involves three stages: crack initiation, where small cracks begin to form; crack propagation, where these cracks grow and spread; and final fracture, resulting in complete failure. Fatigue is a critical consideration in components subjected to repeated stress cycles, such as bridges, aircraft wings, and rotating machinery.

c. **Fracture:** Fracture is the separation or fragmentation of a material under stress and can be classified as either ductile or brittle. Ductile fracture involves significant plastic deformation before failure, while brittle fracture occurs with little to no deformation. Understanding fracture mechanics helps engineers design materials that resist cracking and failure by providing insights into how cracks initiate and propagate.

8.3 Factors Influencing Creep, Fatigue, and Fracture

(Refer back to Year 2, Section 2, Week 7, Mechanical Properties of Materials.)

Creep**,** a time-dependent deformation typically occurring under constant stress at high temperatures, is influenced by several factors including

1. Temperature: Higher temperatures accelerate the creep rate, making it a significant consideration in environments like power plants and jet engines.
2. Stress Level: Increased stress levels also accelerate creep deformation, necessitating careful design considerations.
3. Material Properties: The inherent properties of a material, such as its microstructure and composition, determine its susceptibility to creep.
4. Time: The duration of stress application influences the extent of creep deformation, with longer periods resulting in more significant deformation.

Fatigue**,** characterised by damage accumulation due to cyclic loading, leading to fracture, is influenced by:

1. Magnitude and Frequency of Load: Higher load magnitudes and more frequent cycles increase fatigue risk.
2. Surface Finish: Surface imperfections can act as stress concentrators, reducing fatigue life.
3. Environmental Conditions: Factors such as corrosion can exacerbate fatigue, weaken the material and promote crack growth.

Fracture, the separation or fragmentation of a material under stress, depends on:

1. Material Toughness: Materials with higher toughness can absorb more energy before fracturing, reducing fracture risk.
2. Stress State: The type and distribution of stress in the material influence fracture behaviour.
3. Temperature: Lower temperatures can promote brittle fracture in certain materials.
4. Presence of Flaws or Cracks: Existing imperfections serve as stress concentrators, increasing the likelihood of fracture.

8.4 Differences between Creep, Fatigue, and Fracture

Understanding the differences among material failure mechanisms is essential for engineers and scientists focused on building durable structures. Creep, fatigue, and fracture are three distinct ways materials can fail under stress, each with unique causes and characteristics as shown in Table 4. This overview highlights their behavioural traits and implications, helping to better understand how materials respond to stress over time, during repeated cycles, or under sudden impacts. This knowledge aids in selecting optimal materials for various applications. Regardless of the failure mode, routine inspections, predictive maintenance, and adherence to design standards are critical in detecting early signs of material degradation and ensuring long-term structural integrity.

Table 4 Differences between creep, fatigue and fracture

Aspect	Creep	Fatigue	Fracture
Cause	Occurs under constant stress and high temperature over time.	Results from cyclic loading and repeated stress cycles.	Can occur suddenly due to stress exceeding material strength.
Characteristics	Time-dependent deformation with stages: primary, secondary, and tertiary.	Progressive damage with stages: crack initiation, propagation, and final fracture.	Can be ductile (with plastic deformation) or brittle (sudden, with little deformation).

Common Environments	High-temperature applications such as turbine blades and power plants.	Components subjected to repeated loading, like bridges and rotating machinery.	Occurs in materials susceptible to cracking, like glass under impact.
Example	A turbine blade failing after prolonged high-temperature exposure.	An axle breaks after many stress cycles.	Glass shattering upon impact represents brittle fracture.

8.5 Testing for Material Failure/Methods for Failure Analysis

Failure analysis is a critical process in engineering used to determine the root causes of material or structural failure. It involves a range of techniques that provide valuable insights for improving design, material selection, and maintenance practices as discussed below.

a. Visual Inspection: The first step in failure analysis, visual inspection helps identify obvious signs of damage such as deformation, discolouration, surface cracks, or corrosion. It provides immediate clues about the nature and location of the failure.

b. Non-Destructive Testing (NDT): NDT techniques allow for the detection of internal or surface flaws without causing damage to the component. Methods include:

c. Ultrasonic Testing: Uses high-frequency sound waves to detect internal cracks or voids.

d. Radiographic Testing: Employs X-rays or gamma rays to examine the internal structure of components.

e. Magnetic Particle and Dye Penetrant Testing: Useful for identifying surface cracks in ferromagnetic and non-porous materials, respectively.

f. Fractography (Fracture Surface Analysis): This technique involves examining the fracture surface using optical microscopes or Scanning Electron Microscopes (SEM) to determine the mode of failure—whether it was brittle, ductile, fatigue-related, or stress-corrosion cracking. Fractography reveals features like beach marks, dimples, or cleavage planes, which help trace the origin and progression of the failure.

8.6 Effects of Creep, Fatigue, and Fracture

The consequences of material failure are often severe, affecting not only the functionality of a component but also public safety, the environment, and the economy. These failures can lead to catastrophic structural damage, costly financial losses, environmental degradation, and even loss of life.

For instance, a pipeline failure caused by fatigue can lead to large-scale oil or gas leaks, resulting in environmental contamination, disruption of supply, and millions of dollars in repair and clean-up costs. Similarly, the collapse of a bridge or building due to undetected creep or fracture could endanger countless lives and damage surrounding infrastructure.

Such examples underscore the importance of robust design, appropriate material selection, and preventive maintenance in engineering. By anticipating how materials behave under different conditions and stresses, engineers can mitigate risks, extend the service life of structures, and uphold safety standards.

Notes for Facilitators

1. **Clarifying Concepts:** Create a simple comparison table on the board with columns for Creep, Fatigue, Fracture. Key differences: Time (creep = slow, fatigue = cycles, fracture = sudden), Temperature (creep = high temperature, others = all temperature), Loading (creep = constant, fatigue = cyclic, fracture = single overload).
2. **Common Misconceptions:** The main confusion is between fatigue and fracture. Reinforce that fatigue is the process (slow crack growth from cyclic stress), while fracture is the result (the final, sudden separation).
3. **Low-Cost Demonstrations and Ghanaian Examples**
   a. **Creep:** Use a simple pendulum: a weight on a string. Show that if you just hang the weight, it›s under constant stress. If the string were made of a material like plastic or hot metal, it would slowly stretch over time. This is creep.
   b. **Fatigue:** Use the paperclip bending example. Count how many bends it takes to break. Explain that each bend is a «load cycle,» and the final snap is the fracture.
   c. **Troubleshooting:** When students are identifying failure modes from images or case studies, encourage them to look for specific clues. «Beach marks» (concentric rings) are a tell-tale sign of fatigue. A «cup and cone» fracture surface indicates a ductile failure, while a shiny, flat, chevron-patterned surface indicates a brittle failure.

Learning Tasks

1. Review and reinforce foundational knowledge of material failure modes from earlier coursework
2. Conduct research to identify real-world cases of material failure, focusing on determining the dominant failure mode, (creep, fatigue, or fracture)
3. Engage in a structured discussion to compare and contrast creep, fatigue, and fracture...
4. Each learner demonstrates independent understanding on material failure, assessing depth of understanding and ability to apply concepts.

Pedagogical Exemplars

Talk for Learning

1. Learners will revisit notes and textbooks from previous years to summarise the three primary modes of material failure: creep, fatigue, and fracture.
2. Learners to establish the differences between creep, fatigue or fracture with emphasis on the initiation and cause of the failure, the material types and the extent of damage caused to the materials. In pairs, learners tabulate differences and share with the class.

Research Based Learning

1. Learners use textbooks, academic papers, and reputable internet resources to investigate incidents where material failure occurred. They will analyse the conditions leading to failure and identify whether creep, fatigue, or fracture was the dominant mode.

2. Learners in mixed ability group discuss the characteristics, causes, and consequences of each failure mode. They will use case studies to illustrate their points and prepare a comparative analysis.
3. Each learner receives a structured written assessment questions on the learning indicator. After completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback.

Key Assessment Level 3: Group Concept Mapping

1. A steel part in a power plant works nonstop at high temperatures with a steady load. After many months, the part slowly stretches and becomes longer, even though it doesn't break. In your own words, explain what is happening to the steel part. Your answer should:
    a. Explain the name of this kind of slow change and what causes it
    b. Discuss the conditions that make this happen (like temperature and constant force)
    c. Compare this type of failure with other failures, like cracks from repeated use or sudden breaking in cold weather (5 marks)
2. During the inspection of a failed aircraft wing component, engineers discover microscopic cracks that grew over time due to repeated flight cycles. Eventually, the component broke apart during normal operation.

    What does this scenario primarily illustrate as the key difference between fatigue and fracture? (DOK Level 3)
    a. Fatigue occurs due to repeated loading, whereas fracture usually occurs suddenly under a single load.
    b. Fatigue leads to complete failure in a single event, whereas fracture develops over time.
    c. Fatigue happens only at high temperatures, whereas fracture occurs at any temperature.
    d. Fatigue involves plastic deformation, whereas fracture involves only elastic behaviour. (5 marks)
3. Engineers discovered tiny cracks in a broken aeroplane wing part that had developed over time due to repeated take-offs and landings. The part eventually failed during a regular flight. Using your understanding of material failure, analyse and explain the following:
    a. Discuss the type of failure that occurred and explain the process that led to it.
    b. Compare this type of failure with a sudden break caused by a single, strong force
    c. Justify why regular inspections are necessary for detecting this type of damage, even if the part appears undamaged externally. (10 marks)
4. Materials used in construction, transportation, and industry in Ghana may fail in different ways depending on the temperature and stress they are exposed to. Explain how temperature and stress can lead to creep, fatigue, and fracture in materials. For each type of failure, describe a real-life example in Ghana and explain how the environmental conditions contribute to the failure. (20 marks)

PLC Session 8

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is group concept mapping. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 2 Review

This section introduces learners to understanding mechanical properties and failure of materials. The section discusses the mechanical properties of bamboo, the tensile strength of bamboo, failure of materials and distinguishes between creep, fatigue or fracture in failure of materials. The lessons learnt from the section can be summarised as below:

1. Sustainability: Bamboo grows quickly and has strong properties, making it a good, eco-friendly alternative to materials like wood and steel.
2. Strength and Flexibility: Bamboo is as strong as steel in tension and stronger than many hardwoods in compression. It can bend without breaking, making it great for structures that need to handle movement.
3. Structure: Bamboo's hollow, cylindrical shape and nodes make it stronger and help it resist bending under pressure.
4. Moisture: Too much moisture makes bamboo weaker and less stiff, so it's important to dry and treat it properly.
5. Species Differences: Bamboo's strength and other properties can change depending on the species, so choosing the right type for the job is important.
6. Processing: Methods like drying and laminating can make bamboo more durable. Using consistent methods is key to keeping quality high.
7. Testing: Tests for strength, compression, and flexibility make sure the bamboo meets quality standards.
8. Uses: Bamboo is used in building, furniture, and textiles because it's strong and lightweight, making it a sustainable choice.
9. Material Failure: This happens when a material can't do its job anymore because it's broken down, which can be unsafe.
10. Fracture: The material breaks suddenly under pressure.
11. Fatigue: The material gets damaged from being repeatedly stressed.
12. Creep: The material slowly changes shape under constant pressure, especially at high temperatures.
13. Wear & Corrosion: The material gets worn out or damaged by chemical reactions.
14. Common Causes: Things like too much weight, defects in the material, harsh conditions, bad design, and manufacturing mistakes.
15. Failure Mechanisms: Ways materials fail include cracks growing, parts moving inside the material, and slow changes from heat or chemicals.
16. Non-Destructive Testing (NDT): This finds hidden problems without damaging the material.
17. Mechanical Tests: These check how well a material can handle pulling, repeated stress, and constant pressure.

18. Fractography & Metallography: These methods study how and why materials break and their internal structure.
19. Prevention Strategies: Choose materials that fit the job, design to reduce stress, and keep up with quality checks and maintenance.
20. Real-World Failures: Problems like bridge collapses, plane crashes, and pipeline breaks often happen because of stress, corrosion, or long-term pressure

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 5

Q1 Specific Marking Guide for Design Challenge: Bamboo vs. Steel Structure

Section A: Research and Explanation of Tensile Strength

Criteria	Description	Mark(s)
Definition of tensile strength	The Learner clearly explains tensile strength as the ability of a material to resist breaking under pulling or stretching force	1
Tensile strength of bamboo	Correctly states bamboo has a tensile strength in the range of 140–280 MPa (Any figure within the range is correct)	1
Tensile strength of steel	Correctly states mild steel has a tensile strength in the range of 370–550 MPa (Any figure within the range is correct)	1
	TOTAL	**3**

Section B: Material Comparison and Selection

Sub-Criteria	Full Marks (1.5)	Partial Marks (1)	No Marks (0.5)
Strength	Clearly identifies steel as stronger than bamboo and explains why	Mentions strength, but with weak or unclear comparison	Incorrect or missing
Cost	Correctly identifies bamboo as cheaper, especially in rural areas	Vague or partially correct comparison	Incorrect or missing
Availability	Explains that bamboo is more easily found or harvested locally	Mentions availability but lacks detail	Incorrect or missing
Environmental impact	Bamboo is described as sustainable, low-impact, and steel as energy-intensive	Mentions sustainability but not clearly	No environmental reference
Decision made	Selects one material (bamboo or steel) and supports it logically	Decision present but weak justification	No clear decision or justification

Conclusion	Well-rounded conclusion that reflects understanding of material use in context (low cost, sustainability, function)	Some understanding shown	Poor or missing conclusion
TOTAL	**9**		

Section C: Design and Explanation

Criteria	Description	Marks
Design sketch or drawing	Clear, labelled sketch showing key components: roof, walls, supports	8
Appropriate use of chosen material	Correct application of bamboo or steel for tension elements (e.g., trusses, bracing)	2
Creativity & practicality	Design shows both innovation and suitability for a rural community	2
Explanation of design choices	Explains why specific materials and structure were chosen	2
Link to problem context	Shows how the design solves the community's needs: affordable, eco-friendly, functional	2
	TOTAL	**16**

Sample answer

a. **Research and Explanation of Tensile Strength**

i. **Tensile Strength** is the ability of a material to resist breaking when being stretched or pulled.

ii. **Bamboo**: Bamboo has a tensile strength of around **140–280 MPa** (megapascals), depending on the species and treatment. It is surprisingly strong for a natural material and is often compared with mild steel when used properly.

iii. **Steel**: Mild steel has a tensile strength of about **370–550 MPa,** which is much higher than bamboo. It is stronger, more consistent, and does not vary like natural materials do.

b. **Choosing the Better Material for Tension Parts**

Compare bamboo and steel based on the four key factors:

i. **Strength Steel** is stronger than bamboo in tension. It can handle heavier loads and is more reliable in structural applications.

ii. **Cost Bamboo** is much cheaper than steel, especially in developing areas where it grows naturally. Steel is expensive to buy and transport.

iii. **Availability Bamboo** is widely available in many rural communities and can be harvested locally. Steel may not be easily available and might have to be imported or transported from far.

iv. **Environmental Impact Bamboo** is highly sustainable. It grows quickly, absorbs carbon dioxide, and does not need much processing. Steel has a large carbon footprint. Making steel uses a lot of energy and causes pollution.

v. **Conclusion:** While **steel is stronger**, **bamboo** would be chosen for the tension parts in this structure because:

- It is cheap, available locally, and eco-friendly.
- With the right design (such as bundling or tying bamboo poles together), bamboo can handle tension safely for a small structure.

c. **A Single Building Design Using Bamboo**



The **Roof is** supported by bamboo trusses, tied with natural fibre ropes **the walls** made of bamboo mats bundled, bamboo columns and for stability purposes, the f**oundation was laid with a** cement blocks

Explanation of Design and Materials

1. This design was selected because it uses bamboo for the roof trusses and supports, which are under tension. Bamboo is strong enough for this small structure, and the design spreads the load evenly. The open sides allow good ventilation, and the materials are **natural, affordable,** and **easy to replace or repair**. This helps the community build and maintain it without needing expensive tools or skills.
2. Analyse the advantages and limitations of using bamboo over traditional materials such as wood and steel in construction and manufacturing. Include specific mechanical properties in your analysis. (10 marks)

Marking Guide: Advantages and limitations of using bamboo over traditional material

Criteria	Description	Marks
State two mechanical advantages of bamboo	Identify and explain at least two advantages of bamboo (e.g., high tensile strength, lightweight, flexibility, renewability).	2
State two mechanical limitations of bamboo	Identify and explain at least two limitations of bamboo (e.g., low compressive strength, moisture sensitivity, variability).	2
Compare bamboo with steel	Make a clear comparison between bamboo and steel regarding strength, durability, or reliability.	2
Compare bamboo with wood	Make a clear comparison between bamboo and wood regarding growth, sustainability, or structural performance.	2
Use mechanical property terms	Use at least three mechanical terms accurately (e.g., tensile strength, compressive strength, flexibility, durability, density).	2
	TOTAL	**10**

Sample Answer

Bamboo has some advantages over traditional materials. It is very strong when pulled or stretched, even stronger than some types of mild steel, which makes it good for structures that need to handle tension. Bamboo is also light, so it's easier to move and work with. Compared with wood, bamboo grows much faster, making it a more sustainable material. It is also more flexible, which helps it absorb shocks during things like earthquakes.

But bamboo has some limitations. Its compressive strength (resistance to being squashed) is lower than steel, so it might not hold up well under heavy weight. Bamboo can easily be damaged by moisture, insects, and decay if not properly treated. Unlike steel, which is heavy and has a consistent structure, bamboo's strength can vary depending on its type, age, and how it's treated. While wood also varies in quality, it is usually more reliable than bamboo in big construction projects.

WEEK 6

Q1 Marking Rubric; You have the tensile strength test results for four different bamboo samples. Based on your knowledge of materials used in construction, especially for scaffolding, explain which bamboo sample would be the best choice. In your explanation, compare the importance of tensile strength to other features like moisture content and diameter, and give reasons why your chosen sample would be the safest and most effective for scaffolding. Describe the process used to measure the tensile strength of a bamboo specimen and explain one challenge encountered during the experiment. (8 marks)

Criteria	Expected Response	Marks
Correct identification of the best sample	Clearly states that the sample with the highest tensile strength is most appropriate for scaffolding use.	1
Explanation of tensile strength	Defines tensile strength as the ability of a material to resist pulling or stretching forces without breaking.	2

Justification in relation to scaffolding	Explains that scaffolding needs materials that are strong and reliable to support weight and ensure structural safety.	2
Comparison with moisture content	States that high moisture content can make bamboo weaker, bend easily, or rot, making it less suitable.	1
Comparison with the diameter	Explains that smaller diameter bamboo is lighter but usually less strong and may break easily.	1
Logical conclusion	Summarises that the highest tensile strength is the best choice because it ensures durability and safety in scaffolding	1
	TOTAL	**8**

Sample Answer

The best bamboo sample for scaffolding would be the one with the **highest tensile strength.** This is because tensile strength measures how much pulling or stretching force a material can withstand before it breaks. In scaffolding, the materials need to support the weight of workers and construction materials, so they must be strong and reliable. Although a sample with higher **moisture content** might seem more flexible, it is actually weaker and more likely to bend, warp, or rot over time, especially in outdoor conditions. Similarly, a **smaller diameter** may make the bamboo lighter and easier to move, but it usually has less strength and can break more easily under heavy loads. Therefore, choosing the sample with the highest tensile strength ensures that the bamboo can handle stress without breaking, making the scaffolding safer and more durable

Q2 Marking Guide; Design and justify a tensile strength testing procedure for bamboo in a school or lab setting. Describe the specific steps, tools, and variables you would control to ensure reliable results. Then, evaluate a real or hypothetical challenge you might face during the process (such as sample preparation or measurement accuracy) and explain how it could affect your results and how you would mitigate it.

Marking Scheme (10 Marks)

Criteria	Description	Marks
Procedure Design	Clear, step-by-step process to test tensile strength. Should be logical and feasible for a school or lab setting.	3 marks
Tools & Equipment	Accurate identification and explanation of tools (e.g. clamps, force gauge, ruler, callipers, testing rig).	2 marks
Controlled Variables	Identification of key variables (e.g. moisture content, bamboo diameter, length, loading rate) and how they're controlled.	2 marks
Challenge Evaluation	Realistic challenge described, with an explanation of its potential effect on results.	2 marks
Mitigation Strategy	Reasoned and feasible solution to the identified challenge.	1 mark

Sample Answer

To test the tensile strength of a bamboo sample in a school lab, first cut the bamboo into standardised lengths—around 30 cm—making sure all samples have similar diameter and wall thickness. Use a universal testing machine (if available) or a manual rig with clamps, a pulley system, and a force gauge or spring scale.

Steps

1. Prepare and dry bamboo samples to a consistent moisture level (e.g. 12%) using a drying oven or by air-drying for a set period.
2. Secure the bamboo between two grips in the testing apparatus.
3. Gradually apply tensile force using weights or a crank until the bamboo breaks.
4. Record the maximum force applied before failure.
5. Repeat for at least 3 samples and calculate the average tensile strength.

Tools

- Callipers (to measure diameter)
- Drying oven (to control moisture)
- Force gauge or spring scale
- Clamps and a frame or rig
- Ruler or measuring tape

Controlled Variables

Control the moisture content, sample length, diameter, and loading speed to ensure consistency and reliable comparisons across trials.

Challenge

A major challenge would be securing the bamboo properly. Its round, hollow shape can cause it to slip or crack at the grip points, affecting the accuracy of the force measurement.

Mitigation

To prevent this, use padding material inside the clamps or design custom grips shaped to fit the bamboo securely, reducing slippage without crushing the sample.

Q3 Marking Guide: Evaluate the suitability of bamboo as a construction material in comparison to a traditional material such as steel, concrete, or wood, for a specific building application (e.g., scaffolding, low-rise housing, or roofing). Use data or specific examples to compare mechanical properties, environmental impact, and cost. Based on your evaluation, justify which material would be more appropriate and under what conditions bamboo might be preferred. (10 marks)

Marking Scheme (Total: 10 marks)

Criteria	Description	Marks
1. Application Context	Clear identification of the specific building application (e.g., scaffolding, low-rise housing, roofing)	1 mark
2. Comparison of Mechanical Properties	Accurate comparison using at least two mechanical properties (e.g., tensile strength, weight-to-strength ratio, flexibility, durability)	2 marks
3. Environmental Impact	Evaluation of sustainability, carbon footprint, renewability, biodegradability, or ecological benefits/drawbacks of both materials	2 marks

4. Cost Comparison	Discussion of material cost, availability, and long-term economic considerations (e.g., maintenance, lifecycle cost)	1 mark
5. Use of Data/ Examples	Reference to specific examples or data (e.g., real-life use cases, numbers, studies, or projects involving bamboo and traditional material)	1 mark
6. Evaluation and Justification	Reasoned judgment on which material is more suitable overall for the chosen application, including conditions under which bamboo would be preferred	2 marks

Sample Answer

Application: Low-rise Housing

Bamboo is increasingly being used in low-rise housing, especially in rural or rapidly developing regions. When compared with concrete, bamboo has a high tensile strength (up to 250 MPa), which rivals mild steel, although its compressive strength is lower. This makes it especially useful for components under tension, like roofing frames or wall supports.

Environmentally, bamboo is far more sustainable than concrete. It grows rapidly (up to 1 metre per day in some species), requires little energy to process, and absorbs carbon dioxide. In contrast, concrete production is highly energy-intensive and contributes significantly to global CO_2 emissions.

From a cost perspective, bamboo is much cheaper in areas where it is locally available, reducing both material and transport costs. However, it may require additional treatment to prevent decay, insect attack, or moisture damage, which can add to maintenance expenses.

A good example of bamboo housing is the Green Village in Bali, where whole residential structures are built using treated bamboo, proving it can be both durable and aesthetically appealing.

In conclusion, while concrete remains suitable for applications demanding high compressive strength and permanence, bamboo is a strong, eco-friendly alternative for low-rise housing in regions where sustainability, cost, and speed of construction are priorities. Bamboo is especially appropriate where seismic flexibility and renewable materials are valued.

WEEK 7

Q1 Marking Guide Identification of Evidence on the Failed Part

An engineering team is investigating why a machine part suddenly failed after operating under changing loads for several months. Analyse and explain how the team can determine whether fatigue failure caused the problem. In your response**;**

a. Describe the specific signs or evidence the engineers should look for on the broken part.

b. Explain how this evidence relates to fatigue failure.

c. Propose one method they could use to prevent similar failures in future designs. (8 marks)

Component	Expected Content	Mark (s)
1. Description of evidence	Look for at least three of the following:	
	– Small surface or internal cracks	3 marks – 3 or more correct points with detail
	– Beach marks or striations	2 marks – 2 correct points
	– Crack initiation at stress concentration areas (e.g., bolt holes, corners, welds)	1 mark – 1 correct point
	– Smooth area showing slow crack growth	0 marks – No valid evidence
	– Rough, sudden break zone indicating final fracture	
2. Explanation of fatigue failure	A correct explanation should include:	
	– Fatigue results from repeated/cyclic loading	3 marks – Full explanation with all key points
	– Cracks initiate and grow over time	2 marks – Mostly correct with minor omission
	– Beach marks show stages of crack propagation	1 mark – Partial understanding
	– Final failure occurs when the crack reaches a critical size	0.5 mark – Minimal explanation
		0 marks – Incorrect or no explanation
3. Preventive method	Any one relevant solution such as:	
	– Redesigning to reduce stress concentrations (e.g., rounded edges, fillets)	2 marks – One specific and technically valid method
	– Using fatigue-resistant materials	1 mark – General idea with some technical relevance
	– Surface treatments (e.g., polishing, shot peening)	0.5 mark – Vague or loosely related method
	– Regular inspections using non-destructive testing (e.g., dye penetrant, ultrasonic)	0 mark – No relevant method proposed
	TOTAL	**8 marks**

Sample answer

Evidence to look for on the broken part

The team should look for **small cracks** that appear to have started at the surface or at stress concentration points like corners, bolt holes, or welded joints. These cracks often show a **pattern of beach marks or striations**—lines that indicate slow crack growth over time. The final break may look different from the earlier crack growth, with a more jagged or rough surface.

How does this evidence relate to fatigue failure?

These patterns are typical of **fatigue failure,** which happens when a part is repeatedly loaded and unloaded. The beach marks or striations show the crack growing little by little with each stress cycle. The final fracture happens when the crack becomes large enough to weaken the part completely, even under normal loads. This slow and progressive damage is a clear sign that fatigue, not a single large force caused the failure.

Method to prevent similar failure in future designs

One effective method is to **redesign the part to reduce stress concentrations**. For example, the team could round sharp corners, use fillets, or improve the surface finish to reduce the likelihood of crack formation. Alternatively, they could choose a material with better fatigue resistance or apply **regular non-destructive testing (NDT)** methods, like ultrasonic or dye penetrant inspections, to catch early cracks before failure occurs.

Q2 Marking Guide/Scheme: Material Failure Types; Brittle Fracture and Fatigue Failure

Identify two common types of material failure in engineering applications. For each type, analyse the underlying mechanisms that cause the failure, discuss how these failures can impact structural integrity, and propose engineering strategies or design considerations to prevent or mitigate these failures in real-world materials. (8 marks)

1. Identification of Failure Types (2 marks)
    - **a. 2 marks:** Both brittle fracture and fatigue failure are correctly named as types of material failure.
    - **b. 1 mark:** Only one failure type is correctly named, or both are mentioned but with minor inaccuracies (e.g., slightly incorrect terminology).
    - **c. 0 mark:** Neither failure type is correctly identified, nor are irrelevant terms given.
2. Explanation of Failure Mechanisms (2 marks)
    - **a. 2 marks:** Provides a clear and accurate explanation for both failure mechanisms:
        - *i. Brittle fracture* occurs suddenly with little or no plastic deformation.
        - *ii. Fatigue failure* results from crack initiation and growth under repeated cyclic loading.
    - **b. 1 mark:** Explains only one failure mechanism correctly, or explanations for both are vague, incomplete, or partially incorrect.
    - **c. 0 mark:** Explanations are missing, incorrect, or show a fundamental misunderstanding of both mechanisms.
3. Structural Impact (2 marks)
    - **a. 2 marks:** Accurately describes how each failure affects structural integrity:
        - *i. Brittle fracture* causes sudden and catastrophic failure without warning.
        - *ii. Fatigue failure* leads to progressive damage, resulting in unexpected failure after repeated loading.
    - **b. 1 mark:** Provides a general description of the impact or discusses only one failure type with limited detail.

   c. **0 mark:** Fails to describe the structural impact or gives incorrect information.

4. Preventive Strategies (2 marks)

   a. **2 marks:** Proposes clear, specific, and appropriate preventive measures for both failure types:

      i. For *brittle fracture*: Use tougher, more ductile materials; avoid stress concentrators like sharp corners; control cooling rates in processing.

      ii. For *fatigue failure*: Apply surface treatments (e.g., polishing, shot peening) to reduce crack initiation; design to reduce cyclic stresses; use fatigue-resistant materials.

   b. **1 mark:** Suggests only one valid preventive strategy or gives vague/general recommendations not clearly linked to the failure types.

   c. **0 mark:** No valid preventive strategies or irrelevant suggestions.

Sample Answer

Two common types of material failure in engineering are brittle fracture and fatigue failure.

1. **Brittle Fracture**

Mechanism: Brittle fracture occurs when a material breaks suddenly without significant plastic deformation. This failure mode is typically caused by crack initiation and rapid crack propagation through the material's crystal structure, often along grain boundaries or defects. It happens under high stress and low temperature or when the material is inherently brittle (e.g., cast iron, glass).

Impact on Structural Integrity: Because brittle fracture happens abruptly and without warning, it can lead to catastrophic failure of structures, risking safety and causing severe damage. There is little to no visible deformation prior to failure, making detection difficult.

Prevention Strategies: To prevent brittle fracture, engineers can select tougher materials, avoid sharp corners and stress concentrators, conduct proper heat treatments to improve toughness, and design structures to operate above the ductile-to-brittle transition temperature. Regular inspections to detect cracks early can also mitigate risks.

2. **Fatigue Failure**

Mechanism: Fatigue failure occurs due to repeated cyclic loading, even when the applied stresses are below the material's ultimate tensile strength. Over time, microscopic cracks initiate at stress concentrators such as surface scratches or inclusions. These cracks gradually grow with each load cycle until the remaining cross-section can no longer support the load, resulting in fracture.

Impact on Structural Integrity: Fatigue failure reduces the lifespan of components and can cause unexpected breakdowns in critical structures like bridges, aircraft, and machinery. Fatigue cracks usually start small and can propagate internally, making early detection challenging.

Prevention Strategies: To reduce fatigue failure, engineers can design components to minimise stress concentrations by using smooth transitions and fillets, employ surface treatments like shot peening to improve resistance to crack initiation, select materials with high fatigue strength, and implement routine inspections using non-destructive testing methods to catch cracks early.

Q3 Assessment Rubric: Material Failure in Manufacturing (Any three 15 marks)

Discuss the concept of material failure in manufacturing. Identify and discuss three different causes of material failure. For each cause, analyse how it affects the quality and safety of the final product, and propose specific strategies or engineering controls that manufacturers can implement to prevent such failures from occurring again. (30 marks)

Criteria	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0marks)
Definition of Material Failure	Clear, detailed explanation that it's when a material fails due to cracks, deformation, etc., rendering it unfits for use	Good definition with most key terms, some minor detail missing	Basic or vague explanation	Incorrect or no explanation
Cause 1: Fatigue	Accurately explains fatigue as failure due to repeated stress cycles leading to crack growth and eventual break.	Explains fatigue but lacks mention of crack initiation or cycle loading	Mentions fatigue with unclear or shallow explanation	No mention or incorrect explanation
Cause 2: Corrosion	Describes corrosion as chemical degradation (e.g., rust) and links it to environmental exposure and weakening over time	Explains corrosion well, though may lack one detail (e.g., type of exposure or material affected)	Mentions corrosion but lacks clarity or depth	No mention or incorrect explanation
Cause 3: Overloading/ Design Flaws	Clearly explains structural failure due to exceeding load limits or stress concentration from sharp edges, thin walls, etc.	Explains overloading or design flaws well, but may not clearly link to mechanical failure	General explanation of overloading or weak design	No mention or incorrect explanation
Cause 4: Contamination/ Processing	Explains how impurities or poor processing (e.g., improper heat treatment) lead to weak points, brittleness, or cracks	Mentions contamination or processing issues with some link to material weakness	Identifies one of the causes, but without a full explanation	No mention or unrelated explanation

Effect of Fatigue	Gives a clear real-world example (e.g., engine part cracking) and relates it to stress repetition and failure	Provides an example with minor inaccuracies or lacks specific connection to fatigue	Gives an effect/ example with unclear link to fatigue	No example or incorrect explanation
Effect of Corrosion	Explains weakening, holes, or collapse (e.g., rusted bridge or pipe), clearly linking it to long-term chemical attack	Describes corrosion effect but may lack specific consequence or context	Mentions general damage with vague or partial understanding	No effect or wrong explanation
Effect of Overloading	Clearly links overloading to breakage (e.g., snapped beam or failed crane) with real-world example	Describes overloading effect with limited detail or example	Identifies a general effect without clear connection	No example or wrong explanation
Prevention Measures	Lists appropriate and specific solutions for all causes (e.g., coating, inspections, better design, cleanrooms)	Mentions solutions for most causes, but may miss one or use less technical language	Gives one or two correct prevention methods with limited explanation	No prevention methods or unrelated answers
Relevant Examples	Provides a strong, real-world example for each failure type (e.g., bridge collapse, worn engine part, rusted pipe, brittle plastic casing)	Gives accurate examples for most failure types	Gives general or vague examples with partial relevance	No examples or off-topic responses

Sample answer

Material failure occurs when a material loses its ability to perform its intended function due to defects such as cracks, fractures, deformation, or separation. This failure can happen during or after manufacturing when the material is unable to withstand operational stresses or environmental conditions.

Causes of Material Failure in Manufacturing

1. **Contamination**

   a. Effect on Quality and Safety:

   Foreign particles like dust, dirt, or other impurities embedded in the material create weak points. These can initiate cracks or voids, reducing mechanical strength and

causing premature failure. In critical products like medical devices, this can lead to malfunction and safety risks for users.

b. Prevention

i. Maintain clean manufacturing environments (e.g., cleanrooms).

ii. Implement strict material handling protocols.

iii. Regularly clean equipment and tools.

iv. Perform thorough quality inspections to detect contamination early.

2. **Improper Heat Treatment or Processing Conditions**

a. **Effect on Quality and Safety**

Incorrect temperatures or cooling rates during processes such as moulding, welding, or annealing can cause internal stresses, brittleness, incomplete curing, or residual stress build-up. This leads to deformation, cracking, or failure under load, compromising durability and safety.

b. **Prevention**

i. Use sensors and automated systems to control processing temperatures.

ii. Train operators on thermal process specifications.

iii. Validate and optimise process parameters through trial runs or pilot tests.

iv. Use post-process inspections like thermal imaging or hardness testing.

3. **Mechanical Overloading or Design Flaws**

a. Effect on Quality and Safety

Applying forces beyond the material's design limit or incorporating sharp corners and thin cross-sections causes stress concentrations, leading to cracking or catastrophic failure. Inadequate designs may not account for worst-case operational loads.

b. Prevention

i. Apply engineering design best practices with safety factors.

ii. Avoid sharp corners by introducing fillets or radii.

iii. Conduct Finite Element Analysis (FEA) and stress testing.

iv. Validate product performance under simulated loading conditions.

4. **Corrosion**

a. Explanation Corrosion is a chemical or electrochemical reaction that gradually degrades a material, especially metals, through exposure to moisture, oxygen, salts, or acids. A common form is rusting.

b. Effect on Product

Corrosion weakens material over time, creating holes, thinning, or surface degradation. For instance, rusted pipes may leak, and corroded bridge beams can pose collapse risks.

c. Prevention

i. Paint or coat metals with corrosion-resistant layers.

ii. Use corrosion-resistant alloys (e.g., stainless steel, aluminium).

iii. Store and use materials in controlled environments.

iv. Apply cathodic protection for buried or submerged metals.

5. **Fatigue**

a. **Effect on Quality and Safety**

Fatigue occurs when a material is subjected to repeated or fluctuating stress cycles, even below its ultimate tensile strength. Over time, this leads to the initiation and propagation of microcracks, which can grow and cause sudden and catastrophic failure without warning. Common in components under cyclic loading like rotating shafts, gears, or aircraft wings.

b. **Prevention**

i. Design components to reduce stress concentrations (e.g., smoother transitions, avoid notches).

ii. Perform fatigue testing during development.

iii. Limit cyclic stress by improving load distribution or damping vibration.

iv. Implement scheduled maintenance and non-destructive testing (e.g., ultrasonic or dye-penetrant inspection) to detect early crack growth.

WEEK 8

Q1 Marking Guide: Material Behaviour – Creep

A steel part in a power plant works nonstop at high temperatures with a steady load. After many months, the part slowly stretches and becomes longer, even though it doesn't break. In your own words, explain what is happening to the steel part. Your answer should:

a. Explain the name of this kind of slow change and what causes it

b. Discuss the conditions that make this happen (like temperature and constant force)

c. Compare this type of failure with other failures, like cracks from repeated use or sudden breaking in cold weather (5 marks)

Assessment Area	Expected Response	Mark (s)
a. Identification of material behaviour	Correctly identifies the behaviour as creep and clearly describes creep as a slow, permanent deformation of a material	1
b. Explanation of cause	Explains that creep occurs under constant load/stress and high temperature over time. e.g., The continuous load and heat weaken the metal over time.	2

c. Comparison with other failures	Clearly contrasts creep with:	2
	a) Fatigue: caused by repeated/cyclic loading	
	b) Brittle fracture: sudden break, often at low temperatures	
	TOTAL	**5**

Sample answer

The steel part is experiencing a type of slow change called creep. Creep happens when a material is under a constant force (load) for a long time while being exposed to high temperatures. Temperature and stress are two major environmental factors that affect how materials behave and eventually fail. Over time, the material slowly stretches or deforms even though it doesn't break suddenly. This happens because, at high temperatures, the atoms in the steel move more easily, so the material slowly stretches even though the load is not changing. It doesn't break suddenly, but it becomes longer over time. Creep is different from other types of failure. For example, fatigue happens when a part is used over and over again, like when it bends or moves repeatedly, causing small cracks that grow with time. On the other hand, brittle fracture is when a material breaks suddenly, often in cold temperatures, without stretching or warning. That's why it's important for engineers to check parts that are always under stress and heat, even if they look fine on the outside

Q2 Marking Guide – Material Failure: Fatigue

During the inspection of a failed aircraft wing component, engineers discover microscopic cracks that grew over time due to repeated flight cycles. Eventually, the component broke apart during normal operation.

What does this scenario primarily illustrate as the key difference between fatigue and fracture?

a. Fatigue occurs due to repeated loading, whereas fracture usually occurs suddenly under a single load.

b. Fatigue leads to complete failure in a single event, whereas fracture develops over time.

c. Fatigue happens only at high temperatures, whereas fracture occurs at any temperature.

d. Fatigue involves plastic deformation, whereas fracture involves only elastic behaviour. (5 marks)

Criteria	Expected Response	Mark (s)
The type of failure and process	Clearly identifies the failure as fatigue	1
	Explains fatigue as a gradual process caused by repeated loading, leading to crack growth over time	1
Comparison with sudden fracture	States that fatigue is slow and builds over time, while a fracture happens suddenly from a single, large force	1
	Mentions that fatigue may show no external signs, while a sudden fracture happens immediately	1
Importance of inspection	Explains that fatigue cracks start small and hidden, so inspection is needed even if the part looks fine. Regular inspection helps detect damage early and prevents failure during use	1
TOTAL		5

Sample Answer

The type of failure that occurred is called **fatigue failure**. This happens when a material is repeatedly stressed or loaded over time, even if the amount of stress is not very high. In the case of the aeroplane wing, the part experiences stress during each take-off and landing. Over time, **tiny cracks** formed inside the material. These cracks slowly grew bigger with each cycle until the part eventually **broke,** even during normal use. This is a **gradual process** that happens because the material weakens with repeated use.

Fatigue failure is **different from a sudden break** (called a **fracture**) caused by a single, strong force. In fatigue, the damage builds up **over time** through many small stress cycles. The material can look fine from the outside until it finally breaks. In contrast, a sudden fracture happens **immediately** when a material is hit with a large force that is stronger than what it can handle. There are usually **no warning signs** with a sudden fracture, but it doesn't need repeated loading to occur.

Regular inspections are very important for **detecting fatigue damage**, because the cracks start out **very small and hidden inside** the material. The part might look perfectly fine on the outside, but tiny internal cracks could already be forming. If these cracks are not found and repaired early, they can grow and lead to a **dangerous failure during normal operation,** like what happened in the airplane wing. Inspections using special tools (like X-rays or ultrasonic testing) help engineers catch the damage before it gets worse and prevents accidents.

1. **Specific Marking Guide for Question 3**

Engineers discovered tiny cracks in a broken aeroplane wing part that had developed over time due to repeated take-offs and landings. The part eventually failed during a regular flight. Using your understanding of material failure, analyse and explain the following:

a. Discuss the type of failure that occurred and explain the process that led to it.

b. Compare this type of failure with a sudden break caused by a single, strong force

c. Justify why regular inspections are necessary for detecting this type of damage, even if the part appears undamaged externally. (10 marks)

Part	Marking Point	Specific Expected Response	Mark (s)
Creep	Definition	Learner states creep is slow, continuous deformation under constant load or stress and high temperature	1
	Example	Learner gives example such as steel beams in power plants or factories in hot regions of Ghana	1
	Explanation of environmental effect	Learner explains high temperatures in Ghana make materials softer, causing slow deformation over time	1
Fatigue	Definition	Learner states fatigue is failure from repeated or cyclic loading, even if load is low	1
	Example	Learner gives example such as vehicle suspension parts on buses driving on rough roads in Ghana	1
	Explanation of environmental/ use effect	Learner explains rough roads and heavy traffic in Ghana cause repeated stress leading to crack growth	1

Fracture	Definition	Learner states fracture is sudden breaking of material due to strong impact or force	1
	Example	Learner gives example such as rusted metal tools or pipes breaking suddenly due to corrosion in Ghana's humid environment or accidents causing sudden breakage	1
	Explanation of environmental effect	Leaner explains humidity causes rust/corrosion, weakening materials and making sudden fracture more likely	2
		TOTAL	**10**

Sample Answer

Temperature and stress are two major environmental factors that affect how materials behave and eventually fail. Materials used in construction, transportation, and industry in Ghana can fail in different ways because of the **temperature** and **stress** they experience. Temperature and stress affect materials differently

One common type of failure is creep, which happens when a material is exposed to high temperatures and a constant load over a long period. In Ghana, this can be seen in metal parts of electricity transmission poles in the northern regions, like Tamale, where daytime temperatures are very high. The continuous tension on bolts and metal brackets, combined with the heat, causes these parts to slowly stretch or deform over time. This kind of slow, permanent change in shape is a classic example of creep.

Another type of failure is fatigue, which occurs when a material is repeatedly loaded and unloaded, even if the force is not very high. Over time, this leads to the development of small cracks that can grow and cause the material to fail. A good example in Ghana is the railway line between Accra and Nsawam. The metal rails are subjected to constant movement from trains, as well as weather changes like heat during the day and cooler temperatures at night. These repeated stresses eventually cause fatigue in the rails, which can lead to dangerous cracks if not properly maintained.

Finally, fracture is a sudden break in a material, often caused by a heavy load or by low temperatures making the material brittle. In cold areas of Ghana such as Abetifi in the Eastern Region, steel rods used for building construction can become brittle during very cold nights. If heavy concrete is poured on these rods without proper care, they may suddenly snap. This type of failure shows how a combination of cold temperature and sudden stress can cause a brittle fracture and sudden strong forces or impacts cause fracture.

1. Materials used in construction, transportation, and industry in Ghana may fail in different ways depending on the temperature and stress they are exposed to. Explain how temperature and stress can lead to creep, fatigue, and fracture in materials. For each type of failure, describe a real-life example in Ghana and explain how the environmental conditions contribute to the failure. (20 marks)

Marking Scheme (20 marks total)

Criteria	Marks
Understanding of Creep (definition + mechanism)	3
Relevant Ghana-based example of creep failure	2
Explanation of environmental factors (temperature, stress, etc.) related to creep	2
Understanding of Fatigue (definition + mechanism)	3
Relevant Ghana-based example of fatigue failure	2
Explanation of environmental factors related to fatigue	2
Understanding of Fracture (definition + mechanism)	2
Relevant Ghana-based example of fracture failure	2
Explanation of environmental factors related to fracture	2

Sample Answer

Temperature and stress significantly influence how materials behave and can lead to different types of material failure such as **creep**, **fatigue**, and **fracture**.

Creep is the slow, permanent deformation of a material under constant stress at high temperatures over time. In Ghana, this is often observed in **metal roofing sheets** used in northern regions such as Tamale, where daytime temperatures regularly exceed 35°C. Over time, the metal expands and sags due to the heat and the constant load from its own weight or attached structures. These conditions promote creep, especially when poor-quality aluminium sheets are used.

Fatigue occurs when a material is exposed to **repeated or fluctuating stress**, even if those stresses are below its ultimate tensile strength. A common example in Ghana is the **failure of welded joints in articulated trucks** operating on long-distance routes, such as Accra to Kumasi. Poor road conditions and repeated vibration cycles weaken the joints over time, eventually causing cracking. The constant load-unload cycles, combined with rough terrain, accelerate fatigue failure.

Fracture is the sudden breaking of a material when its strength is exceeded, typically due to a combination of stress concentration and brittleness. In Ghana, **concrete beams or slabs** used in older buildings in Accra or Kumasi can suddenly fracture due to **overloading or poor curing practices** during construction. High humidity levels and improper concrete mix ratios also contribute to internal weaknesses that reduce toughness, making them prone to brittle fracture.

In summary, Ghana's climate (especially high temperatures), poor material quality, and infrastructure conditions increase the likelihood of creep, fatigue, and fracture failures. Understanding these failures helps engineers design safer, more durable structures suitable for the local environment.

SECTION 3: DRAWING PRINCIPLES FOR MANUFACTURING

STRAND: DESIGN AND PROTOTYPING

Sub-Strand: Design and Drawing for Manufacture

Learning Outcome: Understand the representation of materials, machine components, limits, and fits in production drawings

Content Standards

1. *Demonstrate knowledge and understanding of the importance of the representation of materials and machine components in production drawing (Week 9 & 10)*
2. *Demonstrate understanding in Production drawing II. (Week 11 & 12)*

INTRODUCTION AND SECTION SUMMARY

This section of the manufacturing engineering teacher manual provides third-year senior high school learners with an in-depth understanding of production drawings, focusing on conventions, limits, fits, and detailed drawings to ensure precision in manufacturing processes. In Week 9, learners will examine the significance of standardised representations in reducing errors and improving communication, utilising global standards such as ISO, ANSI, and ASME. Week 10 emphasises limits and fits, allowing learners to apply concepts of tolerance, deviation, and allowance, which are crucial for accurate assembly and interchangeability. In Week 11, the course explores detailed drawings, guiding learners to incorporate essential elements like dimensions, tolerances, materials, and finishes while reinforcing principles of quality control. Finally, Week 12 concludes with the creation of a comprehensive part drawing, challenging learners to apply their technical representation skills while ensuring compliance with industry standards. This structured approach equips learners with the ability to produce high-quality, reliable components, thereby fostering efficiency in modern manufacturing engineering.

The weeks and the indicators covered by the section are:

Week 9: Outline the importance of the representation of materials and machine components in production drawing

Week 10: Explain the application of limits and fits in production drawing

Week 11: Explain the application of detailed drawings in production drawings

Week 12: Draw part-drawings of a machine part

Recap weeks

Year 1	**Week 12:** Demonstrate the importance of free hand sketching and visualisation of objects in the design of products

Year 2	**Week 9:** a. Outline the importance of isometric projections in product design b. Explain the application of first-angle orthographic projection in product design

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section provides a structured approach to teaching production drawings, ensuring learners develop the necessary skills for precision in manufacturing. It outlines how teachers should teach, incorporating lectures, discussions, visual aids, and hands-on activities to effectively communicate concepts. Teachers should guide learners through standardised conventions, limits, fits, and detailed drawings, reinforcing their significance in manufacturing processes. Week 9 focuses on materials and components, emphasising standardised representation for accuracy and communication (DOK Level 2). Week 10 covers limits and fits, helping learners understand tolerance applications and ensuring proper assembly through field studies and peer interactions (DOK Level 3). Week 11 introduces detailed drawings, teaching learners to integrate essential specifications using inquiry-based research and comparative analysis (DOK Level 3). Week 12 requires learners to demonstrate their ability to create a complete part drawing, applying their technical knowledge to meet industry standards (DOK Level 3). By the end of this section, learners should know key principles of production drawings, understand their application in manufacturing, and be able to create accurate, reliable technical representations that ensure efficiency in production processes. This approach fosters critical thinking, collaboration, and technical proficiency, preparing learners for real-world engineering challenges.

ASSESSMENT SUMMARY

The section assessment is designed to align with the highest Depth of Knowledge (DOK) level for each indicator, emphasising practical application and critical thinking in production drawing. During Week 9, the focus is on collaborative learning through discussions and exhibitions that emphasise material representation (DOK Level 2). In Week 10, learners engage in assembly exercises, field studies, and peer interactions to explore limits and fits (DOK Level 3). Week 11 reinforces the application of detailed drawing techniques through inquiry-based research, comparative analysis, and design reviews (DOK Level 3). Finally, Week 12 culminates in a hands-on drawing assignment, where learners are tasked with creating a technical drawing of a machine component (DOK Level 3). These assessments are structured to ensure that learners not only grasp fundamental concepts but also develop crucial engineering skills. Table 5 shows a summary for the assessment used in Section 3.

Table 5 Assessment summary for Section 3

Indicators	DOK Level	Assessment Strategy and/or Mode
Outline the importance of the representation of materials and machine components in production drawing	4	1. Educational trip 2. Paired talk 3. Classroom discussion 4. Group project exhibition

Explain the application of limits and fits in production drawing	4	1. Individual work 2. Assembly exercise 3. Field-based studies 4. Peer-to-peer discussion 5. Group projects 6. Individual projects
Explain the application of detailed drawings in production drawings	4	1. Inquiry-Based Presentation 2. Research Report / Article Review 3. Comparative Analysis 4. Hands-on Drawing Task 5. Design Review
Make part drawing of a machine component	4	1. Practice Paper 1 2. Hands-On Drawing Task

WEEK 9

Learning Indicator: Outline the importance of the representation of materials and machine components in production drawing

Focal Area: Importance of conventions of materials and machine components in production drawing

9.1 Introduction

(Refer back to Year 1, Section 3, Week 9 Demonstrate the use of drawing instruments in product design; Year 2, Section 3, Week 9 Outline the importance of isometric projections in product design, Explain the application of first angle orthographic projection in product design; Year 2, Section 3, Week 10 Outline the importance of sectioning, dimensioning, and tolerance of geometric objects)

Production drawings are critical technical documents that provide detailed specifications, dimensions, and assembly instructions essential for manufacturing processes. They bridge the gap between conceptual design and practical execution, ensuring precision, consistency, and efficiency. As a universal language, production drawings facilitate seamless communication among engineers, designers, and manufacturers, transforming complex ideas into actionable plans while aligning teams towards a common goal. The conventions in production drawings, particularly in the representation of materials and machine components, play a vital role in maintaining clarity and reducing ambiguities. Proper representation ensures all stakeholders have a clear understanding of the components, minimising errors in interpretation and execution. Furthermore, the adoption of standardised conventions, such as those established by international organisations like ISO, ANSI, and ASME, has globalised the language of production drawings, enabling collaboration across diverse teams and geographical boundaries. These standards not only harmonise design practices but also enhance manufacturing efficiency by reducing the need for repeated clarifications and mitigating the risk of rework. Accurate representations expedite production planning and execution, saving time and resources while ensuring the final output meets specifications. Hence, conventions in production drawings are indispensable for fostering clarity, standardisation, and efficiency, ultimately supporting the streamlined operations of modern manufacturing engineering.

9.2 Conventions of materials in production drawing

The conventions surrounding materials in production drawing play a vital role in manufacturing engineering, guiding the selection and application of various materials, including metals, glass, wood, concrete, and more. A solid understanding of these conventions ensures that the chosen materials align with performance, reliability, and cost requirements, all of which are critical for the success of a product. The subsequent sections will delve into the key aspects of material conventions in production drawing.

9.3 Material Properties and Selection

In manufacturing engineering, conventions of materials in production drawing are standardised symbols and notations used to represent various materials clearly and accurately. These conventions ensure effective communication among engineers, manufacturers, and stakeholders

by minimising errors and misunderstandings. Details, such as hardness, tensile strength, and surface finish, are represented in production drawings. These factors are often communicated through standardised annotations, symbols, and notes that conform to international standards like ISO, ANSI, and ASME. For instance, hardness may be indicated using specific notations, while tensile strength values can be included alongside material symbols or in supplementary technical notes. Surface finish details are typically represented through graphical symbols or callouts that specify roughness levels and finishing processes. These details ensure that all stakeholders, from engineers to machinists, have a comprehensive understanding of the material and component requirements, enhancing precision and quality in manufacturing processes. Here are the conventions for some common materials:

1. **Metals:** Metals are typically represented in production drawings by specific symbols and standard notations. For instance, steel might be denoted by an "S" followed by its grade, and aluminium by "Al." The conventions reflect the material's properties like thermal and electrical conductivity, strength, and malleability, often adhering to standards like ASTM or ISO.
2. **Glass:** Glass is represented by its type (e.g., annealed, tempered) and thickness. Conventions include symbols that denote their transparency and strength, vital for applications like windows and facades.
3. **Wood:** In drawings, wood is typically represented by its species, grade, and moisture content. Symbols reflect the grain direction and structural properties, ensuring the correct application of wood in construction.
4. **Concrete:** Concrete is depicted by its mix design, strength class, and reinforcement details. Conventions ensure the concrete meets structural and durability requirements, often guided by standards from bodies like the American Concrete Institute.
5. **Liquids:** Liquids such as water, oils, and chemicals are represented by symbols indicating their flow rate and material compatibility. These are crucial for systems involving fluid flow, such as piping and storage tanks.
6. **Packing and Insulating Materials:** These materials are represented by their type, thickness, and thermal conductivity. Symbols ensure they are accurately depicted in drawings to meet energy efficiency and insulation requirements.

9.4 Material Symbols and Notations

In production drawings, material symbols and notations serve as vital communicative tools that ensure clarity and precision in manufacturing processes. These standardised symbols are used to represent various materials, such as steel, aluminium, plastic, and composites, offering a universal language for engineers, designers, and manufacturers across global teams. The symbols are meticulously designed to avoid ambiguity, thereby simplifying the interpretation of design specifications. Additionally, these notations frequently include supplementary information, such as material grades or classifications, to further clarify requirements. Placement of these symbols on drawings is deliberate and consistent, following internationally recognised standards such as those established by ISO, ANSI, and ASME. By adhering to these conventions, material specifications are seamlessly integrated into technical documentation, ensuring accuracy and uniformity in production planning and execution. The use of material symbols and notations thereby plays a critical role in bridging communication gaps, fostering collaboration, and safeguarding the integrity of engineering and manufacturing processes. Figure 27 shows the conventional symbols of some selected materials.

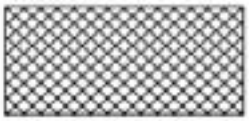
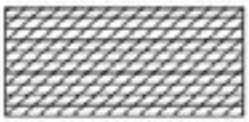
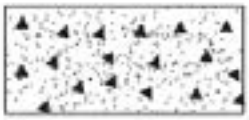
Type	Convention	Material
Metals		Steel, Cast Iron, Copper and its Alloys, Aluminium and its Alloys, etc.
		Lead, Zinc, Tin, White-metal, etc.
Glass		Glass
Packing and Insulating material		Porcelain, Stoneware, Marble, Slate, etc.
		Asbestos, Fibre, Felt, Synthetic resin products, Paper, Cork, Linoleum, Rubber, Leather, Wax, Insulating and Filling materials, etc.
Liquids		Water, Oil, Petrol, Kerosene, etc.
Wood		Wood, Plywood, etc.
Concrete		A mixture of Cement, Sand and Gravel

Figure 27: *Conventional representation of materials (Narayana et al., 2009)*

9.5 Conventions of components in production drawing

Components in production drawings are represented using standardised symbols to ensure clear communication and accurate manufacturing as shown in Figure 28, 29 and 30. These symbols help in identifying the function and placement of various components within a design. Conventions of components in production drawing are standardised symbols, notations, and graphical representations used to depict various machine components. These conventions are crucial for ensuring clear communication and understanding among engineers, technicians, and manufacturers, thereby minimising errors and facilitating efficient production processes.

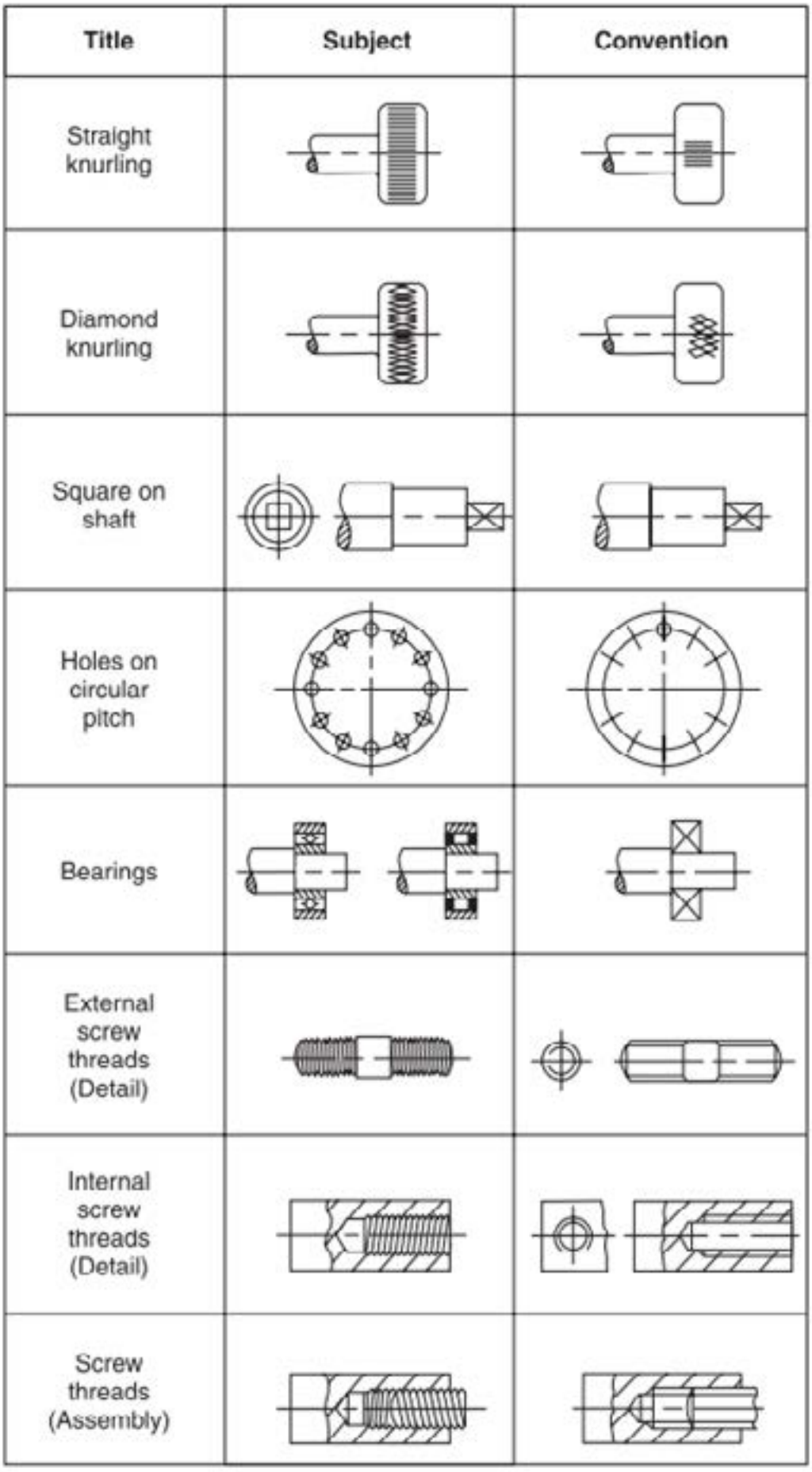


Figure 28: *Conventional representation of machine components (Narayana et al., 2009)*

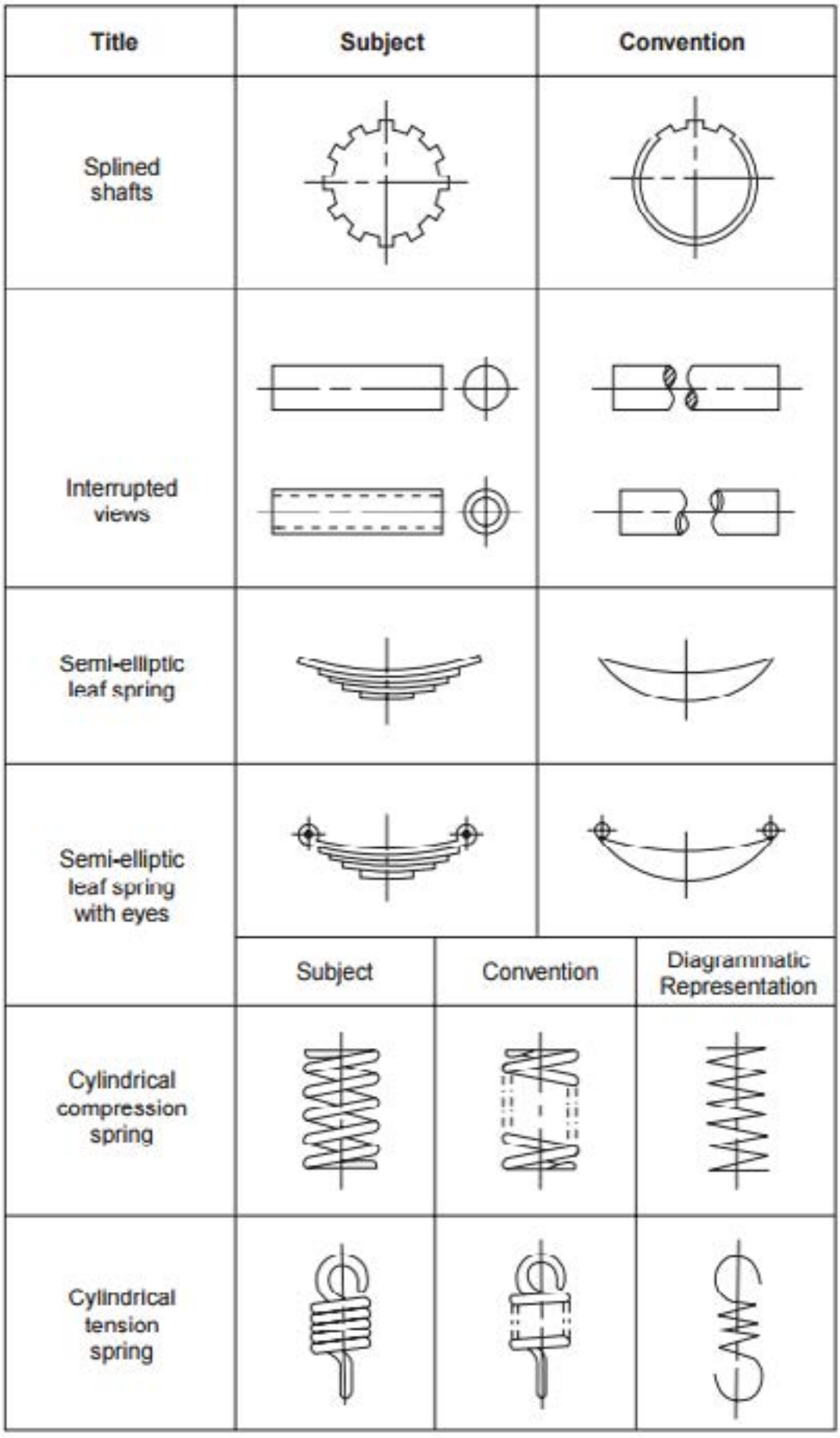


Figure 29: *Conventional representation of machine components (Narayana et al., 2009)*

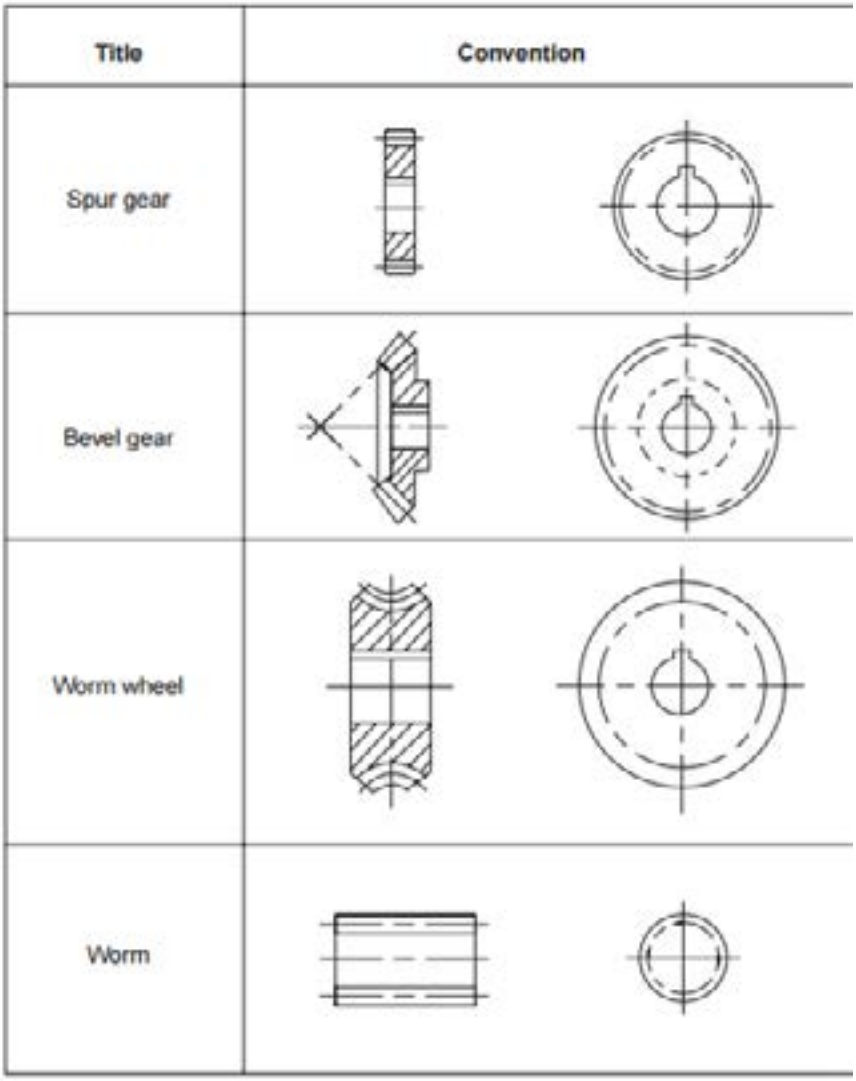


Figure 30: *Conventional representation of machine components (Narayana et al., 2009)*

9.6 Standardised Views and Sections

Standardised views and sections are integral to the accurate depiction of machine components in production drawings, ensuring a comprehensive understanding of complex geometries and internal structures. These representations, often based on conventions established by international standards such as ISO, ANSI, and ASME, include orthographic projections, sectional views, and exploded views. Orthographic projections provide multiple perspectives of a component, such as front, top, and side views, facilitating precise interpretations of its dimensions and features. Sectional views, on the other hand, reveal internal details by slicing through the component, which is particularly useful for illustrating hidden features like cavities, channels, or assembly interfaces. Exploded views further enhance clarity by visually separating a component's parts to showcase their arrangement, connections, and assembly sequence. By employing these standardised techniques, production drawings achieve clarity, precision, and consistency, enabling seamless communication and collaboration among engineers, designers, and manufacturers.

9.7 Dimensioning and Tolerances

Dimensioning and tolerances form the backbone of precision in machine component drawings, enabling the accurate representation of dimensions, fits, and allowable variances that dictate

the manufacturability and functionality of components. These specifications ensure compatibility between parts and adherence to design intent, reducing the margin for error during production. The integration of Geometric Dimensioning and Tolerancing (GD&T), a system defined by international standards such as ISO and ASME, further refines the depiction of complex geometries. GD&T provides a concise framework for specifying permissible variations in size, shape, orientation, and positional relationships of features, facilitating consistent interpretation across global teams. By employing standardised dimensioning practices and tolerances, engineers and manufacturers achieve not only enhanced quality and reliability but also streamlined communication and collaboration, ensuring that design requirements are met with precision.

9.8 Annotations and Callouts

Annotations and callouts play a pivotal role in the precision and clarity of production drawings, especially when representing additional details such as surface finish, welding specifications, or assembly instructions. By providing concise and standardised information, they bridge the gap between design intent and practical implementation, ensuring that critical details are accessible to engineers, machinists, and manufacturers. For instance, surface finish annotations use graphical symbols to denote roughness levels and finishing techniques, while callouts for welding highlight joint types and processes required for adherence to structural integrity. Assembly instructions can be conveyed through numbered callouts that indicate the sequence of operations or the alignment of components. These elements collectively enhance the interpretability of complex drawings, adhering to international standards like ISO and ASME, and fostering uniformity and collaboration across global engineering teams. Examples of conventions for representing machine components include

a. **Shafts**: In production drawings, shafts are often represented by circles or rectangles in cross-sectional views, with annotations indicating dimensions, tolerances, and surface finishes. The conventions ensure that the shaft's design meets the functional requirements and fits correctly with other components.

b. **Pitches**: Pitch refers to the distance between threads in screws or gears, and it is typically represented in production drawings through precise dimensioning and annotations. Understanding pitch is essential for ensuring that threaded components fit together correctly.

c. **Bearings**: Bearings are depicted in production drawings with specific symbols that indicate their type and size, such as ball or roller bearings. These symbols help in identifying the bearing's function and ensuring proper alignment and support in the assembly.

d. **Screw Threads**: Screw threads are represented using standardised thread symbols, which specify the thread type, size, and direction (e.g., right-hand or left-hand threads). This ensures that mating parts are compatible and function as intended.

e. **Springs**: Springs are depicted with symbols that indicate their type (e.g., compression, tension) and characteristics (e.g., coil diameter, wire diameter). Accurate representation of springs is crucial for maintaining the desired mechanical properties and performance.

f. **Gears**: Gears are represented with specific symbols indicating their type (e.g., spur, helical) and attributes such as module, number of teeth, and pressure angle. These conventions ensure that gears mesh correctly and transmit power efficiently.

These conventions are guided by technical standards like those from the International Organisation for Standardisation (ISO) and the American Society for Testing and Materials

(ASTM), ensuring consistency and accuracy in production drawings across the industry. By adhering to these conventions, manufacturers can ensure that components interact seamlessly, reducing the risk of errors and enhancing the overall efficiency of the manufacturing process.

Notes for Facilitators

1. **Clarifying Concepts:** Explain that production drawings are like a recipe for making a part. If the recipe uses confusing symbols or is unclear, the cook (machinist) will make mistakes. Standardised symbols are the universal language that ensures every engineer, regardless of where they trained, understands the recipe.
2. **Common Misconceptions:** Students may think it is easier to just write wood than to use a hatching pattern. Explain that in a complex drawing with many parts, a standardised hatching pattern for steel (diagonal lines) is immediately recognisable, while a written note can be missed or get lost in a crowded drawing.
3. **Low-Cost Demonstrations and Ghanaian Examples**
    a. Symbol Recognition: Give students a simple drawing with a few materials (steel, wood, concrete). Have them identify the material based on the hatching patterns shown in Figure 9.1. This is a simple and effective exercise.
    b. Importance in Industry: Discuss a local scenario: An engineering team in Accra designs a part for a vehicle assembly plant in Tema. If they do not use standardised symbols, the machinists in Tema could misinterpret the drawing, leading to costly errors and delays. This highlights the importance of a shared standard.

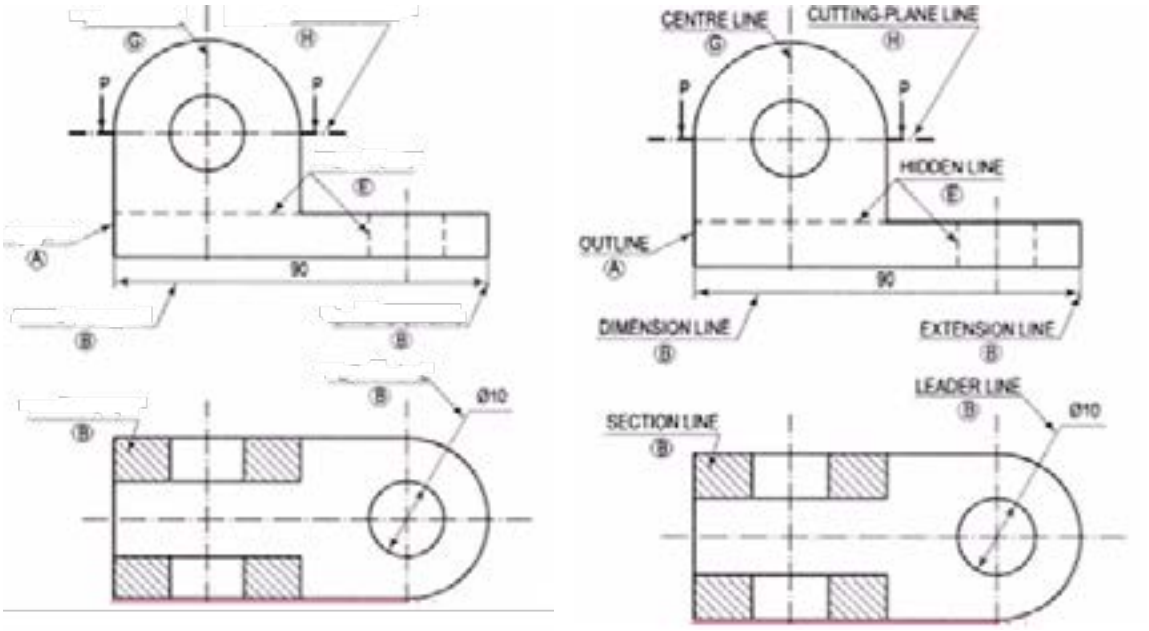
Learning tasks

1. Review conventions learned in Form 1 and 2 (e.g., line types, sectioning, simple component symbols). Learners match drawing symbols to materials and components they studied in previous years. For example, diagonal parallel lines for steel; crossed diagonal lines for cast iron; random dots for rubber/cork; wavy lines for wood endgrain; concentric semicircles for wood longgrain; two concentric circles with centreline for shaft; rectangle with crossed diagonals for bearing; zigzag line for spring; parallel lines with short dashes for screw thread; rectangle with vertical lines for gear; circle with cross for centre of hole; thick dashed line with arrows for cutting plane.
2. Recognise standard graphical conventions used to represent materials and components. Learners observe a real or simulated production drawing and identify symbols representing metals, glass, wood, bearings, shafts, gears, springs, etc.
3. Understand the role of standardised representation in communication and accuracy in engineering drawings. Learners engage in a class discussion or debate on how conventions help prevent manufacturing errors and ensure universal understanding.
4. Demonstrate ability to accurately sketch standard conventions used in production drawings. Learners work in pairs to draw standardised symbols for materials and components.
5. Each learner demonstrates independent understanding of material failure, assessing depth of understanding and ability to apply concepts.

Pedagogical Exemplars

1. **Talk for Learning**

Provide a simplified technical drawing from Form 1 work, containing lines and shapes (Find sample drawing shown in Fig. 31. Ask learners to label types of lines (e.g., hidden, centre, cutting plane), and recall standard representations of materials like wood, concrete, and steel.



(a) Unlabelled drawing (b) Labelled drawing

Figure 31 Sample (a) Unlabelled and (b) labelled drawing

2. **Research-Based Learning:** Bring a printed mechanical part drawing to class. Guide learners in groups to identify and label materials and component symbols using an annotation sheet
3. **Experiential Learning:** Bring a typical production drawing to class and lead learners to identify conventions of materials and machine components used in the production drawing (such as representations for metals, glass, packing and insulating materials, wood, concrete, liquids, shafts, pitch, bearings, screw threads, springs, and gears).
4. **Talk for Learning:** Lead learners to discuss the importance of representing materials and machine components in production drawing.
5. **Collaborative Learning:** Individual learners practice the drawing of the conventions in representing material and machine components in a production drawing. Learners share drawing and received comments in a tolerant manner.
6. **Talk for Learning:** Divide learners into groups to answer: *"What could go wrong if a production drawing used no standardised symbols or conventions?"* Groups present short arguments.
7. **Collaborative drawing activities.**

   Using chalkboard examples and textbooks, demonstrate how to draw conventions for a **shaft, bearing, spring, steel section, concrete, and insulation material**. Learners copy and label on drawing sheets.

Each learner receives a structured written assessment with questions on the learning indicator. After completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback.

Key Assessment Level 4: Educational Trip & Exhibition

1. Evaluate how the identification and representation of a shaft in a mechanical component drawing affect the manufacturing and assembly process. In your response:
    a. Analyse the visual symbols and features typically used to represent a shaft in technical drawings.
    b. Discuss how misinterpreting this representation could lead to production or assembly errors.
    c. Propose strategies to ensure accurate communication of shaft features in engineering documentation. (10 marks)
2. In a small-scale fabrication workshop producing machine housings for a food processing unit, a major delay occurred because the part drawings lacked proper use of sectional views and centrelines. As a result, two internal features—intended to accommodate shaft bearings—were misaligned by 5 mm during CNC machining. 20 unusable units were produced before the error was identified.

    Evaluate this manufacturing failure or near-miss that occurred due to the lack of standard drawing conventions. Identify two specific consequences that resulted from this oversight. Then, propose engineering or procedural solutions that could prevent similar issues in future production environments. (10 marks)
3. Discuss the significance of using crosshatching to represent different materials in production drawings. (14 marks)

PLC Session 9

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is educational trip & exhibition. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessments (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
   a. transfer your chats into your learning planner template.
   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 10

Learning Indicator: Explain the application of limits and fits in production drawing

Focal Area: Applications of limits and fits in production drawing

10.1 Introduction

(Refer to Year 1, Section 3, Week 9 Demonstrate the use of drawing instruments in product design; Year 2, Section 3, Week 9 Outline the importance of isometric projections in product design, Explain the application of first angle orthographic projection in product design; Year 2, Section 3, Week 10 Outline the importance of sectioning, dimensioning, and tolerance of geometric objects)

Limits and fits are fundamental concepts in engineering drawings that define the acceptable variations in the dimensions of manufactured parts. They ensure that components fit together properly and function correctly. Limits specify the maximum and minimum sizes of a feature, while fits describe the dimensional relationship between two parts, such as a shaft and a hole. Understanding limits and fits is vital for achieving precision, minimising manufacturing errors, and ensuring the interchangeability of parts. These concepts are particularly important in production drawings, which guide the precise manufacturing and assembly of mechanical components. Limits outline the permissible range of variation in a component's dimensions, allowing parts to fit together accurately despite minor manufacturing deviations. Fits categorise the relationships between mating parts into three types: clearance, interference, and transition fits. These classifications help reduce errors and misunderstandings during the manufacturing process, thereby improving production efficiency and minimising waste. By specifying dimensional tolerances, limits and fits enhance the interchangeability of parts, which is crucial in precision-driven industries like automotive and aerospace. Additionally, limits and fits aid in the selection of appropriate materials to meet performance and safety standards. In summary, they ensure the accurate representation of components in production drawings, contributing to effective communication, quality control, and overall manufacturing success.

10.2 Limits

Limits refer to the maximum and minimum permissible sizes of a feature, defining the range within which the actual size must lie. They are specified as upper and lower bounds to ensure that parts fit together correctly and function as intended. Understanding limits and fits is essential for ensuring the functionality, interchangeability, and efficiency of mechanical assemblies. They help minimise material waste and manufacturing costs by providing clear guidelines for acceptable variations in part dimensions. Limits indicate the maximum and minimum sizes a feature can have, which is crucial for maintaining the functionality and reliability of mechanical assemblies. Typically, limits are expressed in terms of upper and lower bounds, often referred to as upper and lower deviations, respectively. The application of limits in production drawings is essential for several reasons. Firstly, they ensure that components fit together and function as intended, even when slight variations occur during the manufacturing process. This is particularly important in mass production, where the interchangeability of parts is crucial. By adhering to specified limits, manufacturers can produce components that meet performance criteria without excessive rework or adjustments.

Additionally, limits play a vital role in quality control, helping to minimise material waste and reduce production costs. By clearly defining the acceptable range of dimensions, limits allow for efficient inspection processes, ensuring that only components that meet the specified criteria are approved for assembly. This enhances the overall quality of the final product and contributes to sustainable manufacturing practices by reducing waste and optimising resource use. In practice, evaluating limits involves determining the appropriate fit based on the functional requirements of the assembly, selecting the right type of shaft and hole, and choosing the correct tolerance grade. This systematic approach ensures that each component is manufactured to precise specifications, facilitating seamless integration into larger assemblies. Ultimately, understanding and correctly applying limits in production drawings is a fundamental skill in manufacturing engineering, supporting the production of high-quality, reliable, and cost-effective products.

The method shown in Figure 32 is perhaps the clearest way of expressing limits of size on a drawing, since the upper and lower limits are quoted, and the machine operator is not involved in mental arithmetic. The dimensions are quoted in logical form, with the upper limit above the lower limit and both to the same number of decimal places

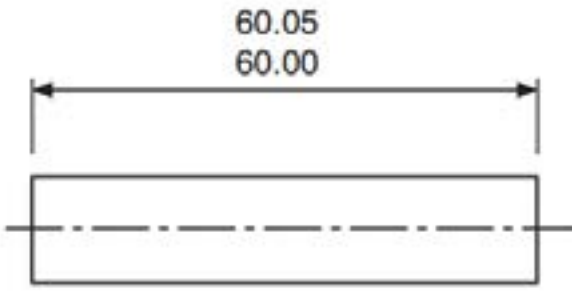


Figure 32: *Limit of size on a drawing (Narayana et al., 2009)*

As an alternative to the method above, the basic size may be quoted and the tolerance limits added as in Figure 33. It is not necessary to express the nominal dimension to the same number of decimal places as the limits. Fits can be taken directly from those tabulated in BS 4500, 'ISO limits and fits', and to indicate the grade of fit, the following alternative methods of dimensioning a hole may be used:

$90\ H7\ \begin{pmatrix} 90.035 \\ 90.00 \end{pmatrix}$ (first choice)

or *90 H7* or $90\ H7\ \begin{pmatrix} +0.035 \\ 0 \end{pmatrix}$

Similarly, a shaft may be dimensioned as follows:

$90\ g6\ \begin{pmatrix} 89.988 \\ 89.966 \end{pmatrix}$ (first choice)

or *90 g6* or $90\ g6\ \begin{pmatrix} -0.012 \\ -0.034 \end{pmatrix}$

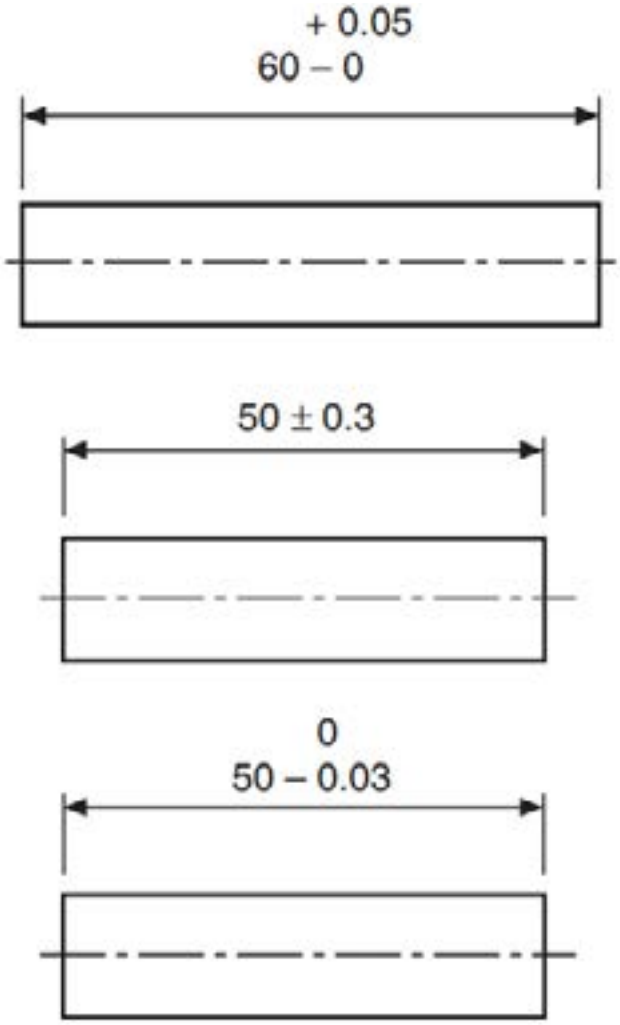
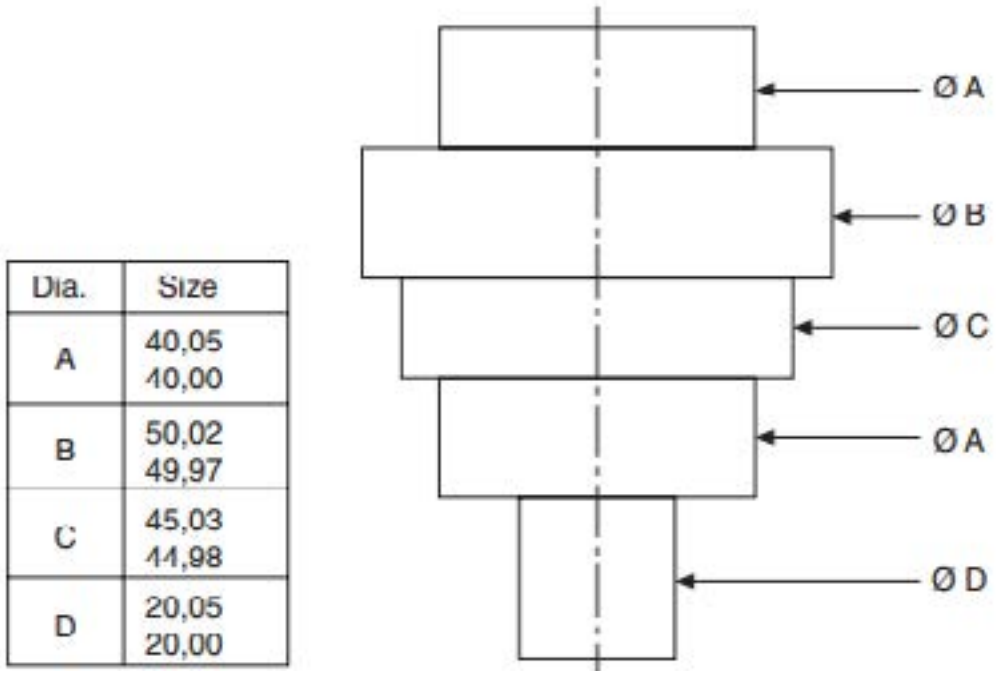


Figure 33: *Dimension shaft (Narayana et al., 2009)*

In cases where a large amount of repetition is involved, information can be given in tabulated form, and a typical component drawing is shown in the Figure. 34.



Dia.	Size
A	40,05 40,00
B	50,02 49,97
C	45,03 44,98
D	20,05 20,00

Figure 34: *Dimension of stepped shaft (Narayana et al., 2009)*

10.3 Fits

Fits describe the relationship between two mating parts, such as a hole and a shaft. They determine the degree of tightness or looseness between the parts. Fits are classified into three main categories: clearance fits, interference fits, and transition fits. Each category serves different functional requirements. Fits are a critical aspect of production drawings that describe how two mating parts, such as a shaft and a hole, relate to each other dimensionally. Fits are classified into three main categories: clearance, interference, and transition fits, each serving a specific purpose in ensuring the correct function of assemblies.

10.3.1 Types of fits

a. **Clearance Fit:** This type of fit provides a space or clearance between the mating parts, allowing for easy assembly and disassembly. It is often used in applications where movement between parts is necessary, such as in rotating shafts or sliding components. A clearance fit (Figure 35), in which the shaft is always smaller than the hole into which it fits.

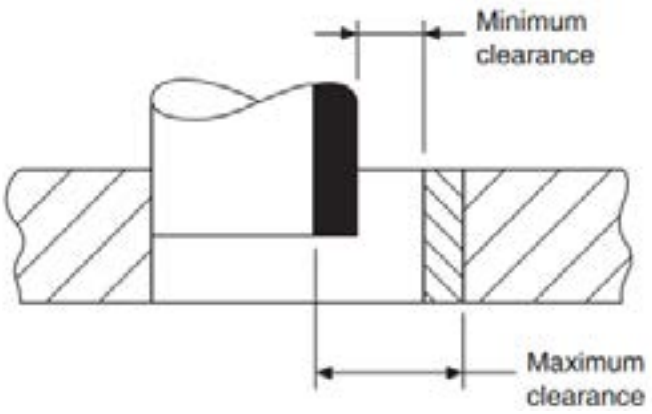


Figure 35: *Clearance fits e allowance always positive (Narayana et al., 2009)*

b. **Interference Fit:** In this fit, the parts are designed to overlap, creating a tight connection that requires force for assembly. Interference fits are used where a secure, non-movable connection is needed, such as in gears pressed onto shafts. An interference fit (Figure 36), in which the shaft is always bigger than the hole into which it fits.

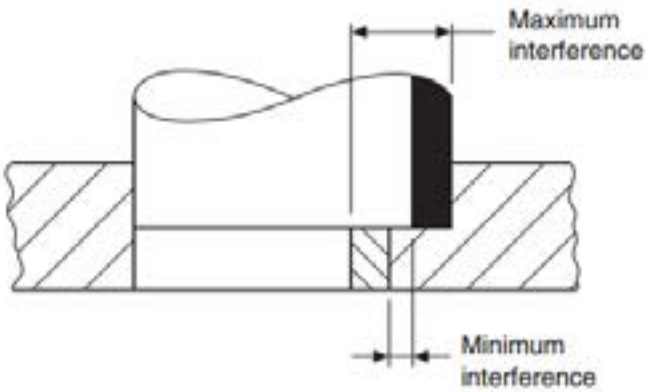


Figure 36: *Interference fits - allowance always negative (Narayana et al., 2009)*

c. **Transition Fit:** This fit is between clearance and interference, allowing for either a slight clearance or interference. It is used in applications where precise alignment is crucial, yet some degree of movement is acceptable. A transition fit (Figure 37), in which the shaft may be either bigger or smaller than the hole into which it fits e it will therefore be possible to get interference, or clearance fits in one group of assemblies.

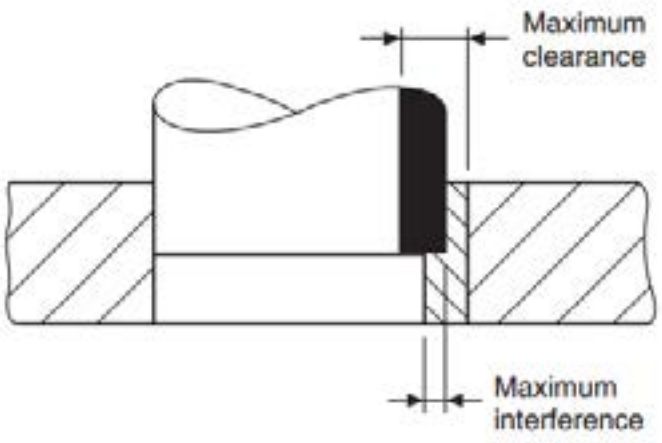


Figure 37: *Transition fit - allowance may be positive or negative (Narayana et al., 2009)*

The application of fits in production drawings is crucial for several reasons. Firstly, it ensures the proper assembly and operation of mechanical components by specifying the permissible dimensional variations, allowing engineers to control the interaction between parts and influencing factors like friction, wear, and load distribution. Moreover, fits facilitate the interchangeability of parts, which is essential in mass production and repair scenarios; by adhering to standardised fit classifications, manufacturers can ensure that components from different batches or suppliers will fit together seamlessly, enhancing efficiency and reducing costs. In practice, selecting the appropriate fit involves considering the functional requirements of the assembly, the materials used, and the expected operating conditions. Engineers use standard tables and charts to determine the suitable fit type and tolerance grades, ensuring that the final product meets the design specifications and performance criteria. Ultimately, understanding and applying fits in production drawings is vital for achieving precision, reliability, and efficiency in manufacturing processes, supporting the development of high-quality mechanical assemblies.

10.4 Elements of Interchangeable Systems

Interchangeable systems are essential in manufacturing engineering, allowing for the efficient assembly and function of mechanical components across various applications. These systems rely on key measurements such as nominal size, actual size, basic size, and limits of size. Nominal size is a convenient designation (e.g., thread diameters of 25, 50, or 60 mm), while actual size reflects the measured dimensions as shown in Figure 38. Basic size serves as a reference for size limits, ensuring compatibility between parts. Limits of size outline acceptable dimensional variations for achieving various fits (clearance, interference, or transition) without sacrificing performance. By grasping these concepts, engineers can design systems that enhance interchangeability, reduce costs, and improve production efficiency, crucial for mass production and repair scenarios. This precision not only ensures reliable mechanical assemblies but also fosters innovative manufacturing solutions. The list and definitions of the elements of interchangeable systems are presented in Table 6.

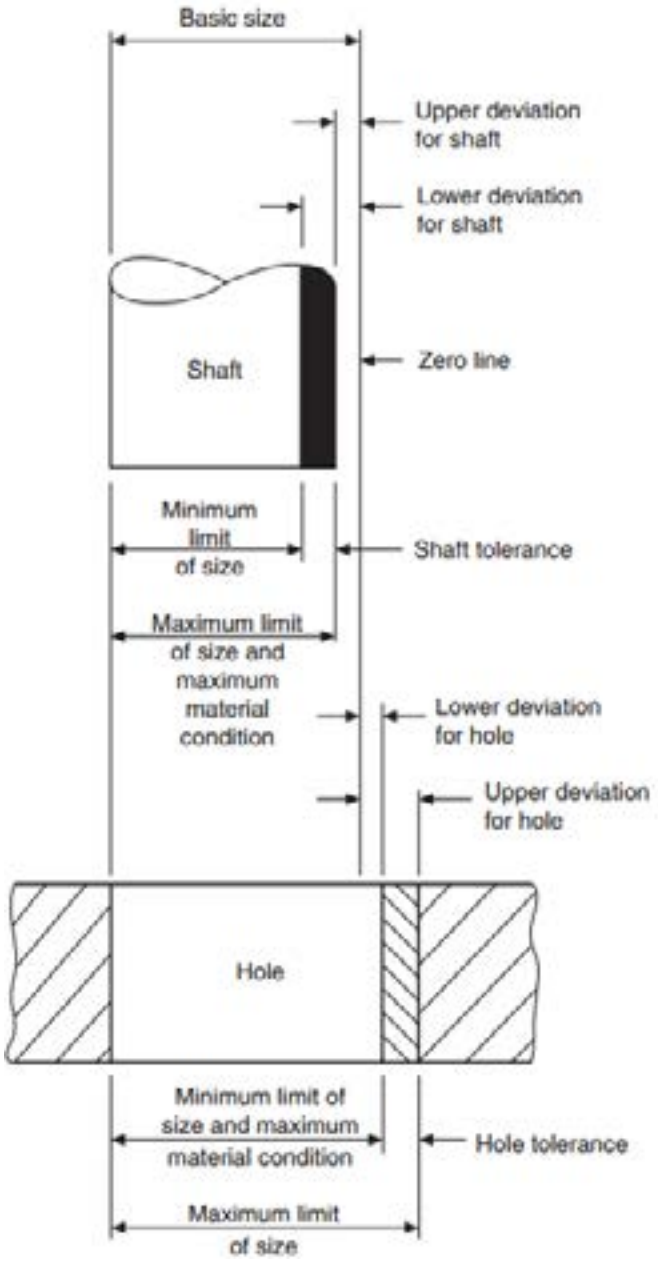


Figure 38: *Elements of interchangeable systems (Narayana et al., 2009)*

Table 6 Elements of interchangeable systems

Term	Definition
1. Nominal size	Convenient size designation of a component, such as 25, 50, or 60 mm thread
2. Actual size	Measured size of a component
3. Basic size	Reference size upon which all limits of size are based, the same for both male and female parts in a fit
4. Limits of size	Maximum and minimum permissible sizes for a specific dimension
5. Tolerance	Total permissible variation in the size of a dimension, the difference between the upper and lower acceptable dimensions
6. Allowance	The difference between the high limit of size of the shaft and the low limit of size of its mating hole can be positive or negative

7. Grade	Indicates the magnitude of tolerance; a lower grade signifies finer tolerance
8. Deviation	Difference between the maximum, minimum, or actual size of a shaft or hole and the basic size
9. Maximum Material Condition (MMC)	Represents the maximum limit of an external feature, such as a shaft produced to its high limits, containing the maximum amount of material. Also refers to the minimum limit on an internal feature, like a hole produced to its lower limit, retaining maximum metal condition
10. Minimum or Least Material Condition (LMC)	Denotes the minimum limit of an external feature, such as a shaft produced to its low limits, containing the minimum amount of material. Also applies to the maximum limit on an internal feature, like a hole produced to its maximum limit, having the maximum amount of material removed, resulting in a minimum material condition

Notes for Facilitators

1. **Clarifying Concepts:** Use a simple analogy: Clearance fit is like a door sliding in its frame (easy movement). Interference Fit is like a rubber stopper being forced into a glass bottle (tight, no movement). Transition fit is like a push-fit plastic cap on a bottle; it›s not loose, but it can be removed with some effort.
2. **Common Misconceptions:** Students confuse «tolerance» and «allowance.» Clarify: Tolerance is the acceptable variation in the size of a single part (e.g., the shaft can be 24.97–25.03 mm). Allowance is the intended difference between the sizes of two mating parts (e.g., the smallest hole is 0.02 mm bigger than the largest shaft).
3. **Low-Cost Demonstrations and Ghanaian Examples**
   a. **Real-World Parts:** Bring in a common Ghanaian product, like a bicycle. Show the relationship between the wheel axle (shaft) and its bearing (hole). Is it a clearance fit (allowing rotation) or an interference fit (pressed into the frame)? Discuss which fit is used where and why.
   b. **Hole Basis vs. Shaft Basis:** Explain that in most manufacturing, it›s cheaper to produce holes with a standard drill bit (hole basis) and then precisely machine the shafts to fit. This is like having a set of standard-sized jars (holes) and making custom lids (shafts) to fit them.

Learning tasks

1. Learners will examine a typical production drawing to identify the use of limits and fits, including tolerance, deviation, and allowance.
2. In mixed-ability groups, learners will research the application of limit systems, such as tolerance, limits, deviation, and allowance, in production drawings and present their findings.
3. Lead a discussion on zone lines, standard tolerances, rules for dimensioning tolerances, hole basis, and shaft basis for fits, selection of fits, limit gauges, machining symbols, and roughness indicators.

4. Learners will practice evaluating limits and tolerances for a component by selecting appropriate fits, determining shaft and hole types, selecting tolerance grades, and evaluating standard tolerances.
5. Each learner demonstrates independent understanding on material failure, assessing depth of understanding and ability to apply concepts.

Pedagogical Exemplars

1. **Experiential Learning:** By examining real production drawings, learners gain practical experience identifying and understanding how limits and fits are applied in real-world engineering contexts.
2. **Collaborative drawing activities:** Learners work in mixed ability groups to research and discuss the application of limit systems, (such as tolerance, limits, deviation, actual deviation, upper deviation, lower deviation, and allowance) as used in production drawings, and share their findings with the class, enhancing their understanding through shared knowledge and teamwork
3. **Talk for Learning:** Engaging in discussions helps learners articulate their understanding of key concepts related to limits and fits, fostering deeper comprehension through dialogue and interaction.
4. **Practical Based Learning:** Learners apply their knowledge by practicing the evaluation of limits and tolerances for a component according to the following steps: selection of appropriate fit based on the functional requirement, selection of the type of shaft and hole, selection of tolerance grade for shaft and hole, evaluation of standard tolerance and evaluation of limits and tolerance, reinforcing their skills through hands-on exercises and real-world problem-solving.

    a. Each learner receives a structured written assessment questions on the learning indicator After completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback.

Key Assessment Level Peer Discussion

1. A machined part is designed with a diameter of 60.00 mm ± 0.03 mm. During inspection, the diameter is measured as 60.05 mm.

    Analyse this situation and explain:

    a. What conclusion the inspector should draw based on the tolerance limits?

    b. What the implications of accepting or rejecting the part might be for functionality and quality?

    c. What steps could be taken in the manufacturing process to prevent this issue from recurring? (10 marks)

2. A shaft is designed as 25.00 mm ± 0.03 mm, and the corresponding hole is 25.08 mm ± 0.02 mm.

    Analyse and explain:

    a. How to calculate the maximum and minimum clearances between the shaft and the hole.

b. What the calculated clearances imply about the type of fit and its function in a mechanical assembly.

c. How tolerances support both interchangeability and performance in production. (10 marks)

3. Explain the importance of tolerances and fits in manufacturing. Discuss how they influence the functionality and assembly of components**.** (16 marks)

PLC Session 10

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

   a. explain the week's concepts in a practical way that will make it easier for learners to understand

   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

   a. The key assessment for the week is peer discussion. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the discussion (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 11

Learning Indicator: Explain the application of detailed drawings in production drawings

Focal Area: Application of detailed drawing in production drawing

11.1 Introduction

(Refer back to Year 1, Section 3, Week 9 Demonstrate the use of drawing instruments in product design; Year 2, Section 3, Week 9 Outline the importance of isometric projections in product design, Explain the application of first angle orthographic projection in product design; Year 2, Section 3, Week 10 Outline the importance of sectioning, dimensioning, and tolerance of geometric objects; Year 2, Section 3, Week 11 Explain the application of detailed and assembly drawings in product design and modelling, Year 2, Section 3, Week 12 Explain the application of detailed and assembly drawings in product design and modelling)

Production drawings are detailed graphical representations that provide comprehensive technical information necessary for the manufacturing of components or assemblies. They include precise specifications for dimensions, materials, tolerances, and finishes, ensuring that the final product meets design requirements. Serving as blueprints for manufacturers, these drawings eliminate ambiguity, facilitating consistent interpretation and execution across teams and facilities. They play a crucial role in ensuring clear communication among designers, engineers, and manufacturers, thereby minimising errors and misunderstandings while supporting quality control to maintain the integrity of the design throughout the manufacturing process. By specifying dimensions, tolerances, and material properties, production drawings ensure the standardisation and interchangeability of parts, which are essential for mass production and global supply chains. Furthermore, they enable efficient planning and resource allocation, contributing to waste reduction and optimised production costs. As indispensable tools, production drawings bridge the gap between engineering design and practical implementation, translating design concepts into tangible products with precision, consistency, and efficiency. Ultimately, they support the successful realisation of complex projects and innovations.

11.2 Application of detailed drawing in production drawing

Detailed drawings are applied in production drawings to convey precise manufacturing instructions. They include dimensions, tolerances, materials, finishes, and title blocks, ensuring that each component is manufactured to exact specifications. Detailed drawings are essential for quality control, reducing errors, and ensuring that the final product meets design requirements.

Notes to Facilitator

1. **Clarifying Concepts:** Explain that a detail drawing is the «identity card» for a single component. It contains everything needed to make that component: its shape (views), its size (dimensions), its allowed error (tolerances), what it is made of (material), and how its surface should be finished.

2. **Common Misconceptions:** Students often treat the title block as an afterthought. Emphasise that the title block is the most important part. It contains the part number, which is the name of the part. In a factory, nothing gets ordered or manufactured without a correct part number and material specification.
3. **Low-Cost Demonstrations and Ghanaian Examples**
    a. Integration: Use a real product, like a plastic chair. Find a simple bracket that holds the legs together. Show a detail drawing of that bracket. Then, show an assembly drawing of the chair frame, pointing out where that specific bracket fits. This demonstrates the connection between a detail drawing and the final product.
    b. Troubleshooting: When students create their own drawings, have them peer review by swapping with a classmate. The task of the reviewer is to see if they can find all the information needed to make the part (material, dimensions, finish, etc.) just from the drawing. This highlights the importance of completeness.

Learning tasks

1. Recap the features and importance of orthographic projection, dimensioning, and sectional views used in mechanical drawings.
2. Learners identify the role of detailed drawings in communicating manufacturing information and quality requirements.
3. In groups, learners research various applications of detailed drawings in production settings (e.g., machining, fabrication, CNC programming). Learners will practice evaluating limits and tolerances for a component by selecting appropriate fits, determining shaft and hole types, selecting tolerance grades, and evaluating standard tolerances.
4. Learners produce a complete, detailed drawing of a mechanical component (e.g., a shaft or bracket) showing dimensions, tolerances, materials, finish, and title block.
5. Each learner demonstrates independent understanding of material failure, assessing depth of understanding and ability to apply concepts.

Pedagogical Exemplars

1. **Talk for Learning:** Learners engage in research activities to explore the application of detailed drawings in production, enhancing their understanding through analysis and presentation of findings.
2. **Research Based Learning:** Learners work in mixed ability groups to research and discuss the application of limit systems, enhancing their understanding through shared knowledge and teamwork. And learners read from the library on the application of detailed drawings in production drawings, present their findings in class and receive feedback.
3. **Practical Based Learning:** Learners apply their theoretical knowledge by creating detailed drawings, allowing them to gain practical skills and demonstrate their understanding of production drawing requirements. Each learner receives a structured written assessment questions on the learning indicator After completing their responses, they use a self-

assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback.

Key Assessment Level 4: Inquiry-Based Presentation

1. Explain why detailed technical drawings are important in the manufacturing process. Describe two specific ways these drawings help ensure accuracy and consistency during production. (10 marks)
2. An engineer is inspecting a technical drawing of a machine part. The part contains multiple internal features that cannot be seen in standard views, and errors have occurred due to misinterpretation of hidden lines. Which drawing view should be used to prevent such errors, and why?

   A. Isometric view – it gives a 3D perspective of the part.

   B. Sectional view – it reveals hidden internal details clearly.

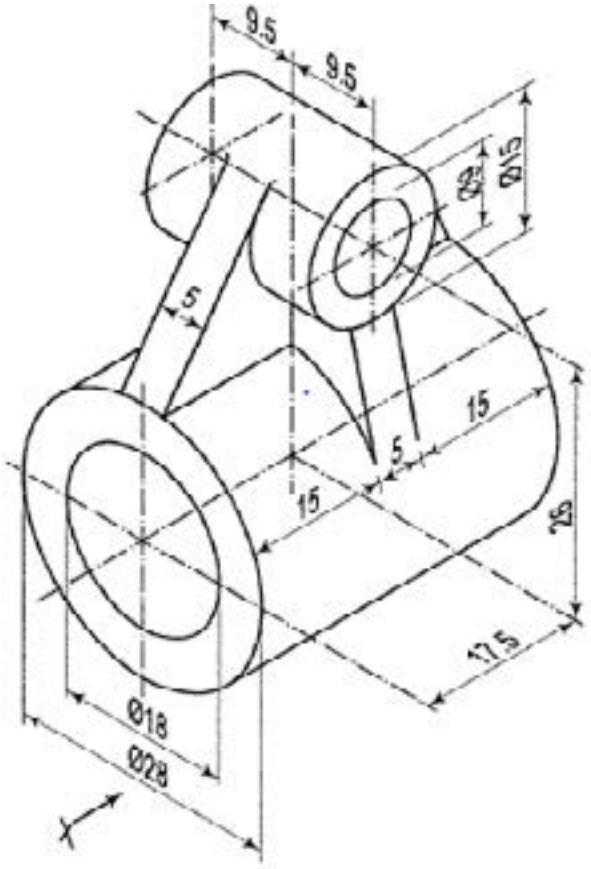
   C. Front view – it shows the design primary shape and features.

   D. Auxiliary view – it displays angled surfaces not shown in other views. (1 mark)

3. The figure below is a machine component drawn in Isometric. Draw twice full size, in first angle orthographic projection.

Note to Facilitators

Ensure learners have access to appropriate drawing paper and instruments, and sufficient time for this detailed drawing task.



a. the front elevation looking in the direction of arrow X (14 marks)

b. the plan (11 marks)

c. the end view (10 marks)

PLC Session 11

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
   a. The key assessment for the week is inquiry-based presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

   b. After the enactment, ask for structured feedback from the group

      i. was the concept explained in a way that a learner with no prior knowledge could follow?

      ii. were the examples grounded in contexts familiar to Ghanaian learners?

      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to

   a. transfer your chats into your learning planner template.

   b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

   c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 12

Learning Indicator: Draw part-drawings of a machine part

Focal Area: Part drawing

12.1 Introduction

(Refer to Year 1, Section 3, Week 9 Demonstrate the use of drawing instruments in product design; Year 2, Section 3, Week 9 Importance of sectioning, dimensioning and tolerance; Year 2, Section 3, Week 10 Importance of sectioning, dimensioning and tolerance; Year 2, Section 3, Week 11 Detailed drawings, Year 2, Section 3, Week 12 Assembly drawings)

Part drawings, also known as detail drawings, are precision graphical representations of individual components used in larger assemblies, including all the necessary information to manufacture a component accurately, such as dimensions, tolerances, material specifications, and surface finishes. Their purpose is to convey exact specifications required for fabrication, serving as blueprints for manufacturers and eliminating ambiguity by providing a clear interpretation of design intent, which ensures consistent production across various manufacturing settings. The importance of part drawings in production cannot be overstated; they ensure precision and accuracy, reduce errors and costly rework, serve as a vital tool for quality control by detailing tolerances and material specifications, and enable interchangeability in mass production by providing standardised references. Additionally, by consolidating all necessary details into a single document, part drawings enhance manufacturing efficiency and reduce interpretation time. Mastery in creating part drawings equips learners to design and produce high-quality, reliable components that meet industry standards and customer expectations, playing a foundational role in manufacturing engineering by ensuring components are produced with precision and function seamlessly within complex assemblies.

12.2 Information on a part drawing

A part drawing, often referred to as a detail drawing or production drawing, is a technical document that delivers comprehensive specifications for the manufacturing of a single component. It serves as an essential communication tool between designers, engineers, and manufacturers, ensuring that the part is produced with accuracy and consistency. The overview of the key information typically included in a part drawing emphasises dimensions, tolerances, materials, finishes, and geometric features.

12.2.1 Title Block

The Title Block serves as a crucial component of technical drawings, encapsulating essential metadata related to the part and its depiction a shown in Figures 39, 40, and Fig. 41. It includes fundamental details such as the Part Name and Description, which identify the specific component, and a Part Number, which provides a unique identifier for inventory and reference purposes. Additionally, a Drawing Number helps differentiate the drawing from others. The Scale indicates the proportional representation of the drawing (e.g., 1:1, 1:2), while the Units specify measurement standards such as millimetres or inches. The Material Specification outlines the material type used (e.g., AISI 304 Stainless Steel or Aluminium 6061), ensuring proper material selection for manufacturing. It also records the Date and Author, marking the

creation or revision date and the name of the designer. Further, the Company Information section presents the name, logo, or contact details of the organisation responsible for the drawing. Spaces for Approval Signatures accommodate engineers or quality control personnel to validate the design, and General Tolerances specify default tolerances if none are individually noted (e.g., ±0.1 mm unless otherwise stated). For example, a title block might include specifications such as "Material: ASTM A36 Steel" and "General Tolerance: ±0.05 mm", ensuring clarity and standardisation in technical documentation.

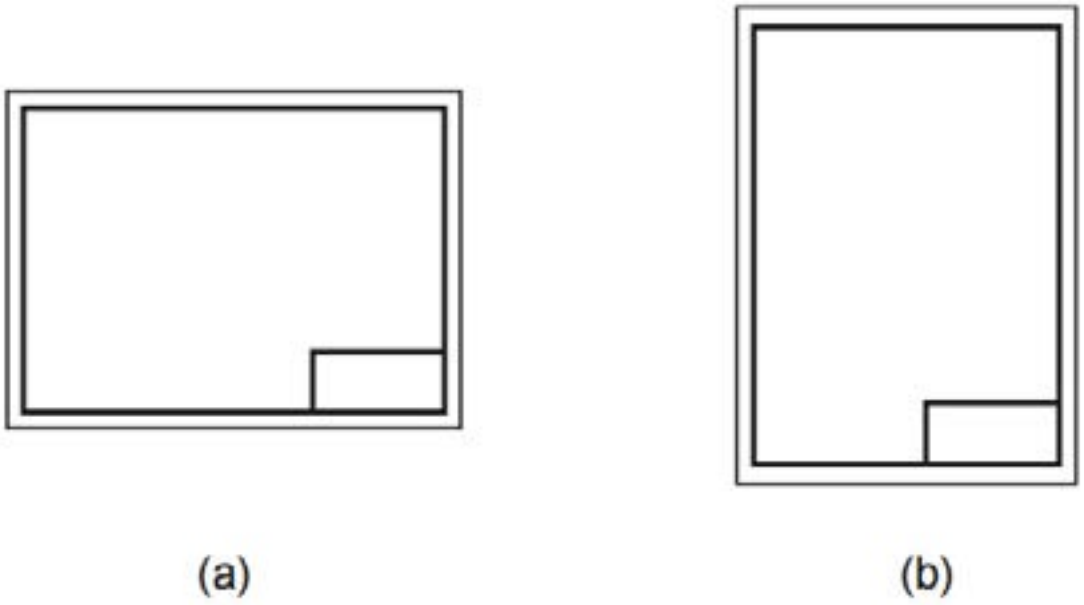


Figure 39: *Location of title block (Narayana et al., 2009)*

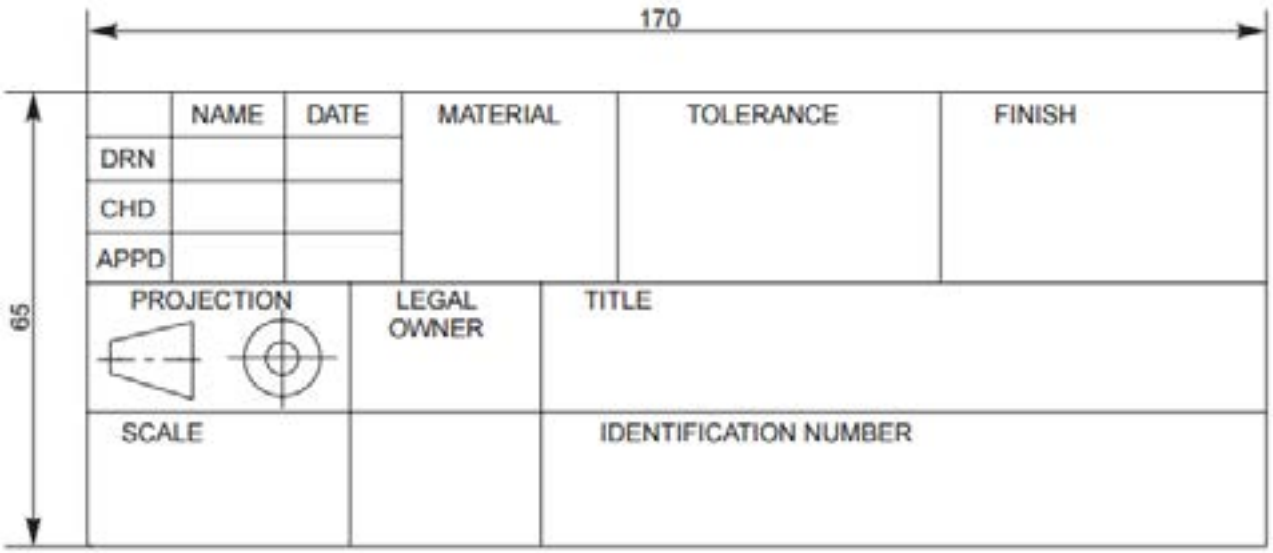


Figure 40: *Details in a title block (Narayana et al., 2009)*

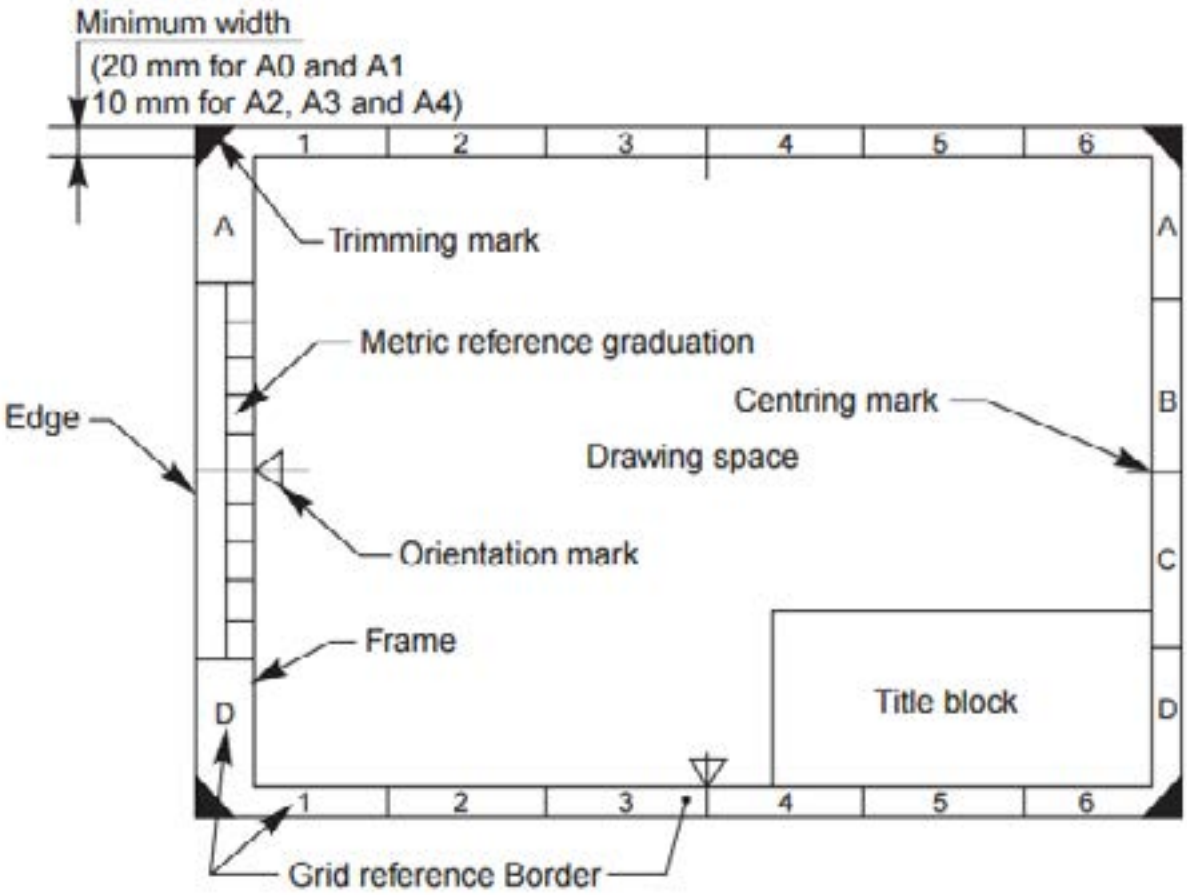


Figure 41 Drawing sheet layout (Narayana et al., 2009)

12.2.2 Dimensions

Dimensions serve a fundamental role in technical drawings by providing precise measurements that define the size and shape of a part. These dimensions come in various forms: Linear Dimensions indicate length, width, height, or distances between features, such as the distance between hole centres; Angular Dimensions specify angles between surfaces or features, like a 45° chamfer; and Radial/Diametric Dimensions apply to circular features, such as specifying a hole diameter (e.g., Ø20 mm).

Technical drawings adhere to standardised conventions to maintain clarity and consistency. Dimensions are typically expressed in millimetres (metric) or inches (imperial) in accordance with industry standards like ISO 128 or ASME Y14.5. Symbols such as **Ø** (diameter), R (radius), or Ⓔ flatness help improve interpretation. To ensure readability, dimensions are carefully positioned with extension lines and arrows, minimising clutter.

For instance, a drawing of a cylindrical component may specify "Ø50 ±0.02 mm" for the outer diameter and "L=100 ±0.1 mm" for the length, ensuring precision in manufacturing and assembly.

12.2.3 Tolerances

Tolerances establish acceptable limits of variation for dimensions to ensure proper functionality and fit in manufactured components. There are several types of tolerances: General Tolerances, which apply to all dimensions unless explicitly specified in the title block; Specific Tolerances, which are assigned to critical features such as a press-fit hole with a tolerance of +0.01/-0.00 mm; and Geometric Dimensioning and Tolerancing (GD&T), which governs the shape, orientation, and position of features, including aspects like flatness, parallelism, and concentricity.

Standard conventions ensure consistency across technical drawings. Tolerances adhere to established norms such as ASME Y14.5 or ISO 8015 and are represented using specific symbols— Ⓔ for flatness, Ⓕ for concentricity— alongside datum references that define precise relationships between features. Tolerance blocks or notes clarify limits, such as "H7" for a precision fit.

For example, a shaft might be specified with "Ø25 h6", indicating a highly controlled fit, along with a parallelism tolerance of "0.02 mm relative to Datum A", ensuring reliability in assembly and operation.

12.2.4 Materials

Materials play a vital role in engineering drawings, as they define the composition of a part to ensure strength, durability, and compatibility with its intended application. These specifications typically include the Material Type, identifying a specific alloy or grade such as AISI 4140 Steel or ABS Plastic. A Standards Reference ensures consistency by citing established norms like ASTM, AISI, or ISO, for example, ASTM A36 for structural steel. To account for cost or availability concerns, Alternative Materials may be listed, such as "Preferred: Aluminium 6061; Alternate: Aluminium 5052." Additionally, critical aspects of Heat Treatment or Processing (like hardening or annealing) are documented, such as "HRC 45-50" for surface hardness.

Material information is often included in the title block or as a material note, ensuring clear communication in manufacturing. In sectional views, hatching patterns indicate material types - for example, diagonal lines represent steel, while wavy lines signify aluminium. An example entry in a title block could be "Material: Stainless Steel 316L, ASTM A240", offering precise material designation for production.

12.2.5 Surface Finishes

Surface Finish specifications define the required texture or smoothness of a part for both functional and aesthetic purposes. One key parameter is Surface Roughness, measured in Ra (roughness average), which quantifies the microscopic irregularities on a surface (e.g., Ra 1.6 µm for a smooth finish). To standardise surface finish requirements, Finish Symbols are used according to ISO 1302 or ASME Y14.36, often represented as a checkmark with a number indicating the Ra value.

Additionally, specific finishing processes may be prescribed to achieve the desired surface characteristics, such as polishing, grinding, or coating (e.g., "Anodise per MIL-A-8625" for corrosion resistance). These finish symbols and notes are carefully positioned near the relevant surface on a drawing or within a designated note section to ensure clarity in manufacturing and inspection. For example, a bearing surface requiring minimal friction may be marked with "Ra 0.8 µm", ensuring precise functionality and optimal performance.

12.2.6 Views and Projections

Views and Projections play a key role in technical drawings, offering multiple perspectives to accurately represent a part's geometry and features. Among the common view types, Orthographic Views provide detailed representations from the front, top, side, or section views, ensuring that all dimensions and features are visible. The Isometric View, though optional, offers a 3D representation that enhances clarity. Additionally, Section Views reveal internal features through cutaways, such as a cross-section of a shaft displaying a keyway.

To maintain consistency, drawings adhere to standardised projection conventions established by ISO 128 or ASME Y14.3, employing either first-angle or third-angle projection methods. This ensures accurate interpretation across different engineering disciplines. For instance, a section view may depict internal threads, accompanied by a hatching pattern that indicates the material, such as steel, providing essential manufacturing details.

12.2.7 Notes and annotations

Notes and Annotations serve as essential additions to technical drawings, offering clarifications or instructions beyond what symbols and dimensions can convey. These notes may include Manufacturing Instructions, such as "Deburr all edges", ensuring smooth finishes; Assembly Notes, like "Press-fit with 0.02 mm interference", which provide critical guidance for part fitting; and Inspection Requirements, such as "100% visual inspection for surface defects", ensuring quality control.

Typically, these notes are strategically placed near the title block or adjacent to specific features to enhance readability and ensure adherence to specifications. Their inclusion supports accurate manufacturing, assembly, and verification, contributing to high-quality production outcomes.

12.2.8 Standards and Compliance

Standards and Compliance ensure that parts meet industry and regulatory requirements, maintaining consistency and reliability in manufacturing. These specifications typically reference established standards such as ISO, ASTM, or DIN, which define criteria for materials, tolerances, and finishes. Additionally, specific compliance notes may be required for specialised industries, such as FDA regulations for food-grade materials or MIL-STD guidelines for military applications. For instance, a material specification might state "Material to comply with ASTM B209 for Aluminium 6061", ensuring adherence to predefined standards.

12.3 Standards Governing Part Drawings

Technical drawings adhere to internationally recognised standards, ensuring precision and clarity in design. Examples of these standards include:

ISO 128 – General principles for technical drawings

ASME Y14.5 – Dimensioning and tolerancing (GD&T)

ISO 1302 – Surface finish symbols

ISO 2553 – Weld symbols

ASTM/ASME/ANSI – Material and testing standards

A part drawing serves as a comprehensive guide for manufacturing, integrating critical specifications such as dimensions, tolerances, materials, finishes, and geometric features. These standardised symbols and notations promote precision, clarity, and compliance, ensuring accurate production, quality control, and seamless global collaboration in engineering and manufacturing.

Notes for Facilitators

1. **Clarifying Concepts:** The part drawing is the contract between the designer and the manufacturer. The designer says, «I need this part,» and the manufacturer says, «I agree to make it to these exact specifications.» If there is any ambiguity in the drawing, the contract is broken, and the wrong part may be made.

2. **Common Misconceptions:** Students may think that more dimensions are always better. Explain that redundant dimensions can cause confusion. Every part should have just enough dimensions to define it uniquely, following the principle of functional dimensioning.
3. **Low-Cost Demonstration and Ghanaian Examples**
   a. **Standardisation:** Show a simple machine part, like a bolt. Have students find a similar bolt in a local hardware store. Discuss how the part number of the bolt and dimensions (e.g., M10 x 1.5 x 50) on the packaging are a part drawing in text form, ensuring they can buy a replacement that fits perfectly.
   b. **Troubleshooting:** When students are drawing, ensure they understand the importance of **projection symbols**. Ask them to state whether they are using first-angle (ISO) or third-angle (ANSI) projection and to place the correct symbol in their drawing. This is a common source of error if the manufacturer uses a different standard.

Learning Tasks

1. Review fundamental concepts of technical drawing, including orthographic projection, line types, and drawing standards. Follow this with a hands-on activity where learners sketch basic shapes using proper line conventions. Learners in mixed ability groups redraw a simple machine bracket using orthographic projection
2. Learners in a mixed ability groups develop a definition collaboratively and create a concept map
3. Labelling exercise with pre-prepared part drawings
4. Annotate a simplified machine part drawing
5. Each group produces their own part drawing using provided dimensions

Pedagogical Exemplars

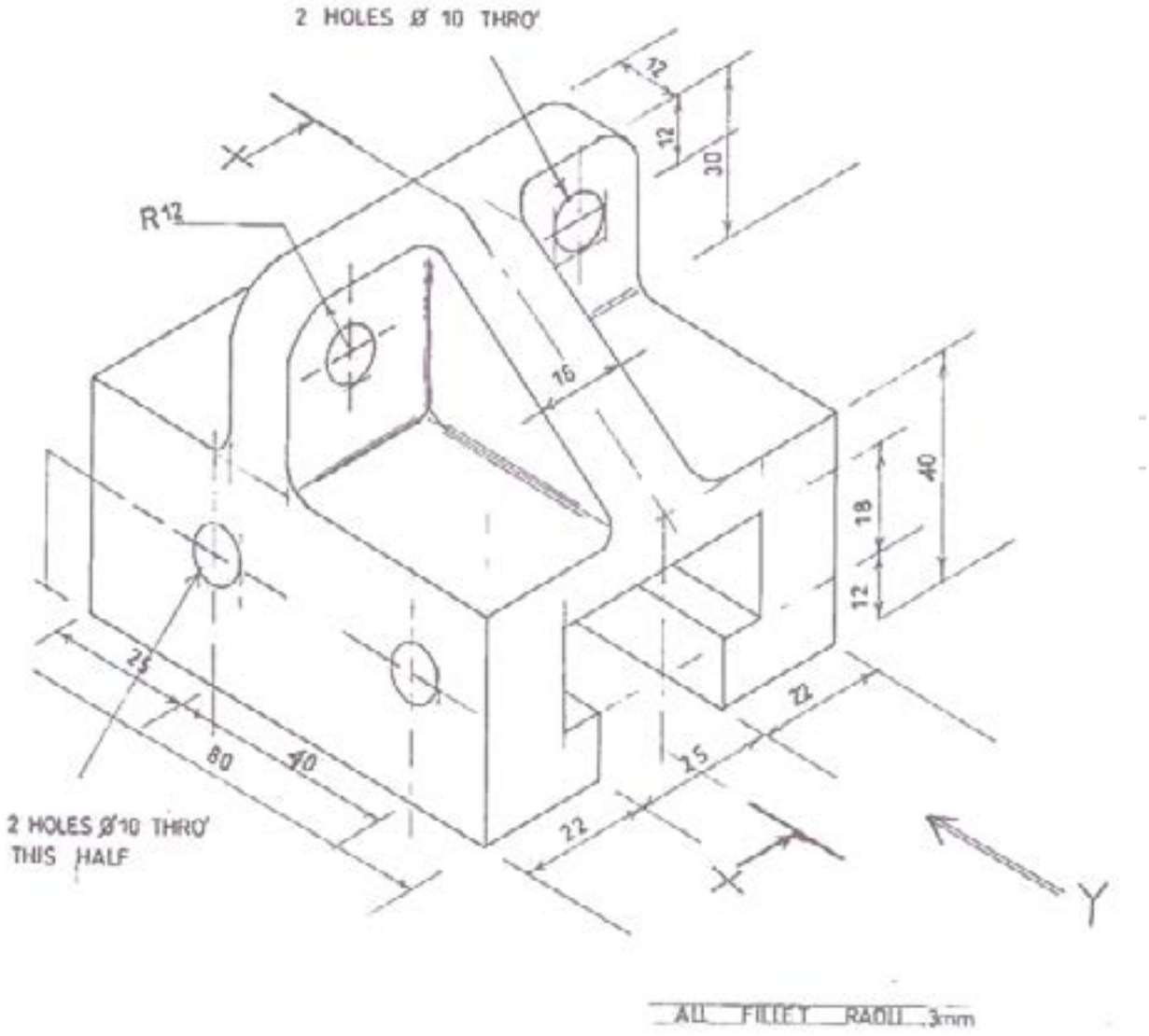
1. **Talk for Learning:** Learners work in pairs to analyse incomplete drawings (e.g., missing hidden lines, wrong scales).
2. **Practical Based Learning:** Teacher presents a physical machine part and its part drawing. Learners analyse a complete sample part drawing and annotate:
   a. Dimensions
   b. Tolerances
   c. Materials
   d. Surface finishes

   Individually or in small groups, learners draw a component (e.g., a stepped shaft, bracket).
5. **Practice-Based Learning:** Individual learners draw a single part of a product providing the material used, dimensions, tolerances, surface finish, joining techniques, etc., needed to manufacture it. Learners share drawing with peers and receive comments.

Key Assessment: Practice Paper 1

1. Explain how part drawings are used strategically during different stages of the manufacturing process to reduce production errors. Provide two specific examples where improper use or misinterpretation of a drawing could lead to costly mistakes. Analyse how correct use of drawings improves efficiency, accuracy, or safety in production. (10 marks)
2. Evaluate the role of tolerance in the manufacturing process. Which of the following scenarios best demonstrates how improper tolerance specifications can impact product quality, functionality, and cost?
    a. Specifying a narrow tolerance range, which increases manufacturing costs but ensures high precision.
    b. Applying a broad tolerance range that reduces costs but may lead to parts not fitting correctly in the assembly.
    c. Using arbitrary tolerance values without considering the function and fit of the parts.
    d. Implementing standard tolerance values across all parts to simplify the manufacturing process (10 marks)
3. Analyse the importance of using different line types, such as visible, hidden, and centre lines, in technical drawings. How do this line types contribute to accurately interpreting and communicating the design intent during the manufacturing process? Discuss potential consequences if these line types were used incorrectly or omitted. (16 marks)
4. Analyse how each of the following features influences the manufacturing process and performance of a machine component. Provide examples to support your explanation:
    a. Tolerance
    b. Surface finish
    c. Material specification (12 marks)
5. The following diagram shows a sliding bracket in isometric projection. Do not copy this, but draw full size in first angle projection, the following views:
    a. a sectional front elevation on X-X;
    b. an end elevation from the direction of arrow Y
    c. a plan.

Show hidden details in plan and end elevation only. Add six important dimensions to your drawing, ensuring to include all necessary views, dimensions, tolerances, material specifications, and surface finishes. (40 marks) (DOK Level 3).



Hint

*Conduct **Practice Paper 1**. It should cover the contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

ITEM SPECIFICATION FOR PRACTICE EXAMINATION 1

1. PAPER 1 (Objective test)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	MATERIALS FOR MANUFACTURING	CLASSIFICATION OF MATERIALS	41.1.1.CS.1 Demonstrate knowledge and understanding of the fundamentals of engineering materials.	1.1.1.LI.1 Explain the relationship between materials science and engineering.	1	1			9
			2.1.1.CS.1 Demonstrate knowledge and understanding of chemical properties and structure of materials.	2.1.1.LI.1 Group materials as metals, ceramics and polymers based on their chemical properties.	1	2	1		
			2.1.1.CS.2 Demonstrate understanding in materials processing and synthesis.	2.1.1.LI.2 Classify materials as metals, ceramics and polymers according to their processing methods	2	1			
		PROPERTIES OF MATERIALS	3.1.2.CS.1 Demonstrate knowledge of mechanical properties of bamboo	3.1.2.AS.2 Level 1 Recall Level 3 Strategic reasoning	2	1			3

2	DESIGN AND PROTOTYPING	DESIGN AND DRAWING FOR MANUFACTURE	1.2.1.CS.1 Demonstrate knowledge and skill in the development of surfaces.	1.2.1.LI.1 Demonstrate the use of drawing instruments in product design.	2	4	2		8
		RAPID PROTOTYPING	1.2.2.CS.1 Demonstrate knowledge and understanding of the basic principles of product prototyping and product development.	1.2.2.LI.1 Explain the fundamental difference between conventional prototyping and rapid prototyping.	1	2	3		6
3	MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES	MANUFACTURING TOOLS AND EQUIPMENT	1.3.1.CS.1 Demonstrate knowledge and understanding of marking out and measurement.	1.3.1.LI.1 Set the datum for a work piece and select coordinates systems for dimensioning an object.	2	2	2		6
		Manufacturing Processes	1.3.2.CS.1 Demonstrate knowledge and understanding the principle of bulk deformation and sheet metal working to roll, forge, cut, bend and draw metal sheets.	1.3.2.LI.1 Understand the fundamentals of metal forming.	1	1	3		5

		SAFETY, QUALITY AND THE ENVIRONMENT	1.3.3.CS.1 Demonstrate an understanding of the importance of workplace safety and workplace organisation.	1.3.3.LI.1 Identify potential hazards in the workplace.		2	1		3
	Total				**12 (30%)**	**16 (40%)**	**12 (30%)**		**40 (100%)**

PAPER 2 (Written)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	MATERIALS FOR MANUFACTURING	CLASSIFICATION OF MATERIALS	2.1.1.CS.2 Demonstrate the understanding in materials processing and synthesis.	2.1.1.LI.1 Identify types of materials processing methods.	1				1
		PROPERTIES OF MATERIALS	3.1.2.CS.2 Demonstrate understanding of the failure of materials	3.1.2.LI.1 Explain the term failure of materials	1				1
3	MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES	MANUFACTURING TOOLS AND EQUIPMENT	3.3.1.CS.1 Demonstrate knowledge and understanding of the use of cutting tools and modern machine tools.	3.3.1.LI.1 Identify and classify cutting tools used in manufacturing.	1				1

		Manufacturing Processes	1.3.2.CS.2 Demonstrate knowledge and understanding of standards, measurement and gauging in the manufacturing process.	1.3.2.LI.1 Recognise and identify dies and presses used for sheet metal working operations.	1		1
		SAFETY, QUALITY AND THE ENVIRONMENT	2.3.3.CS.1 Demonstrate an understanding of procedures to ensure safety in the manufacturing industry.	2.3.3.LI.2 Analyse the effects that various manufacturing activities have on the environment (e.g. the effects of waste disposal, power consumption, processes of raw material.)	1		1
	Total				**5**		**5**

PAPER 3 (Practical)

S/N	Strand	Sub-strand	Number of items				Total
			DOK 1	DOK 2	DOK 3	DOK 4	
1	DESIGN AND PROTOTYPING	DESIGN AND DRAWING FOR MANUFACTURE	2				2
		RAPID PROTOTYPING					
	Total		**2**				**2**

PLC Session 12

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand.
    b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP)
    a. The key assessment for the week is Practice Paper 1. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through the problem individually for 3–4 minutes
    c. the group then works through it together the problem, step by step
    d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 3 Review

This section strengthens learners' understanding of production drawing by transitioning from fundamental engineering sketches to industry-standard technical drawings used in manufacturing. The learning journey began with the study of production drawing conventions, which provide a universal language for engineers and manufacturers.

Learners explored the standardised representation of materials and machine components, identifying common symbols and notation systems that ensure clarity and accuracy in technical communication. Through discussions and practical drawing exercises, they gained an appreciation for the role of conventions in fostering effective collaboration within engineering design and production workflows.

Building on this foundation, the section introduced the critical concepts of limits and fits, emphasising their role in precision engineering. Learners investigated tolerances and allowances, developing an understanding of how clearance and interference fits impact the assembly and functionality of mechanical components. These principles were reinforced through guided activities where learners applied their knowledge to optimise manufacturing efficiency and quality control.

Next, learners delved into the creation of detailed drawings, incorporating essential elements such as dimensions, tolerances, and annotations in compliance with industrial standards. Emphasis was placed on Geometric Dimensioning and Tolerancing (GD&T), equipping learners with tools to achieve consistency and accuracy in their production documents. Collaborative projects allowed them to produce detailed drawings that adhered to best practices, bridging the gap between conceptual design and real-world implementation.

The section concluded with a focus on part drawings, empowering learners to develop clear and precise representations of components. They applied orthographic projection techniques and created sectional views, honing their ability to convey technical information effectively. Through individual assignments, learners practiced drafting production-ready documents, reinforcing their ability to transform engineering concepts into manufacturable designs.

Throughout this journey, learners engaged in experiential activities, discussions, and research, enabling them to critically assess production drawing conventions, justify decisions related to limits and fits, and propose solutions to real-world engineering challenges.

By the end of the section, learners are expected to demonstrate proficiency in producing industry-compliant drawings, apply critical thinking to precision engineering, and effectively communicate technical principles for manufacturing applications

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 9

Marking scheme

Q1. Evaluate how the identification and representation of a shaft in a mechanical component drawing affect the manufacturing and assembly process. In your response:

a. Analyse the visual symbols and features typically used to represent a shaft in technical drawings.

b. Discuss how misinterpreting this representation could lead to production or assembly errors.

c. Propose strategies to ensure accurate communication of shaft features in engineering documentation. (10 marks)

Criteria	Marks
Explanation of standard shaft representation in technical drawings (e.g., section views, symbols)	2 marks
Analysis of how misinterpretation may impact manufacturing or assembly	3 marks
Evaluation of consequences (e.g., fit errors, wrong machining, misalignment)	2 marks
Proposed strategies for improving clarity and accuracy in communication (e.g., annotation, training)	3 marks
Total	10 marks

Sample Answer

In technical drawings, a shaft is typically represented using a combination of circular views (for cross-sections) and long rectangular projections (for side views), often with centre lines running through them to indicate symmetry and axis of rotation. Cross-hatching may also be used in sectional views to show the material and continuity of the shaft. Dimensions such as diameter, length, and tolerance are annotated to guide manufacturing.

If this representation is misinterpreted - such as mistaking it for a hole, a sleeve, or another cylindrical feature - it can result in serious errors during production. For example, incorrect machining of the shaft diameter could lead to improper fits in bearings or couplings, compromising mechanical function or safety. Inaccurate length or alignment could affect assembly with connected components, especially in rotating machinery or drive systems.

To prevent such issues, strategies such as using exploded views, detailed annotations, and consistent symbol standards (e.g., ISO or ANSI) can improve understanding. Providing reference part numbers, fit specifications, and including 3D model views alongside 2D drawings can also aid communication between design and production teams. Regular training for interpreting engineering drawings and encouraging cross-checks during design reviews can further reduce interpretation errors and ensure successful manufacturing.

Q2.

In a small-scale fabrication workshop producing machine housings for a food processing unit, a major delay occurred because the part drawings lacked proper use of sectional views and centrelines. As a result, two internal features—intended to accommodate shaft bearings—were misaligned by 5 mm during CNC machining. 20 unusable units were produced before the error was identified.

Evaluate this manufacturing failure or near-miss that occurred due to the lack of standard drawing conventions. Identify two specific consequences that resulted from this oversight. Then, propose engineering or procedural solutions that could prevent similar issues in future production environments. (10 marks)

Marking Scheme

Criteria	Marks
Explanation of first consequence with clarity and technical accuracy	2 marks
Explanation of second consequence with clarity and technical accuracy	2 marks
Proposed solution(s) clearly linked to the scenario and showing understanding of best practices	5 marks
Structure, clarity, and coherence of argument	1 mark

Sample Answer

In a small-scale fabrication workshop producing machine housings for a food processing unit, a major delay occurred because the part drawings lacked proper use of sectional views and centrelines. As a result, two internal features - intended to accommodate shaft bearings—were misaligned by 5 mm during CNC machining.

First consequence: The misinterpretation led to the production of over 20 unusable units, resulting in material wastage and significant cost overruns.

Second consequence: The customer's assembly line was delayed by two days, damaging the supplier's credibility and incurring contractual penalties.

To prevent such issues, all engineering drawings should adhere to ISO/ANSI conventions, with mandatory use of sectional views to show hidden features. Additionally, implementing a drawing review and approval workflow involving both design and production engineers could ensure clarity and reduce costly misinterpretations.

Q.3. Marking Guide: Discuss the significance of using crosshatching to represent different materials in production drawings. (14 marks)

Introduction – 2 Marks

1 mark: States that crosshatching is used in sectional views to indicate materials that have been "cut."

1 mark: Explains that it uses standardised patterns to enhance clarity and avoid misinterpretation.

Identification of Materials – 4 Marks

1 mark: States that different materials have unique crosshatching patterns (e.g., steel, copper, rubber).

2 marks: Explains that this allows quick identification of materials by machinists, engineers, etc.

1 mark: Example given (e.g., closely spaced lines for steel, dots for rubber).

Enhanced Clarity in Sectional Views – 4 Marks

1 mark: States that crosshatching improves visual clarity in sectional views.

2 marks: Explains that it shows which areas have been cut, making component interiors clear.

1 mark: Example or scenario given (e.g., helps in complex assemblies).

Effective Technical Communication – 4 Marks

1 mark: States that crosshatching supports standardised communication.

2 marks: Explains that it helps different teams (including outsourced or international teams) interpret drawings consistently.

1 mark: Mentions elimination of ambiguity or misreading in material selection

Sample answer

Crosshatching serves to distinguish between different materials in engineering drawings through the application of precise, standardised patterns, thereby enhancing visual clarity and eliminating the risk of misinterpretation in technical communication. It is mainly applied in sectional views to show the interior of components that have been 'cut' along a plane. It ensures that everyone, regardless of location or background, interprets the material types and section views consistently and correctly. The significance of this practice includes:

1. Identification of Materials: Different materials are represented using unique crosshatching patterns (e.g., closely spaced lines for steel, alternating lines for copper, dots for rubber). This enables engineers, machinists, and fabricators to instantly recognise the material specified for each part without relying solely on written notes.
2. Enhanced Clarity in Sectional Views: In complex assemblies or cut-away sections, crosshatching clearly shows which parts are solid, cut through, or composed of different materials.
3. Effective Technical Communication: Crosshatching allows for standardised visual language across all drawings, especially in multi-disciplinary teams or when outsourced.

WEEK 10

Q1. A machined part is designed with a diameter of 60.00 mm ± 0.03 mm. During inspection, the diameter is measured as 60.05 mm.

Analyse this situation and explain

a. What conclusion the inspector should draw based on the tolerance limits?

b. What the implications of accepting or rejecting the part might be for functionality and quality?

c. What steps could be taken in the manufacturing process to prevent this issue from recurring? (10 marks)

Correct calculation and identification of tolerance limits (59.97–60.03 mm)	2 marks
Correct conclusion that the part is out of tolerance and should be rejected	2 marks
Explanation of why tolerances are critical for functionality (e.g., fit, safety)	2 marks
Evaluation of the consequence of accepting/rejecting such a part	2 marks
Suggested improvements in inspection or process control	2 marks

Sample Answer

The tolerance range for the part is 59.97 mm to 60.03 mm. Since the part measures 60.05 mm, it exceeds the upper limit and is therefore out of tolerance. The inspector should reject the part.

Accepting this oversized part could result in problems with component fit, especially in assemblies requiring tight tolerances, possibly causing performance issues or even failure under stress. Rejecting it helps ensure product reliability and adherence to design specifications.

To avoid this in future, tighter control over the machining process is needed—possibly through better tool calibration, more frequent in-process inspections, or automated measuring systems to detect deviations early.

Q2. A shaft is designed as 25.00 mm ± 0.03 mm, and the corresponding hole is 25.08 mm ± 0.02 mm.

Analyse and explain

a. How to calculate the maximum and minimum clearances between the shaft and the hole.

b. What the calculated clearances imply about the type of fit and its function in a mechanical assembly.

c. How tolerances support both interchangeability and performance in production. (10 marks)

Correct calculation of maximum clearance (25.10 – 24.97 = 0.13 mm)	2 marks
Correct calculation of minimum clearance (25.06 – 25.03 = 0.03 mm)	2 marks
Identification of clearance fit and explanation of its purpose	2 marks
Explanation of why tolerances matter for functionality and interchangeability	2 marks
Application of the concept to a real-world production scenario	2 marks

Sample Answer

The maximum clearance occurs when the hole is at its largest (25.10 mm) and the shaft is at its smallest (24.97 mm), giving 0.13 mm.

The minimum clearance is when the hole is at its smallest (25.06 mm) and the shaft is at its largest (25.03 mm), giving 0.03 mm.

This range shows a clearance fit, allowing easy assembly without force but still maintaining alignment and function. This is useful in applications like rotating shafts where movement is required.

Tolerances ensure that even with manufacturing variation, parts still assemble correctly and function as intended. In mass production, this supports both efficiency and quality control, reducing the need for custom fitting.

Q3. Importance of Tolerances and Fits in Manufacturing - Total Marks: 16

(Each criterion is worth 4 marks. Total = 16 marks)

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
1. Definition of Tolerances	Defines tolerance as the permissible variation in a dimension, expressed in upper and lower limits (e.g., ±0.1 mm); links it to precision, function, and quality control.	Gives a clear definition of tolerance as acceptable variation in part size; connects it to consistent production.	Provides a general idea of tolerance; partially explains its purpose but lacks technical clarity or depth.	Gives a vague, incorrect, or confused definition; fails to show relevance to manufacturing.
2. Definition of Fits	Explains fits as dimensional relationships between mating parts; correctly identifies clearance, interference, and transition fits with examples.	Describes fits as how parts like shafts and holes fit together; mentions at least one fit type with a general explanation.	Recognises the term "fit" but gives a limited or unclear definition; no clear mention of types or examples.	Incorrect definition or no attempt to explain fit types or their importance.
3. Impact on Function & Assembly	Clearly links tolerances and fits to motion control, wear, ease of assembly, and alignment; uses real-world examples (e.g., piston and cylinder).	Mentions at least two effects (e.g., assembly and movement); gives a relevant example.	Mentions one basic effect on function or assembly; lacks clarity or example.	Fails to connect tolerances/ fits to product performance or assembly.

4. Interchangeability & Use	Explains that tolerances enable interchangeability in mass production; supports with practical examples (e.g., standard bolts and nuts).	States that tolerances allow part replacement or standardisation; gives a basic industry example.	Briefly mentions interchangeability or replacement without elaborating or contextualising.	No mention of interchangeability or shows misunderstanding of its role in manufacturing.

Sample Answer

Tolerances and fits are essential in manufacturing to ensure that components assemble correctly and function reliably. Tolerances control acceptable variations in size, allowing parts to be produced consistently and enabling the use of interchangeable parts. For example, a bolt manufactured with a tolerance of ±0.1 mm will still fit into a nut with the corresponding internal thread tolerance, ensuring consistent assembly even if parts come from different suppliers. This also permits easy replacement of individual components without requiring rework.

Fits determine how two parts, such as a shaft and a hole, fit together, whether they slide freely, press tightly, or fall somewhere in between. For instance, a clearance fit might be used in a wheel mounted on an axle to allow rotation, while an interference fit would be used in a gear pressed onto a shaft to prevent movement. The proper use of tolerances and fits prevents issues like poor alignment, excessive wear, or assembly failure, supporting efficient production and long-term performance. In particular, tolerances are critical when assigning dimensions to mating parts in assemblies, such as a piston fitting into a cylinder, where both functional clearance and sealing must be ensured.

WEEK 11

Q1. Explain why detailed technical drawings are important in the manufacturing process. Describe two specific ways these drawings help ensure accuracy and consistency during production. (10 marks)

Criteria	Marks
Clear explanation of the overall importance of technical drawings	3 marks
First specific way drawings help in production (with explanation)	3 marks
Second specific way drawings help in production (with explanation)	3 marks
Logical structure, clarity, and completeness of answer	1 mark

Sample Answer

Technical drawings are important in manufacturing because they communicate exact specifications for how a part or product should be made. They help ensure that everyone involved in the process has a shared understanding of the design.

One way these drawings help is by providing accurate dimensions and tolerances. This allows machinists and technicians to produce components that fit and function properly in an assembly.

Another way they help is by showing views and symbols that indicate material types, surface finishes, and special instructions. This helps maintain quality and ensures that the final product meets design requirements.

Q2. Answer: B) Sectional view – it reveals hidden internal details clearly. [1 mark]

Q3. Marking guide/ scheme based on three views

Front Elevation

S/N	Task Description	Mark (s)
1	Drawn in first angle projection	2
2	Drawn twice full size / to scale	1
3	Outline of front view correctly drawn	2
4	Correct representation of triangle or upper profile	2
5	Correct location and diameter of central hole (e.g. Ø10)	2
6	Centre lines correctly used for the hole	1
7	Vertical and horizontal dimensions are correctly indicated	2
8	View labelled as "Front Elevation"	1
9	Line quality and neatness	1
	Total	**14**

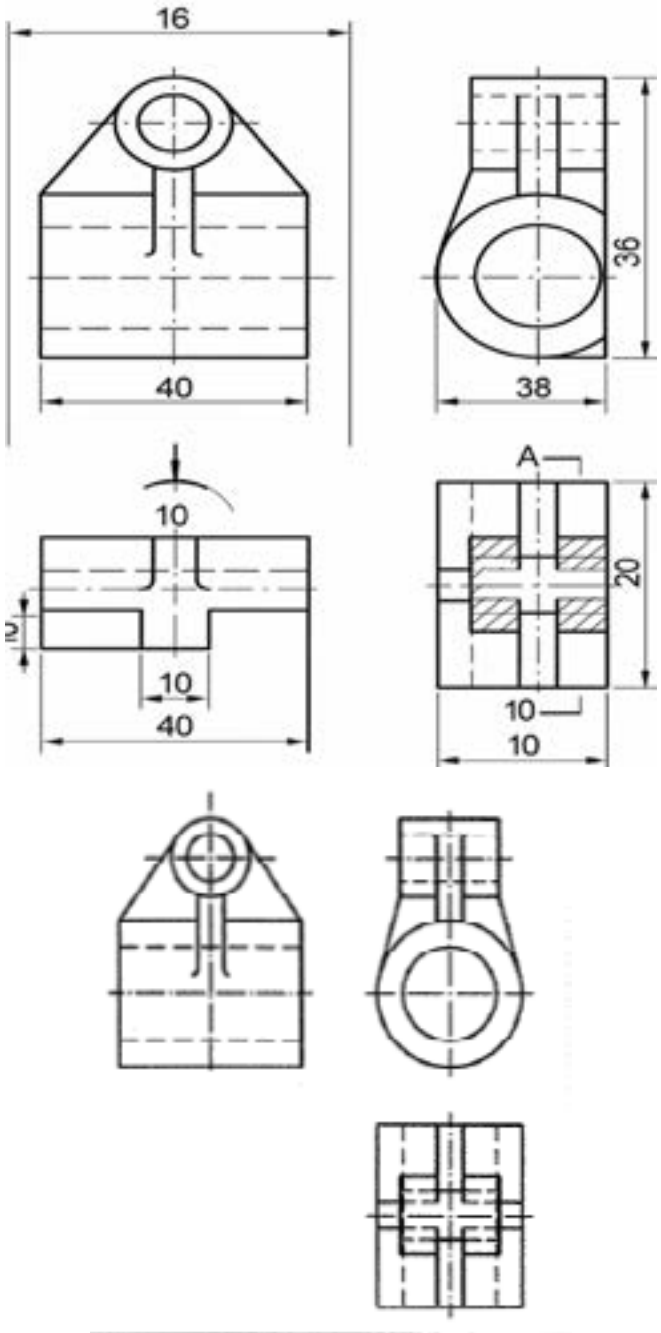
B: PLAN

S/N	Task Description	Mark (s)
1	Correct top view drawn and properly aligned under front view	2
2	Shape accurately reflects the top profile	2
3	Hole correctly represented from top	2
4	Use of centre line for hole	1
5	Relevant dimensions shown (length, hole position, etc.)	2
6	View labelled as "Plan View"	1
7	Line quality and neatness	1
	Total	**11**

C: END VIEW

S/N	Task Description	Mark (s)
1	End view correctly drawn and aligned	2
2	Correct shape represented (triangular side, etc.)	2
3	Hidden or centre lines correctly used	2
4	Key dimensions (height, thickness) clearly shown	2
5	View labelled "End View"	1
6	Line quality and neatness	1
	Total	**10**

Sample answer



WEEK 12

Q1. Explain how part drawings are used strategically during different stages of the manufacturing process to reduce production errors. Provide two specific examples where improper use or misinterpretation of a drawing could lead to costly mistakes. Analyse how correct use of drawings improves efficiency, accuracy, or safety in production. (10 marks)

Criteria	Marks
Explanation of strategic use of part drawings	3 marks
Two relevant examples of misinterpretation or misuse	4 marks (2 per example)
Analysis of how correct drawing use improves manufacturing	3 marks
TOTAL	10 marks

Sample Answer

Part drawings are strategically used throughout the manufacturing process to communicate exact dimensions, tolerances, materials, and surface finishes. These details help ensure every part is produced to fit and function as intended. They also standardise communication between engineers, machinists, and quality control teams.

For example, if a machinist misreads a technical drawing and interprets a diameter as 20.5 mm instead of 25.0 mm due to unclear annotations or missing centrelines, the part may not fit into the assembly, leading to rework or scrap. Another example is during welding: if weld symbols are missing or not understood, the strength or placement of the welds may fail to meet safety standards.

When part drawings are used correctly, they improve production accuracy, reduce waste, and ensure all departments are aligned. This leads to better product quality, fewer delays, and higher safety standards during manufacturing.

Q2. Evaluate the role of tolerance in the manufacturing process. Which of the following scenarios best demonstrates how improper tolerance specifications can impact product quality, functionality, and cost?

a. Specifying a narrow tolerance range which increases manufacturing costs but ensures high precision.

b. Applying a broad tolerance range that reduces costs but may lead to parts not fitting correctly in the assembly.

c. Using arbitrary tolerance values without considering the function and fit of the parts.

d. Implementing standard tolerance values across all parts to simplify the manufacturing process. (10 marks)

Criteria	Marks
Clear explanation of what tolerances are and their purpose in manufacturing	2 marks
Correct identification of the best scenario (C) and justification for its negative impact	3 marks

Evaluation of how improper tolerances affect quality, function, and cost (with examples)	3 marks
Reference to good tolerance practice or contrast with a better approach	2 marks
Total	**10 marks**

Sample Answer

Tolerances in manufacturing refer to the acceptable range of variation in a physical dimension of a part. They ensure that components fit and function properly despite slight variations during production. Tolerances are critical for achieving reliability, performance, and cost-effectiveness in engineering applications.

The best example of how improper tolerance specifications can negatively impact product quality and cost is Option C: using arbitrary tolerance values without considering the function and fit of the parts. This scenario can lead to parts that either do not assemble correctly or are unnecessarily expensive to produce.

For instance, if a non-critical part is given an extremely tight tolerance, this could require advanced machining techniques, increasing production time and cost without adding functional value. On the other hand, loose or arbitrary tolerances in critical components like shafts and bearings may result in misalignment, mechanical failure, or excessive wear.

Improper tolerancing can also increase the rejection rate during quality control, waste materials, and delay assembly processes. In contrast, a functional and fit-based tolerance approach—where tolerances are tailored to the part's role and interaction with other components—helps balance performance with manufacturability.

Therefore, tolerances must be carefully selected based on the function, fit, and material properties to avoid production inefficiencies, high costs, and product defects.

Q3. Rubric: Assessment of Line Types in Technical Drawing

Total: 16 Marks

Criteria	Excellent (4 marks)	Very Good (3 marks)	Satisfactory (2 marks)	Needs Improvement (1 mark)
1. Identification of Line Types	Accurately names and distinguishes visible, hidden, centre, construction, and cutting plane lines. Clearly explains how each appears (e.g., thickness, dashed, long-short dashes, etc.).	Names at least 4 or 3 line types correctly and gives a basic description of their appearance (e.g., "centre line is dash-dot").	Names 2 line types with general understanding of their use, but lacks detail on their appearance or characteristics.	Identifies 1 line type only, with little or no explanation of their appearance; or gives incorrect names.
2. Application in Context	Applies each line type correctly in a complex technical drawing (e.g., sectional view or assembly drawing), showing correct line weight, spacing, and line type.	Applies most line types correctly in a moderately detailed drawing, with only minor errors in line weight or spacing.	Uses some correct line types in a basic drawing, but with inconsistencies or minor confusion in where and how they are applied.	Incorrectly uses or omits several line types; drawing is unclear or confusing due to wrong or missing lines.

3. Impact of Incorrect Use	Gives a specific example of how incorrect use of hidden or centre lines led to manufacturing or assembly errors, and proposes a practical solution (e.g., add centreline to align holes).	Describes how improper line use (e.g., missing hidden lines) could lead to fitting or assembly issues, with some explanation.	Explains in general that wrong line types can cause confusion or error, but lacks clear examples or details.	Mentions the risk of misinterpretation but gives no concrete example; or fails to recognise the impact.
4. Communi-cation and Justification	Clearly explains the function of each line type for technical communication, with specific examples (e.g., centre line ensures hole alignment, hidden lines show depth).	Gives reasonable justification for most line types, with a practical explanation on how they help communicate drawing details.	Gives general justification for line use (e.g., "to show parts"), without linking them to actual drawing elements or examples.	Gives vague or incorrect justification (e.g., "to make the drawing nice"), showing little understanding of their purpose.

Sample Answer

Using different line types like visible, hidden, and centre lines is crucial for accurately interpreting and communicating the design intent in technical drawings. Each line type serves a specific purpose:

Visible lines represent edges and outlines that are directly visible when the object is viewed.

Hidden lines indicate edges and features that are not directly visible in the current view, helping to reveal the complete geometry of the object.

Centre lines are used to denote axes of symmetry or indicate the centre of circular or cylindrical features. If these line types are used incorrectly or omitted, it can lead to misunderstandings and misinterpretations of the design. This might result in manufacturing errors, parts not fitting correctly, or assemblies failing to function as intended. Proper use of line types ensures clarity and precision, facilitating effective communication between designers, engineers, and manufacturers.

Q4. Specific Rubric for Feature-Based Technical Analysis (12 Marks Total)

A. TOLERANCE (4marks)

Level	Description
Excellent (4)	Clearly explains that tight tolerances improve fit/accuracy but require high-precision machining, frequent inspections, and increase cost. Gives a specific example (e.g., hydraulic valve leakage from small deviation).
Very Good (3)	Explains both the impact on fit and cost but with less technical depth or slightly vague examples.
Satisfactory (2)	Gives a general statement about fit or manufacturing difficulty. Example may be unclear or not well-connected.
Needs Improvement (1)	Only mentions one side (fit or manufacturing) or gives a minimal/ inaccurate explanation. The example is missing or off-topic.

SURFACE FINISH (4 marks)

Level	Description
Excellent (4)	Accurately links surface finish to sealing, sliding, or wear-critical parts. Explains how secondary operations like grinding increase cost. Gives a specific example (e.g., piston rings requiring smooth finish to reduce friction).
Very Good (3)	Explains effect on friction and finish-related processes, but with a less specific application. Example is appropriate.
Satisfactory (2)	Mentions rough/smooth surfaces and says they affect function, but no clear link to manufacturing. Vague example.
Needs Improvement (1)	Gives a basic definition only or mentions surface texture without explaining impact. No valid example.

C. MATERIAL SPECIFICATION (4 marks)

Level	Description
Excellent (4)	Explains how materials affect strength, corrosion, and machinability. Links to tool wear, production time, and performance. Gives precise example (e.g., stainless steel needed in marine environments).
Very Good (3)	Addresses most key aspects (e.g., machinability or corrosion), but with less technical detail or example, not fully developed.
Satisfactory (2)	Gives a basic explanation of the material type affecting performance. Little to no discussion of manufacturing challenges.
Needs Improvement (1)	Provides limited understanding. Mentions "strong material" or "hard to cut" with weak or no examples.

Expected answer

a. Tolerance

- **Impact on Manufacturing**

  Tolerances define the allowable deviation from specified dimensions. Tighter tolerances require high-precision machining, frequent inspections, and possibly rework, all of which increase production time and manufacturing costs. Achieving these tolerances often involves advanced CNC machines, temperature-controlled environments, and specialised tooling.

- **Impact on Performance**

  Tight tolerances are critical in high-performance or safety-critical assemblies, where even small deviations can affect fit, function, or reliability. They ensure precise mating of components, reduce vibration, and prevent premature wear.

Example

In a **hydraulic valve**, a spool must fit precisely within a bore. A deviation as small as 0.01 mm could lead to **internal leakage**, **loss of pressure**, or **system failure**.

b. Surface Finish

- **Impact on Manufacturing**

  Surface finish refers to the **texture and smoothness** of a surface, typically measured in **Ra (roughness average)**. Achieving a finer surface finish often requires **secondary processes** like **grinding, honing, or polishing**, which increase **cycle time**, **tool wear**, and **cost**.

- **Impact on Performance**

  Surface finish is especially important in **sealing surfaces**, **sliding parts**, or **wear-critical applications**. A smoother finish reduces **friction**, **heat generation**, and **component degradation**, while poor finish can cause **leakage**, **scoring**, or **mechanical failure**.

Example

A **piston ring** operating in a cylinder bore must have a **controlled surface finish**. If the surface is too rough, it will **wear the ring quickly**; if too smooth, it might **retain oil poorly**, affecting lubrication.

c. Material Specification

- **Impact on Manufacturing**

  Material specification determines a component's **strength, hardness, corrosion resistance**, and **thermal properties**, all of which affect **machinability**. Harder or exotic materials (e.g., titanium, Inconel) may cause **rapid tool wear**, require **slower cutting speeds**, and lead to **longer production times** and **higher costs**.

- **Impact on Performance**

  Using the correct material ensures that the component can withstand **operational loads**, **environmental conditions**, and **functional stresses**. The wrong choice can result in **structural failure**, **thermal deformation**, or **corrosion**.

Example

A component in a **marine environment** requires a material with **high corrosion resistance**, like stainless steel. Using a material with poor corrosion resistance would lead to **early rusting**, **weakening**, and **eventual failure** of the part.

Q5. Simple marking guide/scheme (40 marks)

A. SECTIONAL FRONT ELEVATION ON X–X

S/N	Task Description	Mark (s)
1	Draw in first angle projection	2
2	Draw full size	1
3	Draw outline of object	1
4	Correct representation of face J	1
5	Correct representation of face K	1
6	Correct representation of face L	1

7	Correct representation of the web	1
8	Proper hatching/sectioning of face L	1
9	Title: "Sectional Front Elevation on X–X"	1
10	Line quality and neatness	1
Total		11

B: END ELEVATION (ARROW Y DIRECTION)

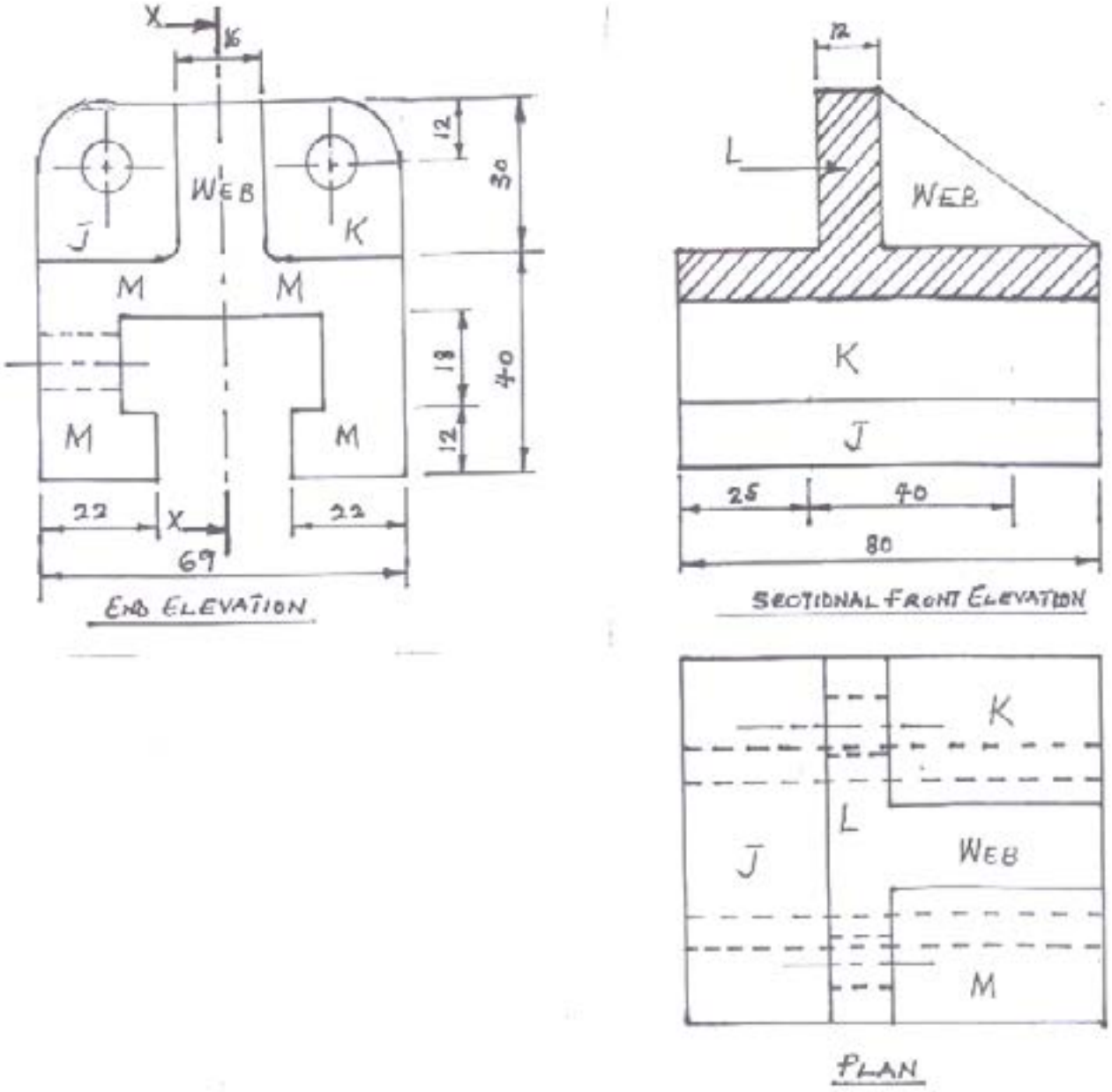
S/N	Task Description	Mark (s)
1	Draw full size	1
2	Draw outline of object	1
3	Draw 5 centre lines accurately	1
4	Draw the web	1
5	Draw face M	1
6	Draw faces J and K	2
7	Draw 2 – Ø10 holes in hidden lines	1
8	Draw the cutting plane X–X	1
9	Draw the 1 – Ø10 hole in hidden lines	1
10	Draw 2 × R12 fillets	2
11	Title: "End Elevation"	1
12	Line quality and neatness	1
	Total	**14**

C: PLAN Total: 16 Marks

S/N	Task Description	Mark (s)
1	Draw full size	1
2	Draw outline of object	1
3	Draw 2 centre lines accurately	1
4	Draw face J	1
5	Draw faces K and M	2
6	Draw the web	1
7	Draw face L	1
8	Draw the 2 – Ø10 holes in hidden lines	1
9	Draw groove in hidden lines	1
10	Title: "Plan"	1

11	Line quality and neatness	1
12	Show any 6 important dimensions	3 (0.5 mark each)
	Total	15

Sample answer



SECTION 4: RAPID PROTOTYPING TECHNOLOGIES AND APPLICATIONS

STRAND: DESIGN AND PROTOTYPING

Sub-Strand: Rapid Prototyping

Learning Outcome: Explain rapid prototyping (RP) technologies and use them to build a prototype

Content Standards

1. *Demonstrate understanding in rapid prototyping technologies I. (Week 13 & 14)*
2. *Demonstrate skills in rapid prototyping II. (Week 15 & 16)*

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the field of rapid prototyping, a key part of modern manufacturing that allows engineers to quickly convert digital designs into physical models. Over four weeks, students are guided through the fundamental principles, technologies, applications, and practical steps involved in rapid prototyping. The section emphasises hands-on learning, critical comparison, safety, and contextual application, preparing students to both understand and apply these technologies within Ghana's evolving manufacturing landscape. Key ideas include:

1. Understanding rapid prototyping: Learners explore the meaning of rapid prototyping and why it is important in modern manufacturing processes.
2. Classification of rapid prototyping technologies: Learners identify and classify different types of rapid prototyping systems based on the materials they use, such as solid, liquid, and powder-based methods.
3. Comparison of rapid prototyping technologies: Learners investigate how specific rapid prototyping technologies like fused deposition modelling (FDM), stereolithography (SLA), and selective laser sintering (SLS) work, and compare them based on accuracy, speed, cost, and material compatibility.
4. Industrial application of raping prototyping: Learners examine real-world examples of how rapid prototyping is used in industries such as automotive, healthcare, and education, including projects relevant to Ghana.
5. Building of prototypes: Learners design, evaluate and build simple 3D models using available rapid prototyping technologies.
6. At the end of this section, learners should be able to:
7. Understand the concept and classification of rapid prototyping technologies.
8. Compare different prototyping methods based on material type, accuracy, speed, and cost.

9. Identify industrial applications of rapid prototyping in local and global contexts.
10. Develop basic skills in preparing and post-processing 3D printed parts.
11. Apply safety and environmental considerations when working with prototyping tools and materials.
12. Collaborate in teams to evaluate and produce basic prototypes using available rapid prototyping technologies.

The weeks and the indicators covered by the section are:

Week 13: Explain the importance of rapid prototyping technologies.

Week 14: Distinguish between solid-based and liquid-based rapid prototyping technologies.

Week 15: Explain powder-based prototyping technology in manufacturing.

Week 16: Build a prototype using available technologies.

SUMMARY OF PEDAGOGICAL EXEMPLARS

Facilitators are expected to use a variety of pedagogical exemplars throughout the section to help learners fully understand and apply the concepts of rapid prototyping. During lessons, facilitators should engage learners in experiential learning activities such as preparing and simulating 3D print jobs, observing material behaviour, and practicing post-processing steps like sanding and finishing. Talk-for-learning should be used regularly through structured peer discussions, group presentations, guided questioning, and class debates to allow learners to express their ideas, compare methods, and justify their choices. Facilitators should also assign research-based tasks where learners investigate real-life applications of rapid prototyping technologies in different industries and local contexts. Additionally, learners should be guided through collaborative problem-solving and project-based exercises, including evaluating case studies, and building context-specific prototypes. These pedagogical approaches are intended to deepen the conceptual understanding of learners, develop their critical thinking skills, and enhance their ability to apply technical knowledge to real-world engineering challenges.

ASSESSMENT SUMMARY

To effectively evaluate learners' understanding and practical competence in rapid prototyping technologies, a range of assessment modes is employed to cater for diverse learning abilities and experiences. Oral assessments are conducted through class discussions, demonstrations, and presentations, allowing learners to explain the principles, processes, and significance of rapid prototyping technologies in modern manufacturing. These activities encourage learners to communicate technical ideas clearly and confidently.

Written assessments, including structured questions, short essays, and problem-solving tasks, are used to assess learners' understanding of rapid prototyping concepts, techniques, materials, equipment, and applications. Learners are also evaluated on their ability to analyse appropriate rapid prototyping methods for different manufacturing situations and justify their choices.

Practical activities form an essential component of the assessment, providing learners with opportunities to design, develop, and build prototypes using appropriate rapid prototyping technologies. Through project-based learning, practical demonstrations, and prototype evaluation, learners apply theoretical knowledge to solve real-world design and manufacturing problems while developing creativity, technical competence, and innovation. This comprehensive assessment approach ensures that learners not only understand the principles of rapid prototyping

but also demonstrate the practical skills required to design, construct, and evaluate functional prototypes. Table S2 provides a summary of the assessment methods aligned with the learning indicators. Table S4 shows a summary of the assessment strategies used in Section 4.

Table 7 Assessment summary for Section 4

Learning Indicator	DoK Level	Assessment Strategy and/or Mode
Explain the importance of rapid prototyping technologies.	Level 2	Learners provide written reports to explain case studies of various rapid prototyping technologies. They engage in group presentations to describe traditional and rapid prototyping, and perform practical prototyping tasks
Distinguish between solid-based and liquid-based rapid prototyping technologies.	Level 2	Learners complete tables comparing features of solid-based and liquid-based rapid prototyping technologies. They follow given criteria to select appropriate technologies and describe basic post-processing steps, including safety measures. Learners write short explanations about cost, safety, and material considerations and give brief presentations explaining their design choices.
Explain powder-based prototyping technology in manufacturing.	Level 2	Learners work in groups to give presentations that describe powder-based rapid prototyping technologies. They write short reports on how powder-based rapid prototyping is used in specific industries. Learners describe basic sustainability features and new developments, and they complete comparison charts showing differences between materials used in powder-based rapid prototyping.
Build a prototype using available technologies.	Level 4	Learners design and create functional prototypes and provide oral presentations justifying design choices. They also perform reflective evaluations of local challenges and provide sustainable solutions through the design and building of functional prototypes.

WEEK 13

Learning Indicator: Explain the importance of rapid prototyping technologies

Recap weeks

Year 2	**Week 16:** Discuss the applications of rapid prototyping in manufacturing.

Focal Area: Importance of rapid prototyping technologies

13.1 Introduction

Rapid prototyping is a group of manufacturing methods used to quickly produce a scale model or actual part of a design using computer-aided design (CAD) data. The most common type of rapid prototyping is 3D printing, where a machine builds an object layer by layer based on a digital file. This technology allows manufacturers, engineers, and designers to test their ideas quickly before going into full production. Rapid prototyping is especially useful when creating parts for new machines, tools, or consumer products, as it reduces the time and cost it would normally take to build models by hand. In the manufacturing industry, rapid prototyping helps convert creative designs into real physical models within hours or days. According to Gibson et al (2015), this process plays a key role in improving the design, testing, and development of products in various fields such as automotive, aerospace, architecture, and even healthcare.

13.2 Importance of Rapid Prototyping Technologies

(Refer to Year 2, Week 16: Discuss the applications of rapid prototyping in manufacturing)

Rapid prototyping technologies are important because they help engineers and designers bring their ideas to life faster, more accurately, and at a lower cost. Instead of waiting for weeks to build and test a product by hand, a prototype can be made within a few hours, helping teams to make quick improvements. This speeds up the design cycle and helps avoid costly mistakes in mass production. It also improves communication, since clients and team members can hold and test a real version of the product. Another reason why rapid prototyping is important is because it encourages creativity. Students and professionals can try out several ideas quickly, compare them, and choose the best one. Rapid prototyping also helps in custom production, where parts are made to fit specific needs, such as making a custom phone holder or medical implant. As 3D printers and similar tools become more common in schools and local workshops, learners can apply their theoretical knowledge through hands-on making. Figure 42 shows a well labelled 3D- printer.



Figure 42: *3D Printer (Prianto and Pramono, 2021)*

Notes for Facilitators

1. **Clarifying Concepts:** Use the drafting-to-model analogy. The traditional way: You draw a picture, then give it to a craftsman who takes weeks to build a model. With RP: You design it on the computer, and the 3D printer can print the model in hours. It›s like the difference between writing a letter and sending it, versus sending an email – both are communication, but one is much, much faster.
2. **Common Misconceptions:** Students might think RP is only for making plastic toys. Explain its vital role in Ghana: designing and testing a prototype for a low-cost medical device, creating a customised prosthetic limb, or even printing a replacement part for a broken agricultural machine that can›t be bought locally.
3. **Low-Cost Demonstration and Ghanaian Examples:** If the school has a 3D printer, bring it to class. If not, show high-quality videos of a print in progress. Discuss each part (filament, nozzle, build plate).

Learning Tasks

1. Learners recap the fundamental difference between conventional prototyping and rapid prototyping.
2. Learners explain the meaning and features of rapid prototyping and describe how a 3D printer works.
3. Learners explain ways in which rapid prototyping helps improve design and production using everyday items.
4. Learners work in groups to create simple prototypes using basic materials and evaluate the process.
5. Learners analyse a real-world case study to understand the impact of rapid prototyping in solving practical problems.

Pedagogical Exemplars

1. **Experiential Learning:** Provide learners with visual aids such as diagrams, animations, and if available, an actual or video demonstration of a 3D printer rapid prototyping technologies and lead them to discuss the importance of rapid prototyping in manufacturing. Organise their thoughts using concept maps or webbing. Learners will observe the printing process, label printer parts, and provide a written report describing the parts of a 3D printer and its operating principles.
2. **Experiential Learning:** Learners examine common classroom items such as phone cases, pen stands, or bottle caps, identify challenges faced in the use of traditional methods to produce these items, and suggest how prototyping could offer better, faster, or cheaper solutions. Learners present their findings in small groups, encouraging peer engagement and multiple perspectives.
3. **Project-based Learning:** Learners in mixed-ability groups design and build simple prototypes using clay, cardboard, or 3D printers if available. They will be assigned a real-world design task (e.g., "Design a mobile phone holder"), simulate prototyping stages, test their designs, and reflect on performance and design changes. Learners make oral presentations of their designs, discussing and comparing the traditional and 3D printing processes used and the associated challenges.
4. **Experiential learning:** Learners analyse a local case study such as a simple project undertaken in their school or community. Through guided reading, class discussions, and reflective writing, learners will make a written report discussing how prototyping helped solve design problems quickly and affordably.

Key Assessment Level 2: Report Writing

1. Describe the steps involved in turning a digital design into a physical prototype using a 3D printer. (10 marks)
2. Describe two materials commonly used in rapid prototyping and explain one typical application for each material. (10 marks)
3. Describe one example where rapid prototyping was used to solve a real-world problem. Explain how it helped improve the design or speed up the process. (10 marks)

PLC Session 13

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is report writing. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the report writing (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 14

Learning Indicator: Distinguish between solid-based and liquid-based rapid prototyping technologies

Recap weeks

Year 2	**Week 16:** Discuss the applications of rapid prototyping in manufacturing

Focal Area: Concepts of solid-based and liquid-based rapid prototyping technologies

14.1 Introduction

Rapid prototyping is an advanced manufacturing process that involves the fast and efficient creation of a physical model of a part or assembly using three-dimensional computer-aided design (CAD) data. This technique is essential in product design and development as it allows engineers and designers to quickly create prototypes for testing, validation, and improvement. Imagine needing a physical part for a new drone design. Instead of spending weeks machining it from metal or plastic, RP allows you to "print" it overnight. The process significantly enhances the ability to visualise and evaluate the design, ensuring that the final product will function as intended. Rapid prototyping plays a critical role in reducing time to market, minimising costs, and enabling innovation by allowing multiple iterations of a design in a cost-effective manner. In the context of manufacturing, rapid prototyping serves as a bridge between the digital and physical worlds, allowing ideas to move from computer screens to tangible objects. This process is especially useful in industries such as automotive, aerospace, healthcare, and consumer goods, where precision, customisation, and speed are paramount. By creating prototypes, manufacturers can test the form, fit, and function of a design before committing to full-scale production, thereby reducing the risk of costly errors and improving overall product quality. Rapid prototyping is also fundamental in fostering collaboration and communication among stakeholders, as it provides a concrete representation of a design that can be easily understood and critiqued. (Gibson et al., 2021). Solid-based and liquid-based rapid prototyping technologies represent two primary approaches to rapid prototyping technologies, each with distinct methods and applications.

14.2 Categories of rapid prototyping

Rapid Prototyping (RP), also known as 3D printing or Additive Manufacturing (AM), includes many different technologies, but they all fall into two main groups based on the starting material and how it becomes solid: **Solid-Based and Liquid-Based technologies**. This split is fundamental because it directly affects the materials you can use, the quality of the parts, the machines needed, and even safety rules. Knowing this difference helps you choose the right tool for a job (whether you need a tough functional part or a highly detailed model). Think of it like choosing between building with LEGO bricks (solid-based) versus sculpting with quick-hardening clay (liquid-based). Both make 3D objects, but the process, results, and tools are very different (Gibson et al., 2021).

14.3 Solid-Based Rapid Prototyping (Building with Solids)

Solid-based RP technologies all start with a material that is already solid. This does not mean a hard block like wood or metal. Instead, it usually means materials in forms like a thin plastic string (filament) or a fine powder (plastic, metal, or ceramic dust). The machine then adds, melts, or glues these solid bits together, layer by layer, to build the object. The two most common examples are Fused Deposition Modelling (FDM) and Selective Laser Sintering (SLS).

Fused Deposition Modelling (FDM) also called Fused Filament Fabrication (FFF) works like a super-precise, computer-controlled hot glue gun. A spool of plastic filament (like ABS or PLA) feeds into a heated nozzle. The nozzle melts the plastic and squeezes out a thin line of molten material onto a build platform. The printer moves the nozzle around to "draw" the shape of each layer as shown in Fig. 43. As the plastic cools, it hardens and sticks to the layer below. Imagine slowly drawing with a tube of toothpaste that hardens as it dries. FDM is popular because it's affordable, uses common plastics, and is relatively safe. However, parts often have visible layer lines and may need support structures to hold up overhanging sections during printing (Chua & Leong, 2017; Gebhardt et al., 2019).

Selective Laser Sintering (SLS) uses a bed of fine powder (nylon, metal, or ceramic) instead of filament as shown in Fig. 44. A thin layer of powder is spread across the build platform. Then, a high-power laser scans over the powder, tracing the shape of the part. Where the laser hits, the powder particles get just hot enough to fuse (sinter) together - like melting the edges of sugar cubes to stick them. The unfused powder stays loose and acts as a natural support for overhanging parts. After one layer is done, the platform lowers, a new layer of powder is spread, and the laser repeats the process. SLS is great for making strong, complex parts without extra supports, but the machines are expensive, powder handling requires safety gear, and the parts have a slightly rough, sandy surface (Gibson et al., 2021).

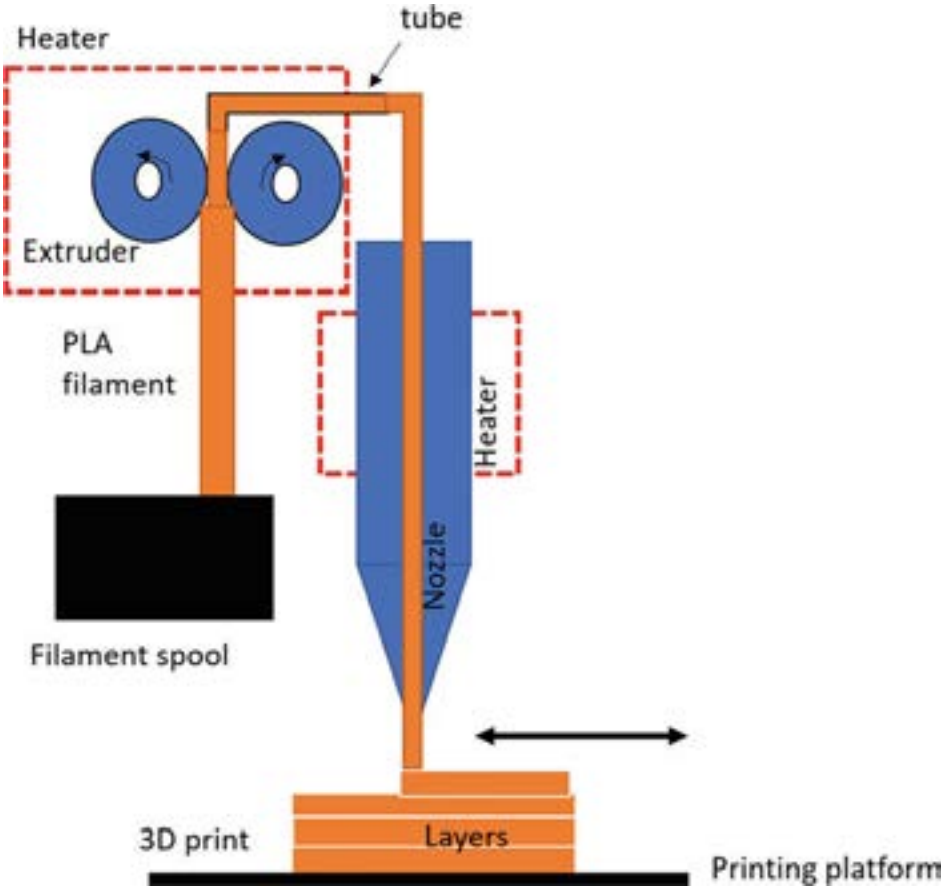


Figure 43: *Principle of fused deposition modelling (Mwena and Akinlabi, 2020)*

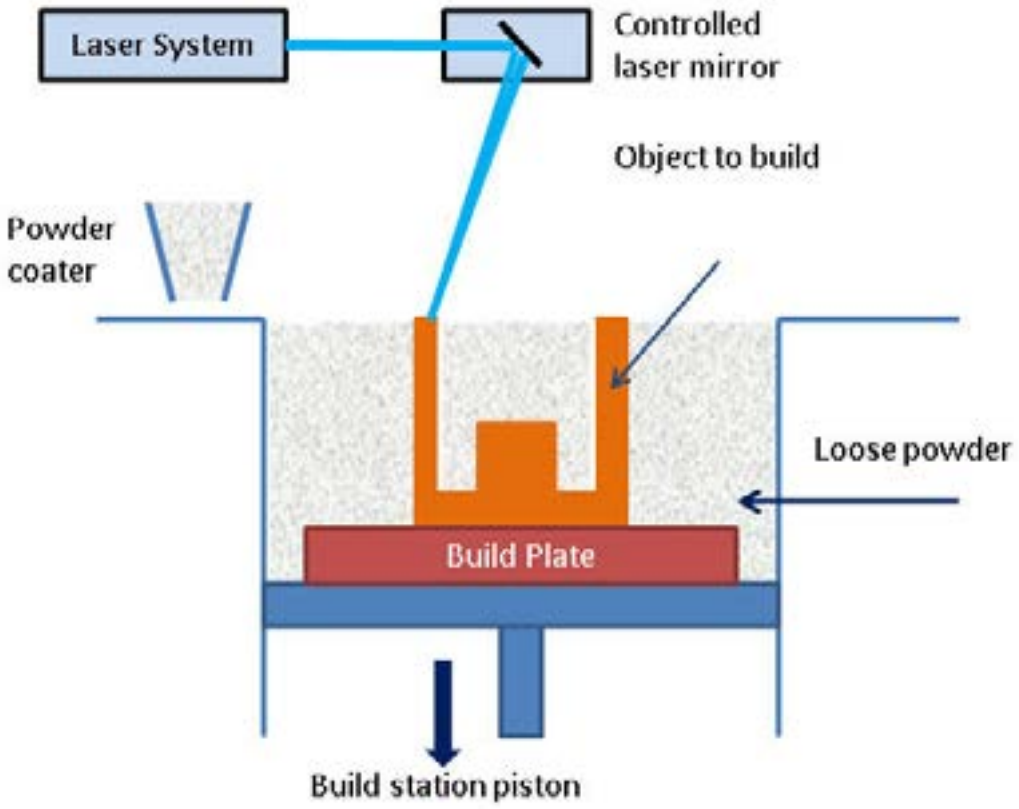


Figure 44: *Schematic diagram of the powder bed fusion process (Rieder et al., 2014)*

14.4 Liquid-Based Rapid Prototyping

Liquid-based RP technologies start with a liquid material, almost always a special type of plastic resin that hardens when exposed to light. This process is called photopolymerisation. Here, the machine uses light - usually ultraviolet (UV) light - to turn specific areas of the liquid into solid plastic, one layer at a time. The two most common methods are Stereolithography (SLA) and Digital Light Processing (DLP).

Stereolithography (SLA) is the oldest and most famous liquid-based technology. It uses a vat (tank) filled with liquid resin. A build platform starts just below the surface of the resin. A UV laser beam, controlled by moving mirrors, scans across the resin surface, tracing the shape of the first layer. Wherever the laser touches, the liquid resin instantly hardens into solid plastic. The platform then lowers slightly, dipping the hardened layer back into the resin and letting fresh liquid flow over it. The laser then traces the next layer, bonding it to the first. This repeats until the part is complete. Figure 45 shows a stereolithography 3D printing. SLA produces incredibly smooth, detailed parts - perfect for prototypes needing a high-quality finish, like figurines or dental moulds. However, the resin is sticky, toxic before curing, and requires careful handling with gloves. Parts also need washing in alcohol and extra UV curing after printing (Gibson et al., 2021; Gebhardt et al., 2019).

Digital Light Processing (DLP) works similarly to SLA but is often faster. Instead of a laser tracing each layer with a single point, DLP uses a digital projector screen (like in a movie theatre) to flash a full image of each layer onto the resin surface. This cures the entire layer at once, like a stamp, rather than drawing it line by line. Figure 46 is a schematic diagram of digital light processing. While DLP parts may have slightly less detail than SLA in some cases, they print faster and are excellent for small, intricate designs. Like SLA, DLP uses liquid resin and requires the same safety steps and post-processing (washing and curing).

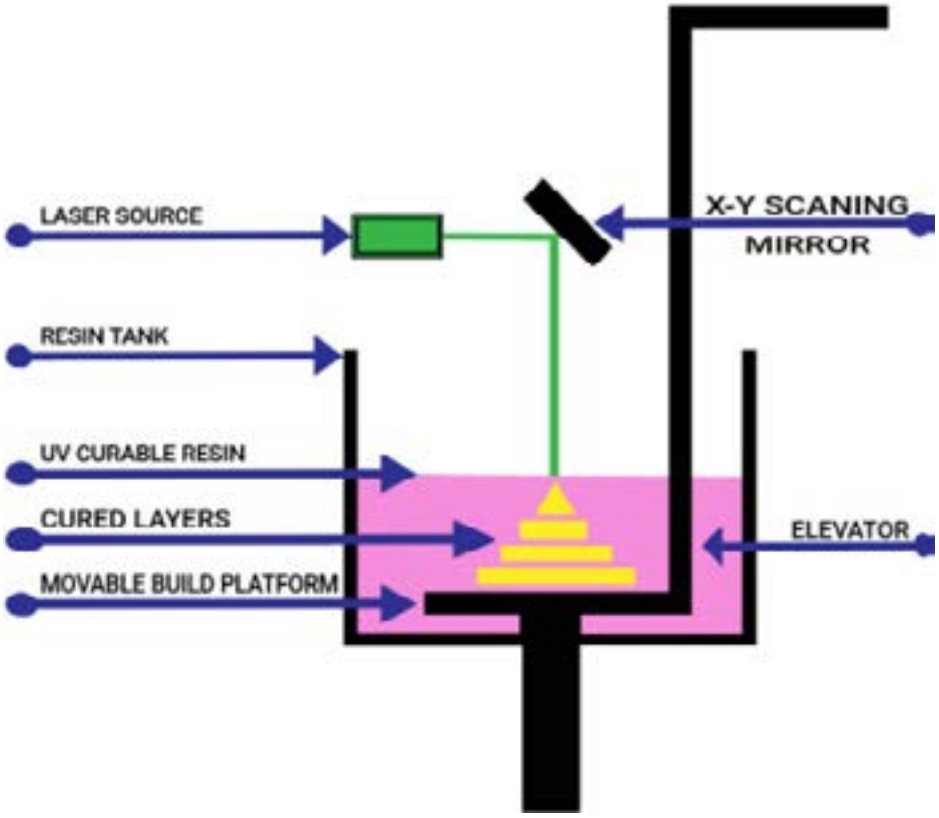


Figure 45: *Stereolithography 3D printing (Husna et al., 2024)*

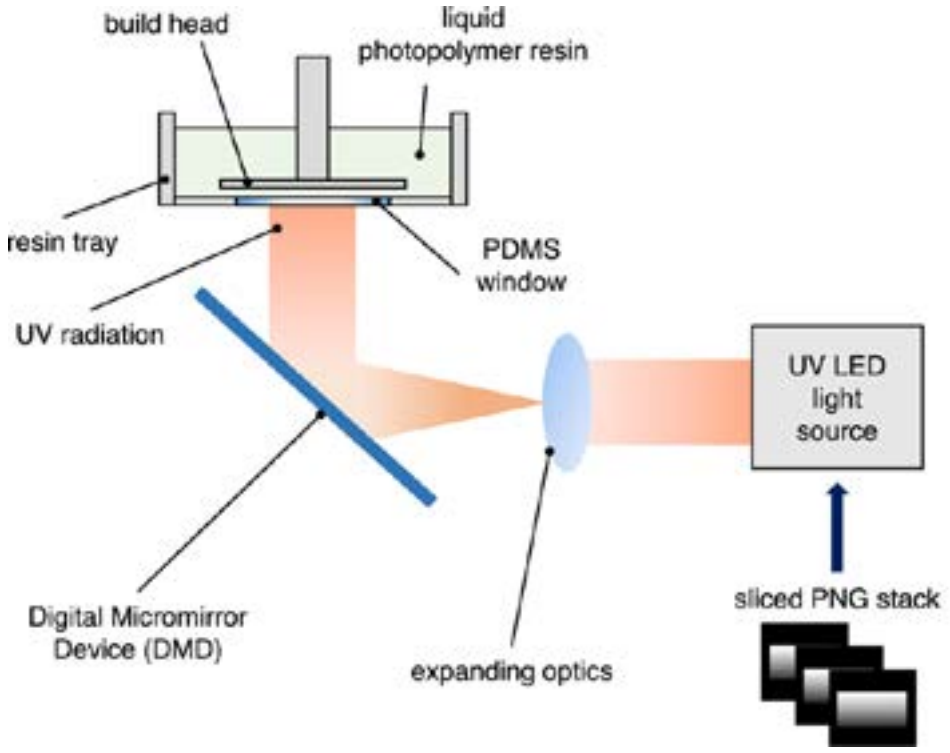


Figure 46: *Schematic diagram of digital light processing 3D printer (Sekmen et al., 2024)*

14.5 Differences between solid-based and liquid-based rapid prototyping

The most fundamental way to tell the difference between solid-based and liquid-based rapid prototyping (RP) is by looking at the starting material and how it becomes solid. Solid-based technologies begin with a solid material like plastic filament or powder, while liquid-based technologies start with a liquid resin. The way these materials are transformed into a solid

object – either through heat (for solids) or light (for liquids) – shapes everything about the process, the results, and how you use the technology. This difference is like comparing building a wall with bricks and mortar (solid-based) versus casting a wall in concrete (liquid-based). Both create walls, but the materials, tools, and steps involved are completely different (Gibson et al., 2021).

14.5.1 Starting Material State

Solid-based RP technologies always start with a material that is already in a solid form. This does not mean a hard block; instead, it is usually a thin plastic wire (filament) fed from a spool, like the plastic used in Fused Deposition Modelling (FDM), or a fine powder, such as nylon or metal powder used in Selective Laser Sintering (SLS). These materials feel solid to the touch even before printing begins. In contrast, liquid-based RP technologies start with a liquid resin stored in a tank or vat. This resin looks and flows like syrup or honey and only becomes solid when exposed to a special light source, typically ultraviolet (UV) light. You couldn't hold this material in your hand before printing without spilling it. This starting point is the first big clue to identifying the technology type (Gebhardt et al., 2019).

14.5.2 How the Material Becomes Solid (Bonding Mechanism)

The method used to turn the starting material into a solid object is the most important distinction. Solid-based technologies primarily rely on heat to bond the material together. In FDM, a hot nozzle melts the solid plastic filament, which then cools and hardens into a solid layer. In SLS, a powerful laser heats the powder particles just enough to make them fuse or "sinter" together at their surfaces without fully melting. Think of it like using a heat gun to melt plastic together or using a laser to weld powder grains. Liquid-based technologies, however, use light energy (almost always UV light) to cause a chemical reaction in the liquid resin called photopolymerisation. When the light hits the resin, it triggers the liquid molecules to link together into solid chains very quickly, turning the liquid into solid plastic instantly, like magic glue activated by a flashlight. No heat is needed to melt anything; the light itself causes the hardening (Chua & Leong, 2017).

14.5.3 Surface Quality and Detail

The way the material is bonded dramatically affects how smooth and detailed the final printed object looks. Liquid-based technologies (like Stereolithography - SLA and Digital Light Processing - DLP) are famous for producing parts with very smooth surfaces and extremely fine details. Because the liquid resin is fluid and the light (laser or projector) can be focused very precisely, these technologies can capture tiny features, sharp edges, and smooth curves exceptionally well. They are often used for detailed prototypes, jewellery, dental models, or figurines where appearance matters. Solid-based technologies typically produce parts with a rougher surface. FDM parts almost always show visible layer lines, like tiny ridges, because the extruded plastic strands sit slightly on top of each other. SLS parts have a slightly grainy or sandy texture because they are made from fused powder particles. While these surfaces can be sanded or smoothed later, they won't match the natural smoothness of a liquid-based print right off the machine (Gibson et al., 2021).

14.5.4 Material Properties and Strength

The types of materials available and the strength of the final parts also differ significantly. Solid-based technologies, especially FDM, use thermoplastics – the same kinds of plastics used in everyday items like water bottles or car parts (e.g., PLA, ABS, PETG, Nylon). These materials are generally tough, durable, and resistant to impact and heat to some degree. SLS can also use

nylons and even metal powders, creating parts strong enough for functional prototypes or even end-use components in machines. Liquid-based technologies use photopolymer resins. While offering amazing detail, most standard resins tend to be more brittle (can snap more easily) and less resistant to long-term heat or sunlight exposure compared to thermoplastics. Specialised tough or flexible resins exist, but they generally don't match the durability and temperature resistance of common FDM or SLS materials for heavy-duty applications (Gebhardt et al., 2019).

14.5.5 Support Structures and Post-Processing

Almost all RP technologies need support structures to hold up parts of the model that hang in mid-air during printing. How these supports work and what you have to do after printing (post-processing) is another key difference. In FDM (solid-based), separate support structures are printed alongside the main part, often using a different material or pattern. These supports must be manually broken or cut away after printing, which can leave marks or require sanding. SLS is unique because the unfused powder surrounding the part acts as its own support, so no extra structures are needed; you just dig the part out of the powder when done. For liquid-based technologies (SLA/DLP), supports made of the same cured resin as the part are always needed to anchor the object to the build platform and hold overhangs. Removing these requires careful cutting and often leaves small marks. Crucially, liquid-based parts require extensive washing in solvents like isopropyl alcohol to remove sticky, uncured resin from the surface, followed by additional curing under UV light to fully harden the part. Solid-based FDM parts generally only need support removal and maybe some sanding; they don't require chemical washing or extra curing (Gibson et al., 2021).

14.5.6 Safety and Handling

Safety considerations are very different between the two categories. Solid-based FDM is generally the simplest and safest for a classroom. The main hazards are touching the hot nozzle (like touching a hot glue gun) and potential fumes from melting plastic, so good ventilation is important. SLS requires handling fine powders, which means masks are needed to avoid breathing in particles, and the lasers are powerful and enclosed. Liquid-based technologies pose more significant handling risks. The uncured liquid resin is toxic and irritating; it can cause skin rashes and eye damage. Gloves and safety glasses are absolutely mandatory when handling resin, resin-filled vats, or uncured parts. Resin spills also need careful cleanup. The solvents used for washing (like isopropyl alcohol) are flammable and require careful storage and use. This makes liquid-based processes generally messier and require stricter safety protocols than desktop FDM (Gebhardt et al., 2019).

14.5.7 Typical Uses and Cost

Because of their different strengths and weaknesses, solid-based and liquid-based technologies are often chosen for different jobs. Solid-based FDM is great for functional prototypes – parts that need to be strong, durable, and tested under real conditions, like brackets, gears, or casings. It's also the most affordable; basic desktop FDM printers are common in schools. SLS is excellent for complex, strong parts without supports, used in aerospace or custom manufacturing, but the machines are very expensive. Liquid-based SLA/DLP is the go-to for high-detail models where appearance, accuracy, and smooth surfaces are critical, such as architectural models, intricate art pieces, jewellery prototypes, or dental/medical models. Desktop resin printers are affordable for detail work, but resin costs more per part than filament.

Understanding the core differences between solid-based and liquid-based rapid prototyping empowers manufacturers to make smart choices. If they need a tough part for a robot, they will

lean towards solid-based FDM or SLS. If they need a super-smooth, detailed model of a sculpture, liquid-based SLA/DLP is the clear choice. They will also understand the safety steps needed (gloves for resin vs. care with heat for FDM) and the post-processing work involved (washing resin parts vs. removing/sanding FDM supports). This knowledge moves them from just knowing names to truly understanding how and why to use different 3D printing technologies (Gibson et al., 2021).

14.5.8 What is the Purpose of Your Prototype?

Start by asking: What will this prototype do? If you need a functional part – something that must be strong, durable, handle stress, or fit with other components (like a gear, bracket, or tool handle) – solid-based technologies are usually better. Fused Deposition Modelling (FDM) uses tough thermoplastics (like PLA, ABS, or nylon) that can withstand impacts and moderate heat, similar to many everyday plastic items. Selective Laser Sintering (SLS) can make even stronger parts from nylon or metal powders, ideal for parts that need to work under real-world loads. If your priority is visual appearance, fine details, or smooth surfaces – for models like figurines, architectural designs, jewellery prototypes, or dental moulds – liquid-based technologies like Stereolithography (SLA) or Digital Light Processing (DLP) excel. These methods produce incredibly smooth surfaces and capture tiny details far better than typical solid-based prints because they use precise light to cure liquid resin layer by layer, resulting in almost glass-like finishes right off the printer (Gebhardt et al., 2019).

14.5.9 Material Requirements

Consider the material properties your prototype needs. Solid-based technologies, especially FDM, offer a wide range of common, affordable thermoplastics with properties similar to injection-moulded plastics. These include PLA (easy to print, biodegradable), ABS (tougher, heat-resistant), PETG (strong, chemical-resistant), and nylon (flexible, durable). SLS expands this to include metals and ceramics for industrial applications. Liquid-based technologies use photopolymer resins. While resins offer amazing detail and smoothness, standard formulations tend to be more brittle (can snap or crack more easily under stress) and less stable when exposed to heat, sunlight, or chemicals over time compared to thermoplastics. Specialised "tough" or "flexible" resins exist but are more expensive and still often lag behind FDM/SLS materials for pure mechanical performance. If your part needs to be functional and durable, solid-based materials are generally superior. If surface quality is king and the part won't face heavy loads, resin is a great choice (Gibson et al., 2021).

14.5.10 Safety and Classroom Environment

Safety is paramount, especially in a high school setting. Solid-based FDM is generally the safest and easiest to manage. The main hazards involve the hot nozzle (similar to a hot glue gun) and potential fumes from melting plastics, requiring ventilation but minimal personal protective equipment (PPE) beyond caution. SLS involves fine powders requiring masks to avoid inhalation and powerful lasers confined within the machine. Liquid-based technologies pose significantly greater handling risks. The uncured liquid resin is toxic – it can cause skin irritation, allergic reactions, and eye damage. Gloves and safety glasses are mandatory whenever handling resin, resin vats, or uncured parts. Resin spills require careful cleanup. Furthermore, post-processing involves washing parts in flammable solvents like isopropyl alcohol, demanding proper storage and ventilation. The extra safety protocols and chemical handling make liquid-based printing messier and more complex to manage in a busy classroom than FDM (Gebhardt et al., 2019).

14.5.11 Cost and Accessibility

Budget and resource availability are crucial considerations. Solid-based FDM printers are the most affordable and accessible, making them ideal for schools and hobbyists. The plastic filament is also relatively inexpensive. While industrial SLS machines are costly, desktop FDM dominates the educational market. Liquid-based desktop SLA/DLP printers are also widely available and have become more affordable. However, the liquid resin itself costs significantly more per part than FDM filament. Additionally, you must factor in the cost of consumables for post-processing: isopropyl alcohol for washing and potentially a separate UV curing chamber. The lower upfront printer cost can be offset by higher ongoing material and consumable expenses for resin printing. For cost-conscious prototyping of functional parts, FDM is hard to beat. For high-detail models where the cost is justified, resin printing is accessible.

14.5.12 Post-Processing Time and Effort

Think about the work required after the print finishes. Solid-based FDM parts generally need relatively simple post-processing: physically removing any support structures (which can sometimes leave marks requiring light sanding) and that's often it. SLS parts need to be removed from the powder bed and cleaned of excess powder, but no support removal is needed. Liquid-based SLA/DLP parts require extensive post-processing that is mandatory, not optional. Parts must be carefully removed from the build platform, support structures (made of cured resin) must be meticulously cut away, the parts must be thoroughly washed in solvent (like IPA) to remove sticky uncured resin, and then they need a final cure under UV light to achieve full strength and stability. This process is messier, takes more time, and involves handling chemicals. If quick turnaround is needed, FDM often wins. If perfection is required and the extra steps are acceptable, resin delivers (Gibson et al., 2021).

14.6 Making the Decision: A Simple Framework

The questions below serve as a guide when choosing solid-based or liquid-based RP technology:

1. Function or Form? Does my prototype need to be strong and work (Function)? Pick Solid-Based (FDM/SLS). Does it need to look super smooth and detailed (Form)? Pick Liquid-Based (SLA/DLP).
2. Safety First: Am I prepared to handle toxic resin safely with gloves and eye protection, and manage solvents? If not, stick with Solid-Based FDM.
3. Budget Check: Can I afford the ongoing cost of resin and cleaning supplies? Filament for FDM is cheaper.
4. Time and Effort: Do I have time for washing and curing resin parts? FDM parts are ready faster with less fuss.

14.7 Real-World Example: Choosing for a Class Project

Imagine students are designing a custom phone holder.

Scenario A: They need a sturdy holder to mount on a bike. It must survive bumps and weather.

Choice: Solid-Based FDM**.** Why? Needs strength and durability (thermoplastics like PETG or ABS). Low cost. Safe for classroom use. Surface finish isn›t critical.

Scenario B: They are creating an artistic, decorative holder shaped like a dragon with intricate scales.

Choice: Liquid-Based SLA/DLP**.** Why? Needs high detail and smooth surfaces. Functionality (holding the phone) is simple. The artistic detail justifies the extra cost and handling precautions.

Notes for Facilitators

1. **Clarifying Concepts:** The fundamental difference is the state of the material and how it is solidified. Use the LEGO (solid) vs. clay (liquid) analogy. Solid-based (FDM, SLS) builds with solid bits (melted string or fused powder). Liquid-based (SLA, DLP) builds with a liquid that is cured into a solid by light.
2. **Common Misconceptions:** Students may think one technology is better. Explain that it is about fit-for-purpose. FDM is like a work truck – rugged, functional, and cost-effective. SLA is like a sports car – smooth, detailed, and precise, but more delicate and expensive to maintain.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Safety Demonstration:** If using an SLA printer, demonstrate proper safety protocol. Show students the gloves, goggles, and the isopropyl alcohol for washing. Explain that uncured resin is toxic and must be handled carefully. For FDM, demonstrate the hot nozzle and explain that touching it would cause a burn. This makes safety very tangible.
    b. **Cost Comparison:** Show students a spool of PLA filament and a bottle of resin. Ask them to guess which is more expensive per kilogram. Then reveal the cost difference, explaining that the higher cost of resin is one factor in choosing a technology.

Learning Tasks

1. Learners recap the applications of rapid prototyping in manufacturing.
2. Learners examine physical samples, videos, or simulations of FDM and SLA machines and describe the processes involved in each technology.
3. Learners create a decision tree or chart to guide the selection between solid-based and liquid-based prototyping technologies based on specific product needs.
4. Learners simulate post-processing steps of both technologies and report on the safety precautions and handling techniques required.
5. Learners write and peer-review comparative essays that analyse the differences between solid-based and liquid-based RP technologies in terms of cost, safety, material properties, and surface quality.

Teacher Note: *For safe simulation of resin poSAProcessing, use water with food colouring to represent uncured resin, clean water for washing, and PlayDoh for support removal, while emphasising that real resin requires gloves, goggles, and ventilation.*

Pedagogical Exemplars

1. **Experiential Learning:** Show learners videos of solid-based rapid prototyping technologies such as selective sintering, laminated objective manufacturing, and fused deposition modelling, and liquid-based rapid prototyping technologies such as stereo lithography, solid ground curing, and droplet deposition manufacturing.
2. **Talk for Learning:** Learners to discuss the difference between solid-based and liquid-based rapid prototyping based on their basic concepts and techniques. Organise ideas and views using mind maps.

3. **Talk-for-Learning:** Learners engage in peer-pair activities to review the applications of rapid prototyping in manufacturing. Learners make mind-maps to show the applications of rapid prototyping in the automobile, aerospace, medical and construction industries.
4. Learners interact directly with 3D printer models (if available) or visual simulations. In pairs, they observe FDM and SLA printing operations and record observations in a comparative table, highlighting differences in material input, bonding mechanism, post-processing, and final part appearance. Through talk-for-learning, learners explain their findings in peer group discussions and construct a shared understanding of how solid and liquid-based technologies differ in practice.
5. In groups, learners review different design case studies (e.g., strength vs. detail requirements) and construct a selection guide. This activity integrates experiential learning (evaluating material properties from printed samples or case visuals) and talk-for-learning as groups discuss and debate which technology best suits different scenarios. Learners present their flowcharts or decision trees to the class and justify their criteria through oral explanation.
6. Through experiential learning, learners engage in mock post-processing tasks (e.g., removing support structures from cardboard FDM parts or role-playing resin washing procedures using non-toxic liquids). This is followed by small-group discussion (talk-for-learning), where students explain the safety requirements and challenges of each process. Groups will summarise and present safety protocols for each technology.
7. Learners draft comparative essays based on class activities and their decision trees. In talk-for-learning mode, they exchange drafts with peers for feedback and revise their work accordingly. Facilitators guide reflective discussions to help learners evaluate the real-world implications of their analysis.

Key Assessment Level 4: Presentations

1. Compare FDM *(Fused Deposition Modelling)* and SLA *(Stereolithography)* technologies by listing how they differ in terms of material state, bonding method, and post-processing. Based on this comparison, state which method would be better for making a small decorative sculpture and give one reason why. (10 marks)
2. Choose one rapid prototyping method that would be suitable for making a strong and safe prototype in a school. Name the method, and explain how its material, machine safety, and post-processing make it suitable. (10 marks)

   Not for facilitator: *FDM is safer for schools because it uses nontoxic solid filament, requires minimal PPE (just eye protection and care around the hot nozzle), has lower cost and maintenance, and produces no hazardous chemical waste, unlike resin printers which need toxic resins, gloves, goggles, and flammable solvents.*
3. Describe how surface quality and support structures are different in SLS and DLP printing. How might these differences affect which one is chosen for a medical product? (10 marks)

PLC Session 14

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 15

Learning Indicator: Explain powder-based prototyping technology in manufacturing

Focal Area: Concept of powder-based prototyping technology in manufacturing

15.1 Introduction

Powder-based rapid prototyping is a type of additive manufacturing (3D printing) that uses fine powders, like plastic, metal, or ceramic, to build objects layer by layer. Imagine spreading a thin layer of powder over a build platform and then using a laser, heat, or glue to selectively stick parts of that powder together into a solid shape. After one layer is done, the platform lowers slightly, a new layer of powder is spread, and the process repeats until the entire object is formed. This method is different from solid-based technologies (which use pre-formed sheets or rods of material) or liquid-based ones (which start with liquid resins cured by light). Instead, powder-based systems offer unique advantages, such as the ability to create highly complex shapes, hollow structures, or interlocking parts without extra support materials, since the surrounding loose powder acts as a natural support during printing. In manufacturing, powder-based prototyping plays a critical role because it speeds up product development, reduces material waste, and enables custom designs that traditional methods struggle with. This technology also supports sustainability by recycling unused powder for future prints. Its versatility makes it ideal for small-batch production, rapid tooling, and creating parts with intricate geometries, transforming how engineers approach design and manufacturing challenges (Gibson et al., 2020).

15.2 Types of powder-based rapid prototyping technologies

Powder-based rapid prototyping technologies are a subset of additive manufacturing techniques that use fine powders as the primary material to create three-dimensional objects. These technologies are integral in modern manufacturing, offering versatility and precision in producing complex parts. Understanding the different types of powder-based rapid prototyping technologies is crucial for students learning about advanced manufacturing processes.

15.2.1 Selective Laser Sintering (SLS)

Selective Laser Sintering (SLS) is one of the most prominent powder-based rapid prototyping technologies. In SLS, a high-powered laser selectively fuses powdered material, such as nylon, ceramics, or metals, to form a solid structure. The process begins with a thin layer of powder spread evenly across a build platform. The laser then traces the design of each layer, sintering the powder particles together. Once a layer is completed, the build platform lowers slightly, and another layer of powder is spread. This process repeats until the entire model is built. SLS is particularly valued for its ability to produce durable and heat-resistant parts with complex geometries, making it popular in industries like aerospace and automotive (Kalpakjian and Schmid, 2020). Figure 47 shows a schematic diagram of the selective laser sintering process.

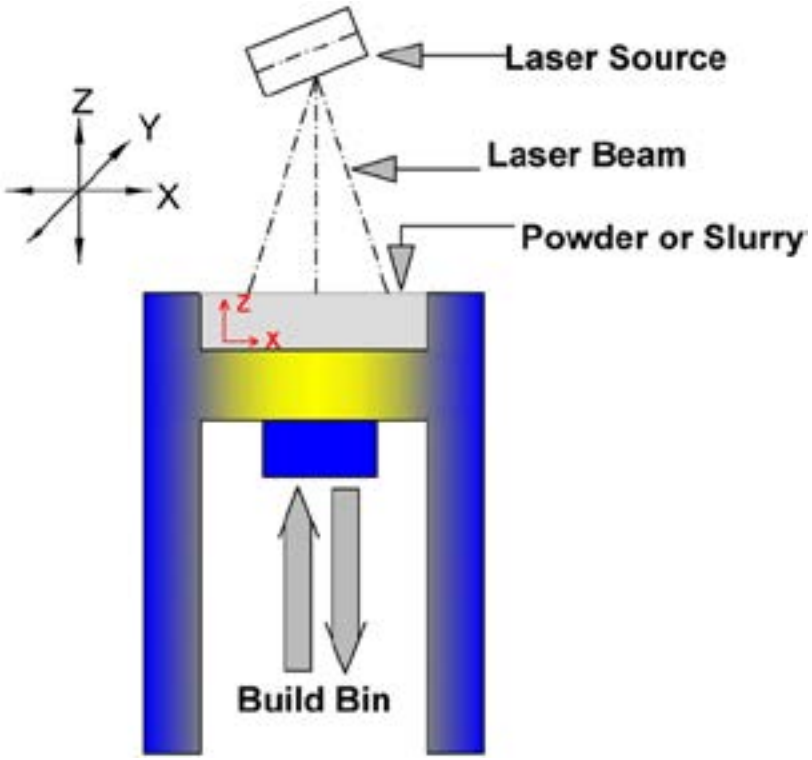


Figure 47: *Schematic diagram of selective laser sintering (Shakor et al., 2019)*

15.2.2 Binder Jetting

Binder Jetting is another type of powder-based rapid prototyping technology. Unlike SLS, Binder Jetting does not use a laser to sinter powder. Instead, it involves depositing a liquid binding agent onto the powder bed, adhering the powder particles together to form each layer. The process involves spreading a layer of powder, which is selectively bonded by the binder according to the design. The platform then lowers, and the process is repeated as shown in Fig. 48. After printing, the object is removed and typically requires post-processing, such as curing or sintering, to achieve the desired strength and finish. Binder Jetting is known for its ability to produce parts quickly and cost-effectively, making it suitable for prototyping and small batch production (Gibson et al., 2014).

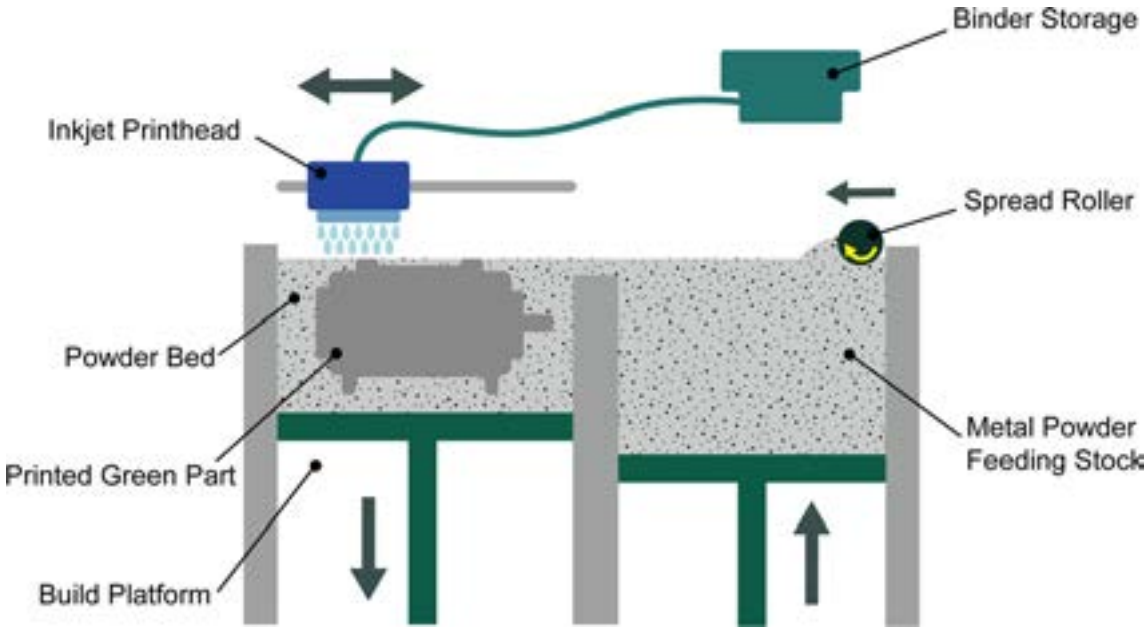


Figure 48: *Schematic diagram of binder jetting 3D printing process (Wang et al., 2024).*

15.3 Materials Used in Powder-Based Prototyping

Powder-based rapid prototyping technologies are at the forefront of manufacturing innovation, allowing for the creation of complex and high-quality parts using fine powder materials. Understanding the materials used in these technologies is crucial, as it affects the properties, applications, and performance of the final product. The selection of materials in powder-based prototyping is influenced by the desired mechanical properties, surface finish, and the specific application requirements. Different materials, including polymers, metals, ceramics and composite powders exist for use in powder-based prototyping.

15.4 Process of Powder-Based Prototyping

Powder-based rapid prototyping is a sophisticated manufacturing process that transforms digital designs into physical objects using fine powders. This process is integral to modern manufacturing due to its ability to produce complex and detailed parts efficiently. Understanding the step-by-step process of powder-based prototyping is essential for learning about advanced manufacturing technologies. Figure 49 is a summary of the step-by-step process of the powder-based prototyping technique.



Figure 49: *Step-by-step process of powder-based prototyping*

15.5 Creation of a 3D CAD Model

The process begins with the creation of a three-dimensional (3D) computer-aided design (CAD) model of the part to be manufactured. This digital model serves as the blueprint for the entire prototyping process. It is crucial to ensure that the model is accurate and detailed, as any errors or omissions will be reflected in the final product. Learners should understand the importance of precision in this initial step, as it lays the foundation for the entire prototyping process. (Kalpakjian & Schmid, 2020).

15.5.1 Conversion to STL Format

Once the 3D CAD model is complete, it is converted into a Standard Tessellation Language (STL) file. The STL format breaks down the model into a series of triangles, which can be easily interpreted by the prototyping machine. This conversion is critical because it allows the digital design to be sliced into thin layers, which will be built sequentially during the prototyping process (Gibson, Rosen, & Stucker, 2014).

15.5.2 Layer Slicing

The STL file is then sliced into thin horizontal layers using specialised software. Each slice represents a cross-section of the final part and serves as a guide for the prototyping machine to follow. This slicing process is essential because powder-based prototyping builds parts layer by layer. By understanding this step, students can appreciate how complex geometries and intricate details are accurately reproduced in the final model. (Simpson, Yu, & Jiao, 2020).

15.5.3 Powder spreading and layer building

The actual prototyping begins with the spreading of a thin layer of powder across the build platform. A mechanism, such as a roller or blade, ensures that the layer is even and smooth. For each layer, a laser or other energy source selectively fuses the powder particles according to the design specified in the slice. This process is repeated layer by layer, with the platform lowering slightly after each pass, until the entire part is built (Chua, Leong, & Lim, 2010).

15.5.4 Post-processing

After the part is fully formed, it undergoes post-processing to enhance its properties and appearance. This may involve removing excess powder, sintering to increase strength, or applying finishes to improve surface quality. Post-processing is crucial for achieving the desired mechanical properties and aesthetics of the final product. Students should recognise the importance of this step in ensuring the functionality and quality of the prototype (Kalpakjian & Schmid, 2020).

15.6 Applications of Powder-Based Prototyping

Powder-based rapid prototyping technologies have transformed the way products are developed and manufactured across various industries. These technologies, which include methods like Selective Laser Sintering (SLS) and Binder Jetting, offer unique advantages that make them suitable for a wide range of applications. Understanding these applications is crucial for students as they explore the capabilities and potential of powder-based prototyping in manufacturing.

15.6.1 Concept models and validation

Powder-based prototyping is instrumental in the creation of concept models, which are physical representations of new product ideas. These models allow engineers and designers to test and validate their concepts early in the development process. By creating tangible prototypes, stakeholders can evaluate the feasibility, functionality, and aesthetics of a design, facilitating informed decision-making. This application is particularly beneficial in industries like consumer electronics and industrial design, where rapid iteration and feedback are essential (Kalpakjian and Schmid, 2020).

15.6.2 Functional prototyping

Powder-based technologies are widely used for functional prototyping, which involves creating prototypes that closely mimic the final product in terms of materials and functionality. These prototypes undergo rigorous testing to ensure they meet performance standards and design specifications. Industries such as automotive and aerospace frequently use functional prototypes to test new components under real-world conditions, helping to refine designs and reduce time to market (Gibson et al., 2014).

15.6.3 Customisation and personalisation

The ability to produce customised and personalised products is a significant advantage of powder-based prototyping. This capability is crucial in industries where products need to be tailored to individual needs, such as healthcare and fashion. For example, in the medical field, powder-based prototyping is used to create patient-specific implants and prosthetics, ensuring a perfect fit and improved patient outcomes. Similarly, in fashion, designers can create unique, customised pieces that cater to individual preferences (Simpson et al., 2020).

15.6.4 Tooling and Jigs

Powder-based prototyping is also used to produce specialised tools, jigs, and fixtures that aid in the manufacturing process. These tools can be created quickly and cost-effectively, enhancing

production efficiency and reducing downtime. This application is particularly useful in industries such as automotive manufacturing, where custom jigs and fixtures are essential for assembling complex components (Chua, 2010).

15.6.5 Spare parts production

Industries such as automotive and aerospace rely on powder-based prototyping for the quick and efficient production of spare parts. This capability is crucial for maintenance and repair services, where downtime must be minimised. By using powder-based technologies, manufacturers can produce spare parts on-demand, reduce inventory costs and improve service efficiency (Gibson et al., 2014).

15.6.6 Education and training

In educational settings, powder-based prototyping serves as a valuable tool for teaching students about product design, manufacturing processes, and hands-on problem-solving. By engaging with these technologies, students gain practical experience and develop skills that are directly applicable to careers in engineering and manufacturing (Kalpakjian and Schmid, 2020).

Notes for Facilitators

1. **Clarifying Concepts:** Powder-based (SLS, Binder Jetting) is like selective gluing of a powder bed. Imagine you have a sandbox. If you could spray a special glue in the shape of a house, then bury it under more sand, and repeat, you would eventually have a solid sandstone house buried in loose sand. You then dig it out. The loose sand is the built-in support structure.
2. **Common Misconceptions:** Students may think powder-based is just a type of solid-based. Clarify the key difference: solid-based FDM uses a continuous strand of material; powder-based uses discrete particles. This allows for overhangs and complex internal geometries without needing to print separate support structures.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Natural Analogy:** Show students a box of loose sand and a model of a sandcastle that was sintered by the sun. Explain that SLS uses a laser to do the same thing, but with plastic or metal powder.
    b. **Local Context:** Discuss how SLS can be used to create very durable custom jigs and fixtures for a local assembly plant. The ability to create complex, interlocking parts in one piece is a huge advantage.

Learning tasks

1. Learners research and present on different powder-based prototyping technologies
2. Learners perform case study analysis on the applications of powder-based prototyping.

Pedagogical Exemplars

1. Divide learners into mixed-ability groups to research various powder-based rapid prototyping technologies such as Selective Laser Sintering (SLS), Binder Jetting, and Multi-Jet Fusion (MJF). Each group will explore the process, materials, applications, advantages, and limitations of their assigned technology. Learners will present their findings through a chosen medium, such as a PowerPoint presentation, video, or poster, which encourages creativity and engagement. This task enhances their research skills and deepens their understanding of powder-based prototyping technologies.
2. In groups, learners will analyse case studies from industries such as aerospace, automotive, and medical devices to understand real-world applications of powder-based prototyping. They will identify how these technologies are used to solve specific challenges, focusing on the advantages and limitations encountered. Each group will prepare a report detailing their findings and present it to the class for discussion and feedback. This task fosters critical thinking and application of theoretical knowledge to practical scenarios.

Key Assessment Level 2: Group Presentation

1. Describe two ways powder-based prototyping technologies have improved manufacturing practices. How do these improvements relate to innovation or sustainability? (5 marks)
2. List one challenge and one opportunity of using powder-based prototyping with traditional manufacturing. Explain how each one affects the process. (5 marks)
3. Name one new material used in powder-based prototyping. Explain how it helps improve the prototyping process or product performance. (5 marks)
4. Give one way powder-based prototyping helps with product customisation. How does this affect customers or manufacturers? (5 marks)

PLC Session 15

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

    a. The key assessment for the week is group presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

    b. all teachers in the group work through a similar problem individually for 3–4 minutes

    c. the group then works through the problem together step by step

    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

    b. After the enactment, ask for structured feedback from the group

        i. was the concept explained in a way that a learner with no prior knowledge could follow?

ii. were the examples grounded in contexts familiar to Ghanaian learners?

iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 16

Learning Indicator: Build a prototype using available technologies

Recap week

Year 1	**Week 11:** Demonstrate understanding of the design process

Focal Area: Building of Prototypes using rapid prototyping

16.1 Introduction

Rapid prototyping is a transformative technology in the field of manufacturing, empowering engineers and designers to swiftly convert digital designs into physical models. This process is crucial in today's fast-paced product development environment, where speed, accuracy, and flexibility are highly valued. The building of prototypes using rapid prototyping involves understanding fundamental principles of rapid prototyping, the technologies involved, and its applications in various industries.

At its core, rapid prototyping is a type of additive manufacturing that constructs objects layer by layer from a digital 3D model. This contrasts with traditional subtractive methods, which remove material from a solid block to create the desired shape. The rapid prototyping process begins with the creation of a detailed 3D computer-aided design (CAD) model. This model is then converted into a Standard Tessellation Language (STL) file, which is sliced into thin horizontal layers. These layers guide the prototyping machine in building the object one layer at a time (Kalpakjian and Schmid, 2020).

One of the primary advantages of rapid prototyping is its ability to produce highly complex and intricate geometries that are difficult, if not impossible, to achieve with conventional manufacturing methods. This capability allows for the creation of prototypes with internal cavities, complex curves, and detailed textures. Moreover, rapid prototyping supports a wide range of materials, including plastics, metals, ceramics, and composites. This versatility enables engineers to test and refine their designs using different materials to meet specific requirements (Gibson et al., 2014).

Rapid prototyping plays a vital role in accelerating product development cycles. By allowing for quick iteration and testing, it reduces the time and cost associated with bringing a new product to the market. This speed is particularly beneficial in industries such as automotive, aerospace, and consumer electronics, where keeping up with technological advancements and consumer demands is essential. Additionally, rapid prototyping facilitates innovation and creativity by providing designers with the freedom to experiment with new ideas without the constraints of traditional manufacturing limitations (Simpson et al., 2020).

In the educational context, teaching learners how to build prototypes using rapid prototyping technologies equips them with practical skills that are directly applicable to careers in engineering, design, and manufacturing. By engaging in hands-on activities, learners gain a deeper understanding of the design process, from concept to creation, while developing critical thinking, problem-solving, and collaboration skills. Visual aids such as images of 3D printers in action, CAD models, and finished prototypes can be included to enhance comprehension and engagement.

16.2 Designing the Prototypes

Designing prototypes is a crucial step in the rapid prototyping process, as it involves transforming ideas into digital representations that can be physically realised. This stage requires a blend of creativity, technical skill, and an understanding of the design requirements. In this section, we will explore the process of designing prototypes using rapid prototyping technologies, ensuring learners grasp the essential elements involved.

16.3 Understanding the Design Requirements

(Refer to Year 1, Week 11: Demonstrate understanding of the design process)

Before starting the design process, it is important for learners to clearly understand the requirements and objectives of the prototype. This includes identifying the purpose of the prototype, the specific features it must include, and any constraints such as size, materials, or functionality. Understanding these requirements helps guide the design process and ensures that the final prototype meets the intended goals. Encouraging learners to use checklists or design briefs can help organise their thoughts and focus on key objectives (Kalpakjian and Schmid, 2020).

16.4 Creating a 3D CAD Model

The next step is to create a detailed three-dimensional (3D) computer-aided design (CAD) model. Using CAD software, learners can design the prototype with precision, incorporating all necessary features and dimensions. This digital model acts as a blueprint for the prototyping process. CAD software allows for easy modifications, enabling learners to experiment with different design iterations and explore innovative solutions. It is important for learners to become familiar with the tools and functions of the CAD software to effectively translate their ideas into digital models (Gibson et al., 2014).

16.5 Iterative Design Process

Rapid prototyping is inherently iterative, allowing designers to quickly modify and test multiple design variations. This approach accelerates the product development cycle by enabling learners to refine their designs based on feedback and testing results. Iterative design involves creating initial prototypes, evaluating their performance, and making necessary adjustments to improve the design. This cycle repeats until the prototype meets the desired specifications. Encouraging learners to keep detailed records of their iterations and the changes made can help them understand the evolution of their design (Simpson et al., 2020).

16.6 Preparing for Prototyping

Once the CAD model is finalised, it is prepared for prototyping by converting it into a Standard Tessellation Language (STL) file. This format breaks down the model into a series of triangles, which can be easily interpreted by the prototyping machine. The STL file is then sliced into thin horizontal layers using specialised software, which guides the machine in building the object layer by layer. Understanding this preparation phase is crucial, as it affects the accuracy and quality of the final prototype (Chua et al., 2010). Figure 16.1 shows the stages for rapid prototyping process from CAD model to 3D part.

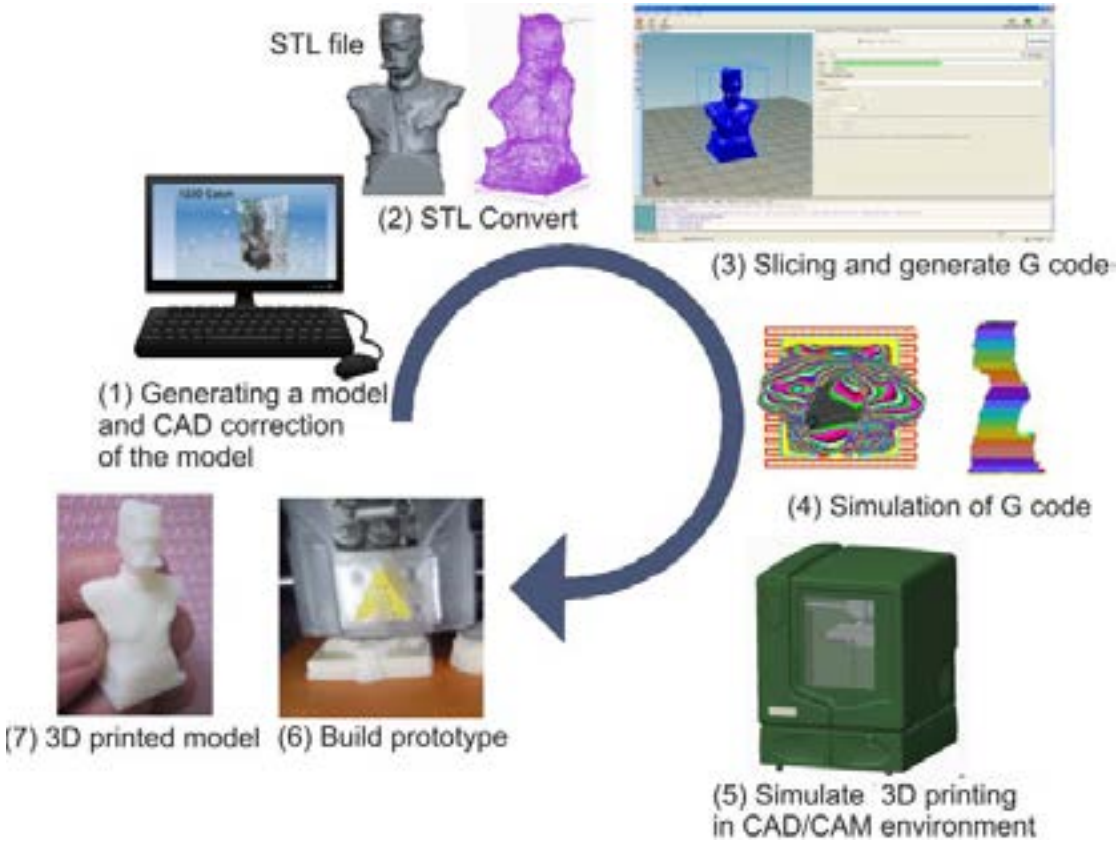


Figure 50: *Stages for rapid prototyping process from CAD model to 3D part (Sivanovic et al., 2019)*

16.7 Collaboration and Feedback

Designing prototypes is often a collaborative effort, requiring input from various stakeholders. Encouraging learners to work in mixed-ability groups fosters collaboration and allows them to benefit from different perspectives and expertise. Peer feedback is an essential part of the design process, providing valuable insights and suggestions for improvement. Learners should be encouraged to present their designs to peers and receive constructive feedback, which can inform further design iterations.

16.8 Computer-Aided Design (CAD) Software

The foundation of any rapid prototyping process is the creation of a detailed 3D model using computer-aided design (CAD) software. CAD software, such as Autodesk Fusion 360, SolidWorks, and Tinkercad, allows learners to design complex geometries and intricate details with precision. These tools offer a wide range of functionalities, including parametric design, simulation, and analysis, which enable learners to test and iterate their designs before printing. CAD software is crucial for ensuring that the digital model accurately reflects the intended design, as any discrepancies will affect the final prototype (Kalpakjian and Schmid, 2020).

16.9 Slicing Software

Once the 3D CAD model is complete, it must be converted into a format that the prototyping machine can interpret. Slicing software, such as Cura, PrusaSlicer, and Simplify3D, plays this critical role by converting the CAD model into a Standard Tessellation Language (STL) file, which is then sliced into thin horizontal layers. This process generates a set of instructions that guide the prototyping machine in building the object layer by layer. Slicing software also allows for adjustments in print settings, such as layer height, print speed, and support structures, ensuring optimal print quality (Gibson et al., 2014).

16.10 3D Printers and Prototyping Machines

The physical manifestation of the digital design occurs through 3D printers and prototyping machines. These machines, which include Fused Deposition Modelling (FDM) printers, Selective Laser Sintering (SLS) machines, and Stereolithography (SLA) printers, each have unique capabilities and material compatibilities. FDM printers, for example, use thermoplastic filaments to create parts, while SLA printers use liquid resins cured by UV light. Understanding the specific capabilities and limitations of each type of machine is essential for selecting the appropriate technology for a given project (Simpson et al., 2020).

16.11 Post-Processing Tools

After the prototype is printed, post-processing is often required to enhance its properties and appearance. Tools for post-processing include sanding equipment, polishing tools, and heat guns, which are used to remove excess material, smooth surfaces, and improve the overall finish of the prototype. In some cases, additional processes such as painting or coating may be applied to achieve specific aesthetic or functional requirements. Understanding the role of post-processing tools is crucial for ensuring the quality and functionality of the final product (Chua et al., 2010).

Notes for Facilitators

1. **Clarifying Concepts:** The goal is to move from pressing print to thinking like an engineer. The process is not just printing; it is a cycle: Design -> Slice -> Print -> Test -> Fail (hopefully) -> Re-design -> Re-print. The "fail fast, learn faster" principle is key to prototyping.
2. **Common Misconceptions:** Students often think the first design will be perfect. Prepare them for the reality that the first prototype is almost always wrong. The purpose of the prototype is to find out how it is wrong so you can fix it.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **The Testing Process:** After printing a simple part, have students perform basic tests. Does it fit? Is it strong enough? Does it function? If it›s a phone holder, put a phone in it. This direct testing is the most important part of the learning process.
    b. **Troubleshooting:** When prints fail, use it as a teaching moment. Was the bed not levelled? Was the first layer not sticking? Did the print warp? Have students photograph the failed print and try to diagnose the cause. This turns a failure into a valuable learning experience.

Learning Tasks

1. Learners design and prototype a sustainable product
2. Learners develop a prototype for an innovative automotive component

Pedagogical Exemplars

1. Learners in mixed-ability groups work to identify a problem or need e.g. a sustainability challenge within the community or environment. Each group brainstorms and designs a sustainable product that addresses this challenge using rapid prototyping technologies. Learners then create a detailed 3D CAD model and use 3D printing to build the prototype. This project will involve research, planning, and design, emphasising the role of rapid prototyping in sustainable product development. Learners present their prototypes and explain how their designs contribute to sustainability.
2. Learners in mixed-ability groups are tasked with designing an innovative automotive component that enhances vehicle performance or safety. Each group creates a CAD model of their component and use Selective Laser Sintering (SLS) or another suitable rapid prototyping technology to produce a prototype. The project will include testing the functionality of the prototype and gathering feedback for further refinement. This learning task highlights the application of rapid prototyping in the automotive industry and encourages learners to think critically about design and functionality.

Key Assessment Level 4: Design and Build

1. Develop and evaluate a prototype for a community-based solution using rapid prototyping technologies. Describe the process, challenges faced, and how you overcame them. (15 marks)
2. Design an innovative product prototype that addresses a specific environmental issue. Analysse how rapid prototyping facilitated the development process and its potential impact on sustainability. (15 marks)
3. Evaluate the economic impact of implementing rapid prototyping in the local manufacturing industry. How does this technology influence production costs and time-to-market for new products? (15 marks)

Notes for Facilitators: *For Q1 and Q2 - To ensure each student contributes, use a combination of group submission and individual reflection: require each team to submit a log of tasks completed by each member, then have students complete a confidential peer evaluation form (e.g., "Rate each teammate's effort and cooperation on a scale of 15") and a short individual writeup describing their specific role and what they learned. Adjust individual grades based on this feedback – a student who did little work should not receive the same mark as an active contributor.*

PLC Session 16

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is design and build. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the design (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).



Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 4 Review

This section focuses on Rapid Prototyping Technologies and Applications. The section is designed to introduce learners to modern approaches in design realisation through additive manufacturing methods. The lessons are structured to align with Ghana's competency-based curriculum and are meant to be delivered using experiential and talk-for-learning pedagogies to engage learners in both theoretical understanding and practical application.

In Week 13, learners are introduced to the concept of rapid prototyping. The facilitator is expected to guide learners in understanding what rapid prototyping means and why it has become a critical process in modern manufacturing. The lesson should cover the general classification of rapid prototyping methods into solid-based, liquid-based, and powder-based processes. The goal of this week is for each learner to be able to define rapid prototyping, identify its different categories, and explain how the transition from digital design to physical model occurs. By the end of the week, learners should appreciate how this technology enables faster and more flexible product development cycles.

Week 14 builds on the foundation laid in the previous week by exploring the technical details of various rapid prototyping methods. Learners are guided to examine Fused Deposition Modelling (FDM), Stereolithography (SLA), and Selective Laser Sintering (SLS). The facilitator should emphasise how each technology works, the types of materials used, the advantages and disadvantages of each method, and the key factors that influence the selection of one method over another. At the end of this week, learners should be able to describe the working principles of these technologies, compare their strengths and limitations, and make informed decisions about which method to use for specific design or production needs. They should also be able to express their evaluations through oral presentations or class discussions.

In Week 15, the focus shifts from understanding technologies to exploring their real-world applications. The facilitator is expected to present a variety of examples from industries such as healthcare, automotive, architecture, and product design. Case studies, such as the use of 3D printing in local educational and fabrication centres, are especially useful to help learners see the relevance of rapid prototyping in the Ghanaian context. Learners should be able to identify industries where rapid prototyping is making an impact, evaluate the benefits of using these technologies in real-life situations, and reflect on how they can apply such innovations to address community needs or create entrepreneurial opportunities.

Week 16 is designed to give learners a practical understanding of the prototyping process and post-processing techniques. The facilitator should lead learners through the steps of preparing a *3D* model for printing using slicing software, adjusting settings such as layer thickness and infill, and converting design files into formats suitable for printing. The lesson also introduces common post-processing activities such as sanding, polishing, curing, and painting to improve the appearance and functionality of printed parts. In addition, safety practices related to the handling of materials like resin and powders should be reinforced. By the end of the week, each learner should be capable of setting up a basic 3D print job, understand how to finish a printed part, and explain essential safety protocols when working with rapid prototyping equipment.

In summary, the content covered in this section is essential for equipping learners with both conceptual and practical skills in rapid prototyping. Learners are expected to leave this section with a solid understanding of what rapid prototyping is, how different technologies function, where they are applied in real life, and how to prepare and post-process 3D prints. This section of the manual not only builds technical knowledge but also develops research, evaluation, and communication skills that are vital for future engineering studies or employment in modern manufacturing environments.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 13

Question 1

Rubrics for question 1. (10 marks)

Criterion	Excellent (2 marks)	Very Good (1.5 marks)	Satisfactory (1 mark)	Needs Improvement (0.5 marks)
Design Preparation	Precisely identifies file types (e.g., CAD to STL/OBJ) and critical pre-checks (mesh errors, wall thickness). Explains why checks prevent print failures.	Lists file conversion and basic checks but omits 1–2 key details (e.g., file repair). Weak "why" link.	Mentions file conversion only. No checks or rationale.	Vague/ inaccurate description (e.g., "upload any file").
Slicing and Configuration	Details slicer settings (layer height, infill, supports, speed) and explains impact (e.g., "supports prevent overhang collapse; low layer height = smoother finish).	Describes slicing but omits 1–2 key settings. Partial cause-effect (e.g., "supports help" without how).	Mentions "slicing software" but no specific settings or purposes.	Incorrect terms (e.g., "slicing = printing").
Printer Setup	Covers 3+ setup steps: bed levelling, material loading (filament/resin), temperature calibration. Links to print success (e.g., "unlevelled bed → poor adhesion").	Describes 2 set-up steps. Weak cause-effect (e.g., "level bed for adhesion" without consequence).	Lists 1 step generically (e.g., "prepare printer").	Inaccurate setup (e.g., "load paper").
Printing Process	Sequentially describes monitoring tasks (first layer adhesion, extrusion consistency, error detection). Notes safety (ventilation for resin, fire hazards).	Lists monitoring tasks but omits safety or 1–2 key checks.	Mentions "start the print" only. No monitoring/ safety.	Focuses only on machine operation (e.g., "press print").

Post-Processing	Details 3+ post-processing steps (support removal, sanding, curing resin) + purpose (e.g., "isopropyl wash removes uncured resin").	Describes 1–2 post-processing steps with partial purpose.	Mentions "remove from bed" only. No finishing.	Incorrect methods (e.g., "break supports with pliers" without safety).

Sample answer

Firstly, a digital CAD design is exported as an STL file and checked for errors like non-manifold edges using software like Netfabb. This ensures the model is printable. Subsequently, the STL file is imported into slicing software (e.g., Cura), where settings are configured: 0.2 mm layer height for detail, 20% infill for strength, and tree supports for overhangs to prevent collapse. The slicer converts this into G-code instructions.

Before printing, the printer is prepared: the build plate is levelled to ensure adhesion, PLA filament is loaded, and the nozzle/bed are heated to 200°C/60°C. During printing, the first layer is monitored for proper adhesion, and extrusion is checked to avoid clogs. Safety precautions include ventilating the room for fumes.

Finally, post-processing occurs: supports are carefully removed with flush cutters, the prototype is sanded to smooth layer lines, and (for resin prints) it's washed in isopropyl alcohol and UV-cured for structural integrity.

Question 2

Describe two materials commonly used in rapid prototyping and explain one typical application for each material.

Marking Scheme (10 marks total):

- Identifies two appropriate rapid prototyping materials (2 marks)
- Describes basic characteristics of each material (4 marks (2 per material))
- Gives one correct application for each material (4 marks (2 per material))

Sample Answer

PLA (Polylactic Acid) is a biodegradable plastic made from corn starch. It is easy to print with and has low warping.

Application: Used for creating conceptual models and prototypes for visual presentation.

ABS (Acrylonitrile Butadiene Styrene) is a strong plastic that can withstand higher temperatures.

Application: Commonly used for functional parts like enclosures and mechanical components.

Question 3

Describe one example where rapid prototyping was used to solve a real-world problem. Explain how it helped improve the design or speed up the process.

Marking Scheme (10 marks total):

- Clearly describes a real-world situation using rapid prototyping (4 marks)

- Explains how it helped improve the design or workflow (4 marks)
- Uses simple, accurate terminology or reasoning (2 marks)

Sample Answer

In the automotive industry, a company used rapid prototyping to 3D print a prototype of a car's dashboard.

This helped designers quickly test the layout of controls and get feedback from users.

The process reduced the time needed to make changes, because they didn't need to wait weeks for new moulds or tooling.

WEEK 14

Question 1

Compare FDM (Fused Deposition Modelling) and SLA (Stereolithography) technologies by listing how they differ in terms of material state, bonding method, and post-processing. Based on this comparison, state which method would be better for making a small decorative sculpture and give one reason why. (10 marks)

Marking Scheme (10 marks)

- Identifies material state difference (2 marks)
- Identifies bonding mechanism difference (2 marks)
- Identifies post-processing difference (2 marks)
- Correctly selects the appropriate method (2 marks)
- Provides a valid justification (2 marks)

Sample Answer

FDM uses solid filament, while SLA uses liquid resin.

FDM bonds layers by melting and extruding plastic; SLA uses a UV laser to cure resin.

FDM post-processing includes removing supports and smoothing; SLA requires curing and washing.

SLA is better for a small decorative sculpture.

This is because SLA produces higher detail and smoother surface finishes.

Question 2

Choose one rapid prototyping method that would be suitable for making a strong and safe prototype in a school. Name the method, and explain how its material, machine safety, and post-processing make it suitable. (10 marks)

Marking Scheme (10 marks)

- Identifies suitable prototyping method (2 marks)
- Describes suitable material (2 marks)
- Describes machine safety features (2 marks)
- Describes simple post-processing (2 marks)
- Provides a clear explanation of suitability (2 marks)

Sample Answer

FDM is a suitable method

It uses Polylactic Acid (PLA), which is strong and non-toxic.

The machine has a closed design and is safe for school use.

Post-processing is simple—just remove support material.

It's safe, affordable, and makes strong enough parts for prototypes.

Question 3

Describe how surface quality and support structures are different in SLS and DLP printing. How might these differences affect which one is chosen for a medical product? (10 marks)

Marking Scheme (10 marks)

- Describes surface quality in SLS (2 marks)
- Describes surface quality in DLP (2 marks)
- Describes support structure in SLS (2 marks)
- Describes support structure in DLP (2 marks)
- Explains how this affects choice in medical use (2 marks)

Sample Answer

SLS has a rougher surface finish.

DLP has a smoother surface finish.

SLS doesn't need extra support structures because the powder supports the print.

DLP needs support structures that must be removed.

DLP might be better for medical use because it gives smoother parts that are easier to clean and more precise.

WEEK 15

Question 1

Describe two ways powder-based prototyping technologies have improved manufacturing practices. How do these improvements relate to innovation or sustainability? (5 marks)

Marking Scheme

- Identifies one improvement in manufacturing practices. (1 mark)
- Identifies a second improvement. (1 mark)
- Connects each improvement to innovation or sustainability. (1 mark each (2 marks))
- Basic explanation showing understanding of the relationship. (1 mark)

Sample Answer

Powder-based prototyping has improved manufacturing by reducing material waste and allowing faster production of complex parts. These improvements support sustainability because less raw material is wasted and less energy is used. They also support innovation because designers can quickly test new ideas with prototypes.

Question 2

List one challenge and one opportunity of using powder-based prototyping with traditional manufacturing. Explain how each one affects the process. (5 marks)

Marking Scheme

- States a valid challenge. (1 mark)
- States a valid opportunity. (1 mark)
- Provides a brief explanation for each. (1 mark each (2 marks))
- Demonstrates basic understanding of integration with traditional manufacturing. (1 mark)

Sample Answer

A challenge is the high cost of powder-based machines, which can make them hard to adopt. An opportunity is that they allow faster part production. The high cost means smaller companies might not use them, while the faster production helps meet deadlines.

Question 3

Name one new material used in powder-based prototyping. Explain how it helps improve the prototyping process or product performance. (5 marks)

Marking Scheme

- Names a suitable material (e.g., nylon, titanium powder). (1 mark)
- Explains how it improves the process or performance (accuracy, strength, etc.). (2 marks)
- Connects material use to real-world prototyping benefits (e.g., lighter parts, more durability). (2 marks)

Sample Answer

Nylon powder is used in powder-based prototyping. It helps because it creates strong and flexible parts. This is useful in making custom tools or parts that need to bend slightly without breaking.

Question 4

Give one way powder-based prototyping helps with product customisation. How does this affect customers or manufacturers? (5 marks)

Marking Scheme

- Identifies a way prototyping supports customisation. (1 mark)
- Explains how this helps customers or manufacturers. (2 marks)
- Demonstrates understanding of a customer-related benefit. (1 mark)
- Demonstrates understanding of a manufacturer-related benefit. (1 mark)

Sample Answer

Powder-based prototyping allows different shapes to be made quickly. This helps customers get products made just for them, like hearing aids. It also helps manufacturers because they don't need to make special moulds for each item.

WEEK 16

Question 1

Develop and evaluate a prototype for a community-based solution using rapid prototyping technologies. Describe the process, challenges faced, and how you overcame them. (15 marks)

Rubrics (15 marks)

Criterion	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0 marks)
1. Community Need Identification	Clear evidence of community engagement (surveys, interviews). Problem scope is specific, urgent, and validated with stakeholders.	Problem identified with basic community input. Scope defined but lacks depth in validation.	Generic problem statement (e.g., help the environment). Minimal community involvement.	No demonstrable link to community needs. Problem irrelevant or assumed.
2. Prototype Design Process	Iterative, user-centred design: Sketches → CAD → MVP → feedback cycles. Justifies tech choice (e.g., FDM for cost, SLS for durability).	Logical design steps documented. Tech choice explained but lacks alternatives. Limited iterations.	Basic description of design. No iteration evidence. Tech choice arbitrary.	Disjointed process. No connection between design and community needs.
3. Prototype Development	Detailed fabrication: Materials, machine settings (e.g., layer height, infill), post-processing. Troubleshooting logs (failed prints → fixes).	Key steps covered. Some settings omitted. Troubleshooting mentioned but not documented.	Superficial build description (e.g., printed on a 3D printer). No failure analysis.	Incomplete/ unrealistic development narrative.
4. Challenge Resolution	Specific, categorised challenges (technical/ social/economic). Innovative solutions with evidence (e.g., before/after test data, user feedback).	Challenges identified. Solutions implemented but lacking depth in impact measurement.	Generic challenges (e.g., printing failed). Solutions superficial.	Challenges ignored or unresolved.

5. Evaluation & Sustainability	Rigorous testing with community (usability, durability). Plan for scalability/maintenance (cost analysis, local training, O and M documentation).	Basic testing performed. Future steps noted but lack concrete plans.	Limited testing (e.g., it worked). No sustainability considerations.	No evaluation. Prototype treated as final solution.

Sample answer

1. Community Need Identification

   Engaged 30 households in Accra (flood-prone informal settlement) through surveys and workshops. Validated need: 92% lacked flood alerts due to cost/access barriers. Core requirement: GHC200 device with 8-hour battery, audible alarms, and no internet dependency.

2. Prototype Design Process

   a. Iteration 1: User co-designed physical interface (large buttons, icon-based LCD). Chose FDM printing (Prusa i3 MK3) for modular housing: fast iterations, PETG material (water/UV resistance).

   b. Iteration 2: Added vibration motor after feedback from hearing-impaired users. Switched to SLS-printed nylon seals for IP67 rating.

   c. Final Design: 3-part snap-fit housing (print time: 4.5 hrs), modular sensor cartridge.

3. Prototype Development

   a. Fabrication: PETG at 240°C/80°C bed, 25% gyroid infill for impact resistance. Post-processed with acetone vapour smoothing.

   b. Challenges and Fixes

   c. Challenge 1: Moisture false positives (humidity >85%).

      Solution: Added hydrophobic PTFE membrane (laser-cut) over ultrasonic sensor.

   d. Challenge 2: Housing warping during monsoon trials.

      Solution*:* Redesigned with draft angle and rib supports (Cura tree supports).

4. Challenge Resolution

   a. Technical: Sensor drift in saline air. Calibrated with NaCl test solutions; added auto-recalibration routine.

   b. Social: Low tech literacy. Created pictogram-based manuals and trained 5 community champions.

   c. Economic: Component cost breached GHC220. Sourced recycled LiFePO4 batteries from local e-waste hubs.

5. Evaluation & Sustainability

   a. Testing: Deployed 10 units for 2 months. 100% accuracy in flood detection (vs. 72% for Iteration 1). User satisfaction: 4.6/5.

   b. Scalability: Partnered with local Fab Lab for assembly. GHC150 /unit at more than 100 scale.

   c. Maintenance: Designed modular sensor cartridges; community trained in replacement (5-minute process).

Question 2

Design an innovative product prototype that addresses a specific environmental issue. Analyse how rapid prototyping facilitated the development process and its potential impact on sustainability. (15 marks)

Rubrics (15 marks)

Criterion	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0marks)
1. Environ-mental Issue Definition	Specific, data-driven problem (e.g., plastic microfibres from laundry = 35% of ocean microplastics). Clear target user/ ecosystem and base-line impact metrics.	Identifies focused issue but lacks quantitative validation. User/ ecosystem defined.	Generic problem (e.g., plastic pollution). No metrics or user specificity.	Unclear or irrelevant environmental focus.
2. Prototype Innovation	Novel, technically viable solution ad-dressing root causes. Integrates circular economy princi-ples (recyclability, biomimicry). Pat-ent-search-aware design.	Functional innovation but derivative elements. Some sustainable features.	Basic adaptation of existing ideas. Minimal originality.	Technically infeasible or copies existing solutions.
3. Rapid Prototyping Process	Detailed, iterative workflow: CAD → simulation → material selection → multi-tech printing (e.g., FDM plus SLS). Justifies tech choices with parameters (layer height, infill).	Clear prototyping steps. Tech choices explained but lacks alternatives/ parameters.	Superficial description (e.g., we 3D printed it). No iteration evidence.	No prototyping process described.

4. Sustainability Impact Analysis	Quantified lifecycle assessment: CO_2 reduction, waste diversion, energy savings against conventional solutions. Scalability roadmap (materials sourcing, end-of-life plan).	Qualitative impact claims. Basic scalability discussion.	Limited environmental benefits stated. No scalability.	No impact analysis or greenwashing claims.
5. Challenge and Iteration	Specific technical/social challenges plus data-backed solutions (e.g., material warping → annealing optimisation). More than 2 iterations with user feedback.	Challenges identified. Solutions implemented but untested. 1–2 iterations.	Generic challenges (e.g., printing failed). Minimal iteration.	No challenges documented.

Sample answer

Product: AquaMesh – Low-Energy Microplastic Capture System for Laundry

1. Environmental Issue
    a. Problem: Laundry releases 500,000 tonnes of synthetic microfibres annually into oceans (IUCN 2022). Conventional filters capture less than 50% of particles below 100µm.
    b. Target: Household washing machines (primary emission source).
    c. Baseline Impact: 1 wash cycle releases approximately 700,000 microfibres.
2. Innovative Solution
    a. Biomimetic Design: 3D-printed filter cartridge with shark-skin denticle pattern (disrupts water flow to trap 99% of 10–500µm fibres).
    b. Circularity: Cartridge uses recycled ocean plastic (rPET). End-of-life return programme for pellet reuse.
3. Rapid Prototyping Process
    a. Iteration 1: FDM-printed PLA housing (Prusa i3). Tested flow dynamics – 73% capture (too low).
    b. Iteration 2: SLS-printed nylon denticles (Formlabs Fuse 1). Added electrostatic layer (carbon-doped TPU). Capture: 89%.
    c. Final Prototype:
        i. Material: Recycled PETG (FDM) and PA11 (SLS)
        ii. Parameters: 0.1mm layers, 100% infill for pressure resistance

iii. Post-Processing: Acetone smoothing to reduce fibre snagging

4. Sustainability Impact
   a. Reduction per Unit: Prevents 2.1kg/year microfibre pollution per household (0.8 kg for commercial filters).
   b. Lifecycle Savings:
      i. CO_2: 60% lower than stainless steel filters (0.8 kg and 2.1kg CO_2e/unit)
      ii. Waste: 100% recyclable; 92% less virgin plastic and competitors
   c. Scalability:
      i. Materials: Local rPET supply chains
      ii. Production: Injection moulding from 3D-printed masters
      iii. End-of-Life: Take-back programme → pelletise for new cartridges
5. Challenges & Solutions
   a. Challenge 1: Nylon denticles warped at 60°C wash cycles.

      Solution: Annealed SLS parts at 170°C plus added cellulose reinforcement (capture efficiency: 99.2%).
   b. Challenge 2: User resistance to maintenance.

      Solution: Designed snap-open mechanism (no tools) plus app alerts. User-test satisfaction: 94%.

Question 3

Evaluate the economic impact of implementing rapid prototyping in the local manufacturing industry. How does this technology influence production costs and time-to-market for new products? (15 marks)

Rubrics (15 marks)

Criterion	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0.5 marks)
1. Cost Structure Analysis	Comprehensive breakdown of cost changes: tooling, labour, materials, waste. Quantitative comparison (e.g., 70% lower tooling costs). Distinguishes short-term against long-term impacts.	Identifies major cost categories. Includes some data but lacks depth in trade-offs.	Generic statements (e.g., reduces costs). No quantitative support.	Inaccurate or missing cost analysis.

2. Time-to-Market Evaluation	Detailed timeline mapping: Design to prototype to production. Metrics-driven (e.g., compressed from 18 to 6 weeks). Discusses iterative advantage for market responsiveness.	Explains time reductions with examples. Omits specific metrics or iteration benefits.	Basic time savings claim. No process breakdown.	No connection to time-to-market.
3. Local Industry Impact	Multi-faceted analysis: Job creation/reskilling, SME competitiveness, supply chain localisation. Regional case studies with data (e.g., Detroit auto suppliers reduced research and development costs by 34%).	Covers local benefits qualitatively. Examples lack geographic specificity.	Limited local focus (e.g., helps local businesses). No evidence.	Ignores local context.
4. Hidden Costs and Trade-offs	Critical examination of overlooked expenses: equipment maintenance, material premiums, training. Balanced view (e.g., 25% higher per-unit cost offsets tooling savings in low-volume runs).	Mentions 1–2 hidden costs. Lacks quantification or mitigation strategies.	Superficial trade-offs (e.g., "machines are expensive").	No critical perspective.
5. Evidence and Examples	Industry-specific, data-rich examples (e.g., medical device compliance savings via 3D-printed jigs). Sources cited (reports, case studies).	Relevant examples provided. Limited data or sourcing.	Generalised illustrations (e.g., a company used it). No sources.	No examples or fabricated claims.

Sample answer

Rapid prototyping (RP) technologies - such as FDM, SLS, and metal binder jetting - deliver profound economic advantages for local manufacturers by slashing production costs and accelerating time-to-market, though strategic implementation is essential to mitigate hidden expenses.

1. Cost Structure Revolution

   - Tooling Elimination: Traditional injection moulding requires GHC100 000 – GHC 1000 000 in tooling; RP reduces this to near-zero.
   - Labour Efficiency: RP reduces skilled labour dependency.

- Material/Waste Reduction: Additive methods average 30–60% less waste than subtractive processes. Trade-off*:* Specialty powders (e.g., Ti6-Al4-V) cost 5–3 times more than bulk metals, necessitating volume-based strategy.

2. Time-to-Market Acceleration
    - Design Compression: RP enables same-day prototype iterations versus weeks for CNC.
    - Production Agility: On-demand RP lets local factories respond to demand spikes. During 2023 supply chain disruptions, Michigan manufacturers used binder jetting to reduce lead times by 65% for spare parts.
3. Local Industry Revitalisation
    - SME Competitiveness: RP democratises research and development.
    - Job Transformation: While automating low-skill tasks, RP creates high-value roles (e.g., CAD designers).
    - Supply Chain Localisation: Onshore production becomes viable.
4. Hidden Costs & Mitigation
    - Equipment/Training: Industrial RP systems cost GHC500, 000 – GHC1000 000 with 12–18% annual maintenance.
    - Per-Unit Economics: RP struggles at scale. Solution*:* Hybrid workflows (e.g., RP prototypes to traditional mass production) balance flexibility and cost efficiency.

SECTION 5: APPLICATIONS OF MACHINE TOOLS AND COMPUTER NUMERICALLY CONTROLLED MACHINES (CNC)

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

SUB-STRAND: MANUFACTURING TOOLS AND EQUIPMENT

Learning Outcome: Recognise and use cutting tools and modern machine tools

Content Standards

1. *Demonstrate knowledge and understanding of the use of cutting tools and modern machine tools. (Week 17 and 18)*
2. *Demonstrate understanding of modern machine tools. (Week 19 and 20)*

INTRODUCTION AND SECTION SUMMARY

This section of the manufacturing engineering teacher manual equips third-year senior high school students with a comprehensive foundation in the classification, application, and operation of cutting tools, as well as the principles of computer numerically controlled (CNC) machining. Over the course of Weeks 17 to 20, learners will build expertise through a progressive exploration of key concepts and hands-on activities. In Week 17, students investigate how cutting tools are identified and classified, considering factors such as manufacturing method, cutting action, material, geometry, and intended application. Week 18 shifts focus to the practical use of cutting tools in woodwork, metalwork, and machining, emphasising tool selection, handling, and rigorous safety practices through real-world tasks and demonstrations. Week 19 introduces the fundamentals of CNC machines as advanced machine tools, covering their core components, operational principles, and programming with G-code. Special attention is given to types of CNC machines—including milling, drilling, turning, and grinding centres—and the structure of effective CNC programmes. Finally, Week 20 provides an in-depth look at the setup, operation, and industrial application of CNC machines, highlighting procedures, safety, and the transformative impact of CNC technology across manufacturing sectors. By following this structured approach, learners develop the technical proficiency to classify and select appropriate tools, apply them safely and effectively across materials, and programme and operate CNC machines. These skills ensure precision, repeatability, and efficiency in modern manufacturing, preparing students for further study and professional practice in engineering and advanced manufacturing industries.

The weeks and the indicators covered by the section are:

Week 17: Identify and classify cutting tools used in manufacturing

Week 18: Demonstrate the application and use of cutting tools in manufacturing

Week 19: Explain computer numerically controlled (CNC) machine as a machine tool

Week 20: Understand the operation and application of a computer numerically controlled (CNC) machine

Recap weeks

Year 2	**Week 16:** Differentiate between manual-hand tools (e.g. hacksaw, cold chisels, screw drivers, taps, dies, engineer's hammer, etc.) and power-hand tools (e.g. grinding, drilling, screw, etc.) in manufacturing.

SUMMARY OF PEDAGOGICAL EXEMPLARS

This section presents a methodical framework for teaching the classification, operation, and application of cutting tools and CNC machines, aimed at building learners' competence and confidence in modern manufacturing. Teaching methods blend research, experiential learning, guided practice, and project-based activities to convey complex technical concepts effectively. Instructors are encouraged to scaffold instruction, starting with foundational knowledge—such as tool identification and classification—progressing to hands-on demonstrations and culminating in applied projects. The instructional flow integrates lectures, group discussions, industry visits, and interactive demonstrations, ensuring accessibility, engagement, and real-world relevance. Learners are introduced to both conventional and non-conventional machining processes, safety protocols, and tool selection criteria through direct observation and guided inquiry. Week 17 focuses on identifying and classifying cutting tools, using research assignments and workshop visits to help learners distinguish between tool types and manufacturing processes (DOK Level 2). Week 18 advances to the practical application of cutting tools in woodwork, metalwork, and machining, emphasising hands-on experience, tool handling, and safety, supported by project-based learning and peer presentations (DOK Level 3). In Week 19, learners are introduced to computer numerically controlled (CNC) machines, focusing on principles, programming (G-code), and types, with video demonstrations and comparative analysis to help differentiate CNC from manual processes (DOK Level 3). Week 20 develops operational skills further, guiding learners through CNC setup, safety, and industrial applications, while real-world tasks and research-based group projects connect theory to practice, culminating in tasks where learners justify tool selection or design CNC programmes for specific manufacturing needs (DOK Level 3). By the end of this sequence, learners master essential technical concepts in manufacturing and CNC operation, appreciate the importance of precision, safety, and standardisation, and can apply their knowledge to authentic production challenges, nurturing critical thinking, collaborative problem-solving, and technical expertise for success in engineering and advanced manufacturing environments.

ASSESSMENT SUMMARY

The section assessment is designed to align with the highest Depth of Knowledge (DOK) level for each indicator, prioritising experiential learning, critical thinking, and practical mastery in the field of manufacturing and CNC technology. During Week 17, the emphasis is on conceptual understanding and classification of cutting tools (DOK Level 2), where learners participate in collaborative activities, research projects, and chart creation to distinguish between various tool types, materials, actions, and applications, fostering analytical skills through active exploration and peer discussion. In Week 18, assessment activities advance to applied practice (DOK Level 3) as students demonstrate the use of cutting tools in woodwork, metalwork, and machining operations, documenting their processes, justifying tool selection, and addressing safety

considerations during hands-on exercises to reinforce practical competence and technical reasoning. Week 19 focuses on the comprehension and application of CNC machine technology (DOK Level 3) through video analysis, structured written responses, and presentation assignments, allowing students to compare manual and CNC-controlled operations, evaluate automation and precision, and design basic G-code programmes—challenging learners to synthesise theoretical knowledge with real-world scenarios and enhance their problem-solving and digital literacy. Finally, Week 20 culminates with integrative tasks (DOK Level 3) requiring learners to explain, evaluate, and justify the operation and application of CNC machines, using summative assessments such as research presentations, scenario-based discussions, and case studies on CNC implementation across manufacturing contexts to ensure a comprehensive grasp of both practical skills and critical engineering principles. These assessments, as summarised in Table 8, are purposefully structured so that students not only understand foundational concepts but also acquire and demonstrate the essential competencies required for modern manufacturing and engineering practice.

Table 8 Assessment summary for Section 5

Indicators	DOK Level	Assessment Strategy and/or Mode
Identify and classify cutting tools used in manufacturing	3	Classwork Homework (Case study analysis)
Demonstrate the application and use of cutting tools in manufacturing	4	Classwork Project Homework (Case study analysis)
Explain computer numerically controlled (CNC) machine as a machine tool	2	Classwork Project
Understand the operation and application of a computer numerically controlled (CNC) machine	4	Classwork Homework Project

WEEK 17

Learning Indicator: Identify and classify cutting tools used in manufacturing

Focal Area: Identification and classification of cutting tools used in manufacturing

17.1 Introduction

Cutting tools are precision instruments designed to remove material from a workpiece through shear deformation. They are essential in shaping, sizing, and finishing components within the manufacturing process. As fundamental components of machining operations, cutting tools enable the accurate removal of material, allowing for the creation of workpieces that adhere to specific design specifications. Serving as the interface between machines and materials, they transform mechanical motion into productive work. To ensure accuracy, repeatability, and efficiency, cutting tools are crucial for producing components across various industries. Proper identification and classification of these tools are vital for selecting the appropriate tool for a particular task, optimising performance, and prolonging tool life. The study of cutting tools introduces learners to the diverse array of tools used in manufacturing, spanning from single-point tools used in turning operations to multi-point tools found in milling and drilling processes. By understanding the distinctions among tool types based on geometry, material, and application, learners become better equipped to make informed decisions in workshop environments, thereby fostering a greater appreciation for process planning. Moreover, classifying cutting tools according to international standards promotes consistency in tool selection and usage, reducing errors and enhancing communication among technicians, engineers, and machinists.

17.2 Classification based on the method of manufacturing

(Refer to Year 2, Week 16: Differentiate between manual-hand tools and power-hand tools in manufacturing)

Conventional machining processes, including turning, drilling, milling, and grinding, employ sharp cutting tools or abrasives to remove chips from a workpiece. Alongside these traditional methods, there are various alternative techniques for material removal, collectively known as non-traditional machining. This category encompasses a range of methods that utilise mechanical, thermal, electrical, or chemical energy to remove material without the use of sharp cutting tools or abrasives in the conventional sense. Non-traditional machining processes have developed since World War II, primarily to meet new and unique machining requirements that traditional methods could not satisfy.

Commercial and technological importance of the non-traditional processes, include the need to machine newly developed metals and nonmetals, the need for unusual and/or complex part geometries that cannot easily be accomplished by conventional machining and the need to avoid surface damage that often accompanies the stresses created by conventional machining.

Many of these requirements are associated with the aerospace and electronics industries, which have become increasingly important in recent decades. There are literally dozens of non-traditional machining processes, many of which are unique in their applications. The non-

traditional processes are often classified according to the principal form of energy used to effect material removal. By this classification, there are four types:

1. Mechanical: Mechanical energy in some form other than the action of a conventional cutting tool is used in these non-traditional processes. Erosion of the work material by a high-velocity stream of fluid or abrasives (or both) is a typical form of mechanical action in these processes.
2. Electrical: These non-traditional processes use electrochemical energy to remove material.
3. Thermal: These processes use thermal energy to cut or shape the work part. The energy is generally applied to a very small portion of the work surface, causing it to be removed. The thermal energy is generated by the conversion of electrical energy.
4. Chemical: Most materials (particularly metals) are susceptible to chemical attack by certain acids. In chemical machining, chemicals selectively remove material from portions of the work part, while other portions of the surface are protected by a mask.

17.3 Classification based on cutting action

Classification based on cutting action serves as a foundational method for organising cutting tools in manufacturing, categorising them into three primary types: single-point cutting, multi-point cutting, and abrasive action. The classification of cutting tools based on cutting action, Number of edges, and typical applications is displayed in Table 9. Single-point cutting tools, such as lathe tools and boring bars, have a solitary cutting edge and are predominantly utilised for operations like turning, shaping, and planning. This design enables precise shaping of materials. In contrast, multi-point cutting tools, exemplified by broaches, feature several cutting edges that efficiently remove material in a single pass, making them ideal for producing gears and engine components. Abrasive action, on the other hand, involves tools such as grinding wheels, honing stones, and lapping plates. These tools utilise numerous hard abrasive particles with undefined cutting edges to achieve exceptionally smooth finishes and tight tolerances, particularly when dealing with hard materials. By categorising cutting tools based on their cutting action, engineers can optimise machining processes to enhance accuracy, efficiency, and surface quality across a broad spectrum of manufacturing applications.

Table 9 Classification of cutting tools

Category	Tool Type / Examples	Number of Cutting Edges	Typical Operations	Description
Single-Point Cutting	Lathe tool, Boring bar	1	Turning, Shaping, Planning, Boring	Used in operations requiring precision, simple geometry, and ease of manufacturing. Produces fine finishing and controlled material removal.
Multi-Point Cutting	Drill bit, milling cutter, Broach, Hobs, Circular saw blade	2 or more	Drilling, Milling, Broaching, Sawing	Multiple cutting edges allow higher material removal rates, improved surface finish, and longer tool life. Suitable for mass production and complex geometries.

Abrasive Action	Grinding wheel, Sandpaper	Many (abrasive grains)	Grinding, Honing, Lapping	Material is removed by the action of countless abrasive grains. Used for fine finishing and high-precision surface generation.
Form Tools	Thread cutting tool, Gear cutter	Varies	Thread cutting, Gear shaping	Tools designed to produce specific shapes or profiles on a workpiece.

17.4 Classification based on tool material

The classification of cutting tools based on their material is crucial in manufacturing, as different tool materials offer distinct advantages suited to specific applications. Tool materials such as high-speed steel (HSS), carbide, ceramic, and diamond are selected according to the demands of various machining operations and workpiece materials.

Choosing the appropriate tool material involves understanding several key properties such as:

1. High hardness: The tool material must be harder than the workpiece to cut efficiently and maintain its sharp edge.
2. Hot hardness: The ability to retain hardness at elevated temperatures, often achieved by alloying with elements like chromium, tungsten, and vanadium.
3. Wear resistance: Essential for resisting abrasion during cutting, this property is enhanced by the presence of hard carbides in the tool matrix.
4. Strength and toughness: Tools must withstand the forces and shocks encountered during machining without breaking or deforming.
5. Thermal conductivity and specific heat: High thermal conductivity helps dissipate heat, while adequate specific heat prevents excessive temperature rise in the tool.
6. Low coefficient of friction: Reduces heat generation and prolongs tool life.
7. Chemical stability: Prevents adverse reactions between the tool and workpiece, minimising tool wear.
8. Cost-effectiveness: The overall cost includes not just the initial price, but also maintenance and replacement expenses.

A comprehensive understanding of the various characteristics of cutting tool materials is essential for manufacturers as it enables the classification and selection of the most appropriate tools (be it high-speed steel, carbide, ceramic, or diamond) for optimal machining operations that are efficient, precise, and economically viable. Figure 51 classifies cutting tool materials into ferrous and nonferrous.

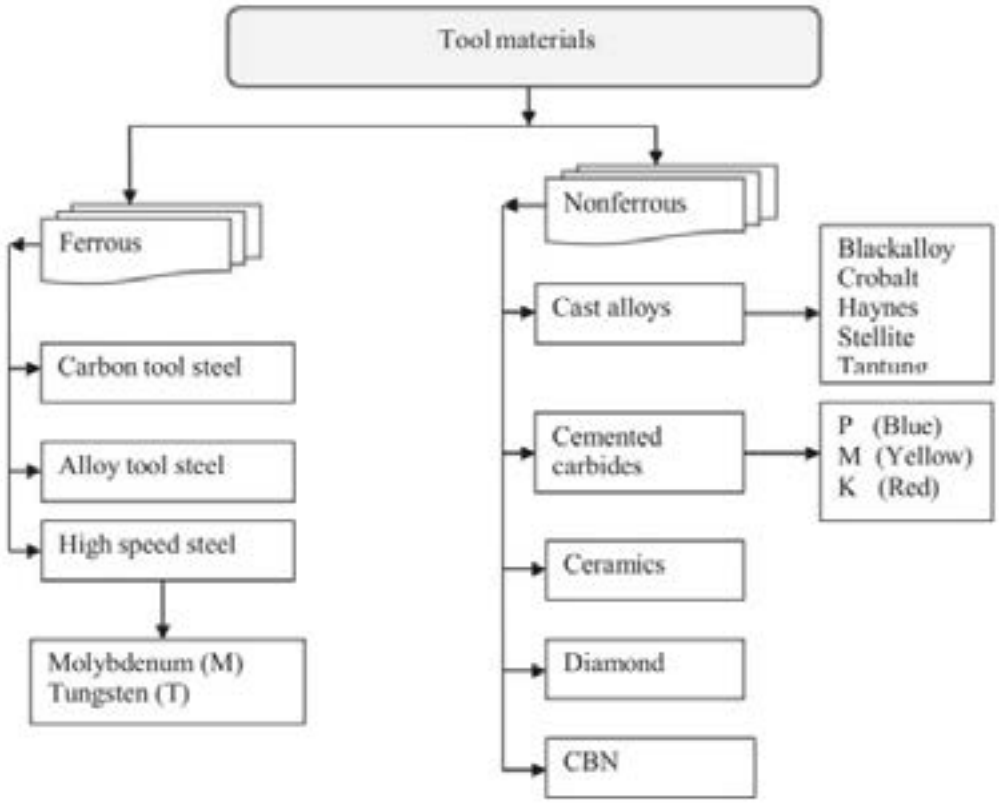
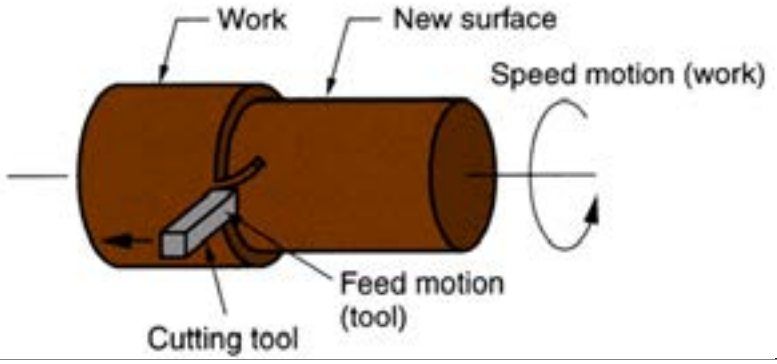


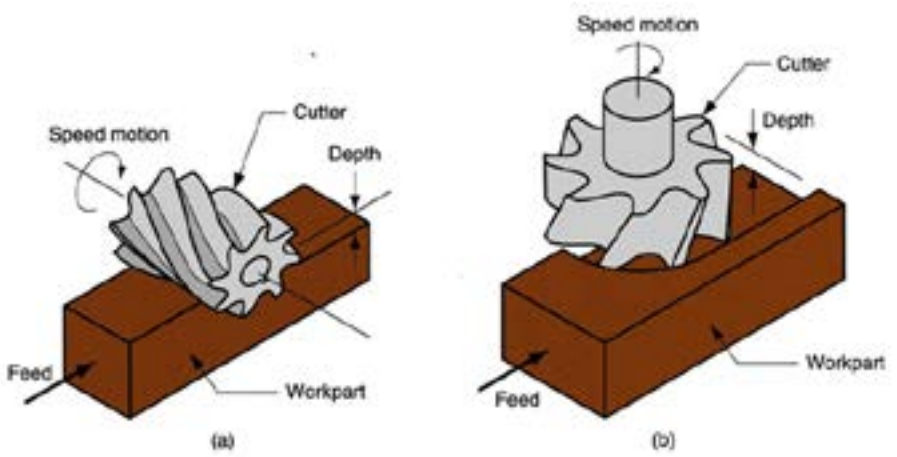
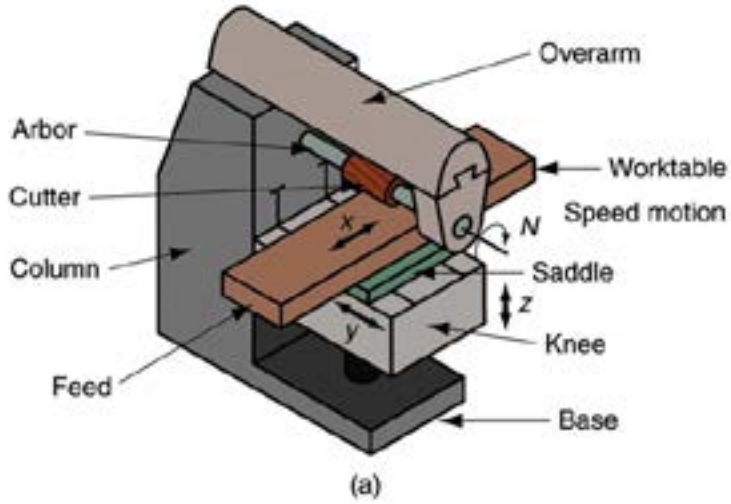
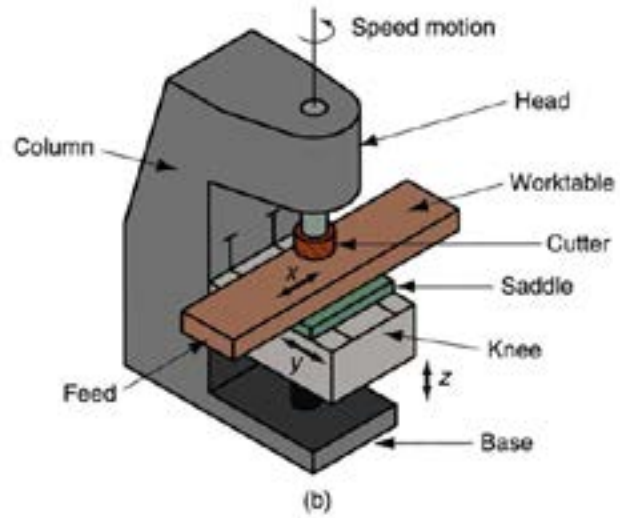
Figure 51: *Classification of cutting tool materials into ferrous and non-ferrous materials (Groover, 2021)*

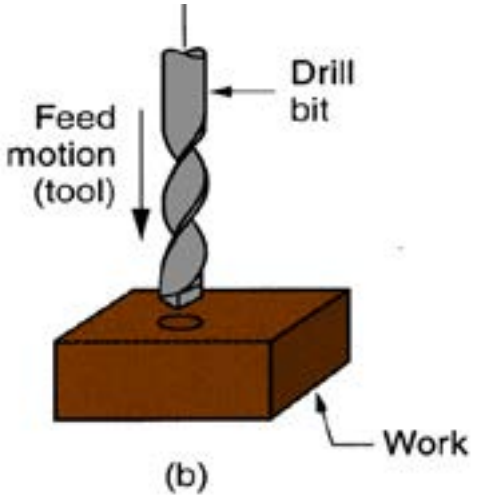
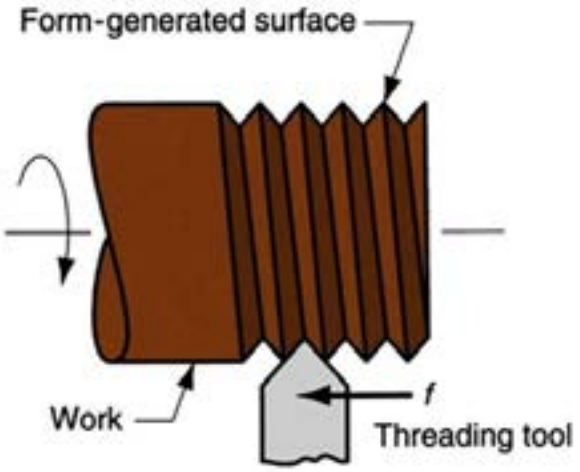
17.5 Classification based on machining operation

In manufacturing engineering, cutting tools are also classified based on the type of machining operation they are designed to perform. Each machining process (whether it involves removing material by rotating the workpiece, rotating the tool, or creating threads) requires tools with specific geometries, materials, and cutting characteristics as shown in Table 10. Understanding this classification helps connect tool design with its practical application in the workshop. This classification helps in understanding the relationship between tool design and machining function, reinforcing the importance of selecting the right tool for the right job. It also builds a foundation for more advanced topics such as tool wear, cutting parameters, and CNC programming.

Table 10 Machining processes (Groover, 2021)

Machining operation	Image
Turning operation	

Milling Cutters	 (a) peripheral milling, (b) face milling
	 horizontal knee-and-column milling machine
	 (b) vertical knee-and-column milling machine

Drilling tools	
Threading tools	 thread cutting on a lathe machine

17.6 Classification based on application

Manufacturing processes can be effectively categorised by their field of application, namely woodwork, metalwork, and machining. Woodwork encompasses the shaping, joining, and finishing of wood to create furniture, cabinetry, and construction components, utilising tools such as hand saws, planes, and various power tools, while emphasising safety practices like eye protection and avoiding loose clothing. Metalwork, on the other hand, involves cutting, forming, and joining metals for products like automotive parts, structural frameworks, and hardware, employing equipment such as files, welding machines, and grinders, and adhering to safety protocols that include using gloves, face shields, and ensuring proper ventilation. Machining stands apart as a precision-focused category that removes material from metals or plastics to achieve exact dimensions, relying on drill presses, lathes, milling machines, and CNC systems. Safety in machining centres on securing workpieces, maintaining a safe distance from rotating parts, and utilising guards and emergency stops. Each application has distinctive tools, techniques, and safety requirements, shaping the unique workflows and finished products within its respective domain. Table 11 shows the classification based on application.

Table 11 Classification based on application

Application	Description	Common Tools	Materials	Key Safety Practices
Woodwork	Shaping, joining, and finishing wood for furniture, cabinetry, and construction.	Hand saws, planes, power tools	Wood	Eye protection, avoid loose clothing
Metalwork	Cutting, forming, and joining metals for automotive parts, frameworks, and hardware.	Files, welding machines, grinders	Metals (steel, aluminium, etc.)	Gloves, face shields, proper ventilation
Machining	Precision material removal for exact dimensions in metals or plastics.	Drill presses, lathes, milling machines, CNC systems	Metals, plastics	Secure workpieces, maintain a safe distance from rotating parts, and use guards

17.7 Factors to consider when selecting cutting tools

Selecting the right cutting tool is crucial for ensuring efficiency, quality, and cost-effectiveness in manufacturing operations. Several important factors must be considered to achieve optimal performance and results. This includes

1. Workpiece Material: The hardness, toughness, and abrasiveness of the material being machined influence the required tool properties.
2. Tool Material: The material of the cutting tool should be chosen based on its ability to withstand cutting forces and high temperatures (e.g., high-speed steel, carbide, ceramic, diamond).
3. Type of Machining Operation: Operations such as turning, milling, drilling, or grinding each require specific tool geometries and strengths.
4. Cutting Speed and Feed Rate: Higher speeds and feeds generate more heat and stress, demanding tools with excellent heat resistance and durability.
5. Tool Geometry: Features like rake angle, relief angle, and nose radius affect chip formation, cutting forces, and surface finish.
6. Surface Finish Requirements: Desired surface quality may require particular tool shapes and cutting conditions.
7. Tool Life and Cost: Longer-lasting tools reduce downtime but may come at a higher initial cost. Balancing durability and expense is important.
8. Machine Capability: The machine's rigidity, power, and speed range can limit tool choices and performance.

Notes for Facilitators

1. **Clarifying Concepts:** Organise the classification around a simple question: What is the cutting action? A single-point tool (lathe) is like a sculptor with one chisel. A multi-point tool (milling cutter) is like a sculptor with a whole set of chisels working at once. An abrasive tool is like sandpaper – many small, random cutting points.
2. **Common Misconceptions:** Students often confuse conventional with old and non-conventional with new. Explain that non-conventional methods are specialised for specific tasks (e.g., machining hardened steel), not replacements for all conventional methods.
3. **Low-Cost Demonstration and Ghanaian Examples**
   a. **Tool Material Show-and-Tell:** Bring in a set of HSS drill bits and a set of masonry (carbide-tipped) drill bits. Ask students to feel the difference in weight and describe the colour. Explain why one is used for wood and the other for drilling into concrete walls (a common task in Ghana).
   b. **Application:** Discuss how a local furniture maker uses saws (multi-point), chisels (single-point), and sandpaper (abrasive) to finish a piece of furniture. This connects the classifications to a real, observable craft.

Learning Tasks

1. Learners recap previous knowledge from Years 1 and 2 by identifying and classifying cutting tools used in manufacturing, such as saws, chisels, files, and drill bits, based on their function, material application, and mode of operation.
2. Learners research and explore various systems used to classify cutting tools in manufacturing.
3. Learners are provided with sample manufacturing scenarios involving different workpiece materials (e.g., wood, plastic, soft metals) and specific operations (e.g., cutting, drilling, shaping, turning and milling).

Pedagogical Exemplars

1. **Research-based Learning:** Learners research cutting tools for woodwork, metalwork, and machining, and present their results in class for feedback.
2. **Experiential Learning:** Learners in mixed ability groups perform the following activities each with a different sample material and operation:
   a. Soft wood block – Task: Cut a groove to fit a rectangular key
   b. Acrylic plastic sheet – Task: Drill three holes (Ø 6 mm, 8 mm, 10 mm)
   c. Aluminium rod – Task: Reduce diameter by 1 mm using a turning operation (lathe)

Notes for Facilitators

Before starting any task, wear safety goggles to protect against flying debris, secure the workpiece firmly using a vice or clamps to prevent spinning or slipping, keep hands and loose clothing away from rotating parts, use sharp tools only with the correct cutting direction, and never remove chips by hand – use a brush. For the aluminum turning task, also wear a face

shield to guard against hot, sharp chips, and ensure the lathe chuck key is removed before switching on the machine.

Key Assessment Level 3: Classwork

1. Identify a cutting tool used in modern manufacturing. Classify the identified tool as conventional or non-conventional and justify your selection based on how the tool interacts with the workpiece. (5 marks)
2. Analyse the properties and typical applications of cutting tools made from different materials. Based on this, argue which tool would be most appropriate for high-speed machining of hardened steels, justifying your choice. (5 marks)
3. Compare and contrast classification by cutting action and by tool geometry, and evaluate how these classifications might influence tool selection in a manufacturing process. Include one real-world example for each classification method. (6 marks)
4. Using case examples, distinguish between conventional and non-conventional cutting tools. Evaluate the advantages and limitations of each in terms of precision, material compatibility, and production cost. (6 marks)

PLC Session 17

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

    a. The key assessment for the week is classwork. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the classwork (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

    b. all teachers in the group work through a similar problem individually for 3–4 minutes

    c. the group then works through the problem together step by step

    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).

    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.

    b. After the enactment, ask for structured feedback from the group

        i. was the concept explained in a way that a learner with no prior knowledge could follow?

        ii. were the examples grounded in contexts familiar to Ghanaian learners?

        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).

8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 18

Learning Indicator: Demonstrate the application and use of cutting tools in manufacturing

Focal Area: Application of cutting tools

18.1 Introduction

Cutting tools are essential in shaping, sizing, and finishing materials in manufacturing, making their effective use crucial for achieving precision, efficiency, and superior finishes across various machining operations. This week's focus is on the practical applications of cutting tools in woodworking, metalworking, and machining, with particular emphasis on tool selection, handling, and safety. By understanding how different tools function—whether for turning, milling, drilling, or threading—one is equipped to make informed decisions that enhance productivity and tool longevity. The topic underscores real-world scenarios, hands-on activities, and the importance of factors such as tool material, geometry, and cutting conditions, all of which influence performance. Mastery of these concepts not only prepares individuals for technical careers in manufacturing and mechanical engineering but also cultivates foundational skills needed to select and use appropriate tools safely and effectively in any manufacturing environment.

18.2 Woodworking

Woodworking is a fundamental branch of manufacturing that focuses on the shaping, carving, and finishing of wood for applications ranging from furniture and cabinetry to decorative elements and structural components. The process encompasses a variety of techniques such as chiselling, carving patterns with gouges, and refining surfaces using rasps, files, and sandpaper. Essential tools include hand saws, planes, chisels, mallets, and an array of sanding implements, each selected for their ability to manipulate wood according to grain direction and desired finish. Mastery in woodwork not only requires skill in tool handling and surface preparation, but also a strong focus on safety practices, such as wearing goggles and dust masks, ensuring proper clamping of workpieces, and maintaining safe cutting strokes, is imperative. By emphasising both creativity and precision, woodworking transforms raw timber into finished products that balance form and function, showcasing craftsmanship while upholding rigorous safety standards throughout each stage of the process.

18.2.1 Application of Woodworking

- **Focus:** Shaping, carving, and finishing wood using appropriate tools.
- **Materials:** Wood block samples
- **Tools Used:** Chisels**,** Hand saws**,** Planes**,** Rasps and files**,** Sandpaper and sanding blocks

Activities

a. Demonstrate shaping a wooden block using a chisel and mallet.

b. Carve simple patterns using gouges.

c. Smooth surfaces using rasps and sandpaper.

d. Discuss grain direction and its effect on cutting.

Skills Developed

a. Tool handling and control

b. Surface preparation

c. Safety in wood cutting

Safety Emphasis

a. Use of goggles and dust masks

b. Proper clamping of workpieces

c. Safe direction of cutting strokes

Note: Ensure documentation of the entire process, including observation

18.3 Metalworking

Metalworking is a vital discipline within manufacturing, dedicated to the cutting, shaping, and finishing of metals for a wide array of applications, from machinery components and structural frameworks to precision instruments and decorative objects. The process encompasses numerous techniques, such as sawing with hacksaws, filing with various file types (flat, round, half-round), and marking with centre punches and hammers. Essential tools include hacksaws, files, centre punches, hammers, and bench vices, each chosen for their specific ability to manipulate metals based on their hardness and intended purpose. Mastery in metalworking requires not only skill in tool handling and material preparation, but also a steadfast commitment to safety practices. These include wearing gloves and goggles, ensuring secure clamping of workpieces with a bench vice, maintaining correct posture and grip, and remaining vigilant around sharp edges. By emphasising both accuracy and safety, metalworking transforms raw metals into refined products that exemplify both utility and craftsmanship, all while adhering to strict safety standards throughout every stage of the process.

18.3.1 Metalworking Applications

- **Focus:** Cutting and shaping metal using hand and machine tools.
- **Materials:** Metal rods
- **Tools Used:** Hacksaws**,** Files**,** Centre punch and hammer**,** Bench vice

Activities

a. Cut mild steel rods using a hacksaw.

b. File edges to remove burrs and achieve smoothness.

c. Mark out drilling points using a centre punch.

d. Discuss differences in filing techniques for soft vs. hard metals.

Skills Developed

a. Precision in cutting and filing

b. Understanding metal hardness

c. Manual dexterity

Safety Emphasis

a. Use of gloves and goggles

b. Proper posture and grip

c. Awareness of sharp edges

Note: *Ensure documentation of the entire process, including observation*

18.4 Machining

Machining is a core aspect of manufacturing that involves shaping, cutting, and finishing a variety of materials—often metals and plastics—using powered machinery. This discipline covers techniques such as turning cylindrical shapes on a lathe, removing material with milling machines, creating precise holes through drilling, and forming threads using taps and dies. Fundamental tools and equipment include lathes, drill presses, milling machines, and tapping sets, each selected for its specific capacity to manipulate material with accuracy and consistency according to the intended design. Mastery in machining goes beyond understanding machine operation; it demands careful tool selection, adjustment of cutting parameters (such as speed, feed, and depth), and ongoing evaluation of surface finishes to ensure high-quality results. Equally important is a rigorous approach to safety: employing proper machine guarding, always using personal protective equipment like goggles, aprons, and ear protection setting up and aligning workpieces with precision, and remaining vigilant about emergency stops and safe working practices at every stage. By combining technical skill with a steadfast commitment to safety, machining transforms raw stock into precision components, exemplifying both engineering excellence and a culture of responsibility in the workshop.

18.4.1 Machining Applications

- **Focus:** Performing basic machining operations using machine tools.

18.4.1.1 Turning Operation

- **Materials**: Mild steel or aluminium rods
- **Tools Used**: Lathe machine, single-point cutting tool, calliper or micrometre, bench vice

Activities

Mount the metal rod on the lathe.

Perform facing and straight turning to reduce the diameter.

Measure the final diameter using a calliper.

Discuss how feed rate and depth of cut affect surface finish.

Skills Developed

a. Precision in diameter reduction

b. Understanding of lathe operation

c. Measurement and inspection techniques

Safety Emphasis

a. Tie back long hair and avoid loose clothing

b. Use safety goggles

c. Keep hands away from rotating parts

Documentation

a. Record initial and final dimensions

b. Note tool settings and observations on surface finish

18.4.1.2 Drilling Operation

- **Materials:** Mild steel or plastic plates

Tools Used

a. Pillar drill or bench drill

b. Twist drill bits

c. Centre punch and hammer

d. Safety goggles

Activities

a. Mark hole positions using a centre punch.

b. Drill holes of different diameters.

c. Deburr holes using a countersink tool.

d. Discuss drill bit selection based on material.

Skills Developed

a. Accurate hole positioning

b. Drill speed and pressure control

c. Tool selection for different materials

Safety Emphasis

a. Clamp work securely

b. Use correct drill speed

c. Wear eye protection

Documentation

a. Record hole sizes and spacing

b. Note any issues like bit wandering or overheating

Notes to Facilitators

1. **Clarifying Concepts:** The focus here is on safety and process. Before any practical work, spend time on the «why» behind safety rules. Explain that a lathe can grab a loose shirt sleeve, pulling a hand into a rotating part in milliseconds. The rule (no loose clothing) is not arbitrary; it›s a direct response to a specific hazard.
2. **Common Misconceptions:** Students often underestimate the force of a machine. Demonstrate with a small, hand-cranked machine if possible, showing how easily it can cut or shape material. This builds respect for the tools.

3. **Low-Cost Demonstration and Ghanaian Examples**

   a. **Safety First:** Have a dedicated safety briefing before any hands-on activity. Use a PPE checklist. Have students point out potential hazards in the workshop before they start.

   b. **Machining:** For the turning activity, demonstrate the step of «touching off» to set the tool. Show how to make a light cut, measure the diameter, calculate the difference, and then set the cross-slide dial to take the final cut to size. This is the practical skill of machining.

Learning tasks

1. Learners recap previous knowledge through guided practice in using basic cutting tools. They perform drilling, filing, and sawing operations on various materials (wood, plastic, and soft metal), focusing on:
   a. Selecting suitable drill bits, files, and saws for different materials
   b. Applying correct tool speed, pressure, and cutting direction
   c. Securing workpieces safely during operations
   d. Creating accurate holes and clean cuts, then comparing outcomes across materials
2. Learners engage in a guided machining session to perform basic turning or milling operations using available machine tools.
3. Each learner demonstrates independent understanding on machining processes.

Pedagogical Exemplars

1. **Experiential Learning:** Learners visit a local manufacturing industry and observe the use and applications of cutting tools in woodwork and metalwork. If a visit is not possible, have the learners watch videos on the use and applications of cutting tools in woodwork and metalwork.
2. **Talk for Learning:** Through questions and answers, lead learners to discuss the application and use of cutting tools.
3. **Project-based learning:** Learners undertake a hands-on workshop project where they use appropriate cutting tools to perform practical operations such as cutting shafts, machining keyways, and creating threads.

Key Assessment: Practice Paper 2

1. A learner is assigned to drill holes in a ceramic tile for a school project. The available tools include a twist drill bit, a diamond-coated bit, and a carbide-tipped masonry bit.
   a. Identify the most appropriate tool for the task.
   b. Justify (a) based on material properties and tool performance.
   c. Describe two precautions one should take during the operation.

2. Design a simple workshop activity where learners shape a wooden block, drill a hole in a metal plate, and polish a polymer surface. For each material:
   a. Specify the tool to be used
   b. Describe the machining process
   c. Identify one safety precaution

Hint



*Conduct **Practice Paper 2**. It should cover the contents taught from Year 1 to 3. Refer to the **Table of Specification and Structure of the Paper** at the end of this section. Learners' papers should be marked immediately and scores entered into the SAP.*

ITEM SPECIFICATION FOR PRACTICE EXAMINATION 2

PAPER 1 (Objective test)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	MATERIALS FOR MANU-FACTURING	CLASSI-FICATION OF MATE-RIALS	3.1.1.CS.1 Demonstrate understand-ing in the use of advanced materials.	3.1.1.LI.1 Outline the importance of advanced ma-terials such as semiconduc-tors, biomate-rials, smart and nanomaterials.	1	2			6
			3.1.1.CS.2 Demonstrate knowledge of bamboo as a material for manu-facturing.	3.1.1.LI.3 State the applications of semiconduc-tors, biomaterials, smart materials and nanomaterials.		1			
			3.1.1.CS.2 Demonstrate knowledge of bamboo as a material for manu-facturing.	3.1.1.LI.1 Classify bamboo based on its structure, physical properties and processing.		2			

		PROPERTIES OF MATERIALS	1.1.2.CS.1 Demonstrate knowledge and understanding of the physical properties of materials	1.1.2.LI.1 Explain thermal conductivity, specific heat capacity, thermal expansion, melting point and thermal diffusivity as thermal properties of materials.	2	2	1		16
			1.1.2.CS.2 Demonstrate knowledge in the mechanical properties of materials.	1.1.2.LI.1 Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials.	3	2	3		
				1.1.2.LI.2 Explain permeability, retentivity and reluctance as magnetic properties of materials.	2	1			
2	DESIGN AND PROTOTYPING	DESIGN AND DRAWING FOR MANUFACTURE	2.2.1.CS.2 Demonstrate knowledge and understanding of the projection of objects as necessary for product design.	2.2.1.LI.2 Explain the application of first angle orthographic projection in product design.	3	2	1		6

		RAPID PROTO-TYPING	3.2.2.CS.1 Demonstrate understand-ing in rapid prototyping technolo-gies I.	3.2.2.LI.1 Explain the importance of rapid prototyping technologies.	1	3	1		5
3	MANUFAC-TURING TOOLS, EQUIPMENT AND PRO-CESSES	MAN-UFAC-TURING TOOLS AND EQUIP-MENT	3.3.1.CS.2 Demonstrate understand-ing of mod-ern machine tools.	3.3.1.LI.2 Understand the operation and application of a CNC machine.			1		1
		Manu-facturing Processes	3.3.2.CS.1 Demonstrate under-standing of material removal pro-cesses using conventional machining processes.	3.3.2.LI.2 Recognise and gain under-standing of turning, drilling and milling opera-tions using the centre-lathe machine.			3		3
		SAFETY, QUALITY AND THE ENVI-RON-MENT	3.3.3.CS.2 Demonstrate an under-standing of the use of quality assurance and quality control in manufactur-ing.	3.3.3.LI.1 Describe the role of qual-ity control in manufacturing process.		1	2		3
	Total				12 (30%)	16 (40%)	12 (30%)		40 (100%)

PAPER 2 (Written)

S/N	Strand	Sub-strand	Content standard	Learning indicator	Number of items				Total
					DOK 1	DOK 2	DOK 3	DOK 4	
1	MATERIALS FOR MANUFACTURING	CLASSIFICATION OF MATERIALS	3.1.1.CS.1 Demonstrate understanding in the use of advanced materials	3.1.1.LI.2 Explain the structure of semiconductors as engineering materials.	1				1
		PROPERTIES OF MATERIALS	2.1.2.CS.2 Demonstrate understanding on the tensile properties of materials.	2.1.2.LI.1 Explain elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.	1				1
2	MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES	MANUFACTURING TOOLS AND EQUIPMENT	1.3.1.CS.2 Demonstrate knowledge and understanding of standards, measurement, and gauging in the manufacturing process	1.3.1.LI.1 Understand standard unit of measurement for work pieces.	1				1
		Manufacturing Processes		1.3.2.LI.2 Discuss cutting, bending and drawing as sheet metal working operations.	1				1

		SAFETY, QUALITY AND THE ENVIRON-MENT	1.3.3.CS.2 Demonstrate an under-standing of ways in which the manu-facturing in-dustry affects society.	1.3.3.LI.2 Explain how the man-ufacturing industry affects the local and international economy. (e.g. With respect to job creation, standard of living, sustainability and conser-vation of the environ-ment.)	1		1
	Total				**5**		**5**

PAPER 3 (Practical)

S/N	Strand	Sub-strand	Number of items				Total
			DOK 1	DOK 2	DOK 3	DOK 4	
1	DESIGN AND PROTOTYPING	DESIGN AND DRAWING FOR MANUFACTURE	2				2
		RAPID PROTOTYPING					
	Total		2				2

PLC Session 18

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous session, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand.
   b. identify three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q).

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Use your app to plan and administer the mode of assessment for the Student Assessment Portal (SAP)

   a. The key assessment for the week is Practice Paper 2. Chat with your app to plan this assessment by reviewing or developing the assessment items/tasks and marking schemes/rubrics for the practice paper (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or topic/idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

   b. all teachers in the group work through the problem individually for 3–4 minutes

   c. the group then works through it together the problem, step by step

   d. highlight the most common errors made at each step (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 19

Learning Indicator: Explain computer numerically controlled (CNC) machine as a machine tool

Focal Area: Computer numerically controlled (CNC) machine

19.1 Introduction to CNC machines

CNC (Computer Numerically Controlled) machines are automated tools that perform precise operations such as cutting, drilling, milling, and turning, based on programmed instructions usually written in G-code and M-code. They have revolutionised manufacturing by enabling the production of complex, high-precision components with minimal human intervention. CNC machines operate autonomously once programmed, delivering exceptional precision and repeatability. Using computer-aided design (CAD) software, part designs are created and then converted into instructions via computer-aided manufacturing (CAM) software. They utilise motors and actuators to move along multiple axes and rely on sensors for real-time feedback. Key advantages of CNC machines include high production speed, consistent quality, reduced human error, and the ability to create complex shapes. They are essential in industries like aerospace, automotive, electronics, and medical device manufacturing, capable of machining a variety of materials such as metals, plastics, and wood.

19.2 Computer Numerical Control (CNC)

Computer numerical control (CNC) systems have brought a major leap forward in manufacturing, with on-board computers at the machine tool managing all data processing, control sequences, and responses to input. This setup delivers several key benefits: it allows for greater storage of programmes directly at the machine, enables users to edit programmes on-site, and supports control system upgrades as needed. Additionally, optional integration of Computer-Aided Manufacturing (CAM) software offers tool path simulation and verification, boosting accuracy and flexibility.

CNC machines themselves have transformed industries by automating the precise shaping of materials like metal, plastic, and wood, relying on pre-programmed instructions to ensure consistency, minimise errors, and achieve remarkable accuracy. The technology spans a range of machine types, each tailored to a specific manufacturing purpose: milling machines use rotating cutters to create complex shapes, drilling machines bore exact holes, turning centres form cylindrical components, and grinding machines produce fine surface finishes. A solid understanding of each machine's features, functions, and best applications is essential for selecting the right CNC tool for any modern industry, whether aerospace, automotive, or electronics. By combining advanced computing, versatile software, and machine specialisation, CNC systems enable efficient, high-quality, and repeatable production across an array of manufacturing sectors. Images of a typical CNC machines is presented in Figure 52.



Figure 52: *Industrial CNC milling machine*

(https://www.freepik.com/premium-ai-image/modern-manufacturing-with-cnc-milling-machine_248552565.htm)

19.3 Types of CNC machines

Computer numerically controlled (CNC) machines have revolutionised modern manufacturing by automating the precise shaping of materials such as metal, plastic, and wood. Operating with pre-programmed instructions, these machines deliver exceptional accuracy, consistency, and efficiency across a variety of production processes. Each of the primary types of CNC machines serve unique roles. CNC milling machines, for example, use rotating multi-point cutting tools to remove material from a stationary workpiece, moving along multiple axes that range from 3-axis (X, Y, S) to more complex 4- and 5-axis setups, sometimes featuring rotary tables and spindles for added versatility. These machines, commonly controlled by G-code, are capable of a wide variety of operations such as face milling, end milling, drilling, tapping, and shoulder milling, and are suitable for both roughing and finishing tasks. Notable types include Vertical Machining Centres (VMCs), Horizontal Machining Centres (HMCs), and multiaxis machines. Alongside milling, CNC drilling machines specialise in boring precise holes, while turning centres (CNC lathes) rotate the workpiece to efficiently shape cylindrical parts. CNC grinding machines, on the other hand, use abrasive wheels to produce fine surface finishes and achieve tight tolerances. Mastering the functions, principles, and applications of these CNC machine types is crucial for selecting the right equipment to meet the rigorous demands of industries such as aerospace, automotive, and electronics. Table 19.1 offers a comparison of common CNC machining centre types, their configurations, axes, and additional features, while Table 19.2 provides an overview of various CNC machine types, detailing their operational methods, distinctive features, common applications, and the typical tolerances achieved in precision manufacturing.

19.4 CNC machine components and systems

CNC machine is an integration of several critical subsystems that work in concert to achieve precise and efficient machining. At its core is the control system, often referred to as the machine's "brain," which interprets G-code instructions, manages user interface inputs, and directs the sequence of operations through the CNC controller and display. The motion control system translates these instructions into precise movements along the machine's axes, utilising stepper or servo motors, ball screws, and linear guides to ensure accurate positioning and speed. The tooling system is responsible for holding and changing cutting tools, featuring tool holders, turrets, and automatic tool changers (ATC) to enable seamless multi-operation machining with minimal manual intervention. Equally vital is the work holding system, which secures the workpiece in place during machining; this system uses chucks, vices, clamps, or fixtures to maintain rigidity and alignment, thereby preventing vibration and ensuring dimensional accuracy throughout the manufacturing process.

19.5 CNC programming

Computer Numerical Control (CNC) programming is the process of instructing a CNC machine tool how to move and operate to machine a part. CNC machines are automated milling, turning, or other machining tools that follow a programmed sequence of instructions encoded in a specialised language. This language primarily consists of G-codes (preparatory commands) and M-codes (miscellaneous machine commands). Understanding CNC programming involves knowing the G-code language, effective programming techniques, and how a typical CNC programme is structured. This subsection explores the foundations of G-code, essential programming strategies, and the typical structure of a CNC programme, equipping learners with the skills necessary to harness the full power of CNC technology in modern engineering environments.

19.5.1 Machine coordinate system designation

The direction of each finger represents the positive direction of motion, with the axis of the main spindle always designated as the Z axis and its positive direction pointing into the spindle. On a milling machine, the longest travel slide is identified as the X axis, which is always perpendicular to the S axis. If you look into your middle finger while rotating your hand, your forefinger then represents the Y axis. The base of your fingers indicates the start point, or the machine's origin, defined as (X0, Y0, S0). A visual guide demonstrating the right-hand rule for identifying linear axes and their corresponding rotational movements (A, B, and C axes) on CNC machines, aiding operators in understanding axis orientation and direction for precise programming and operation is shown in Figure 53.

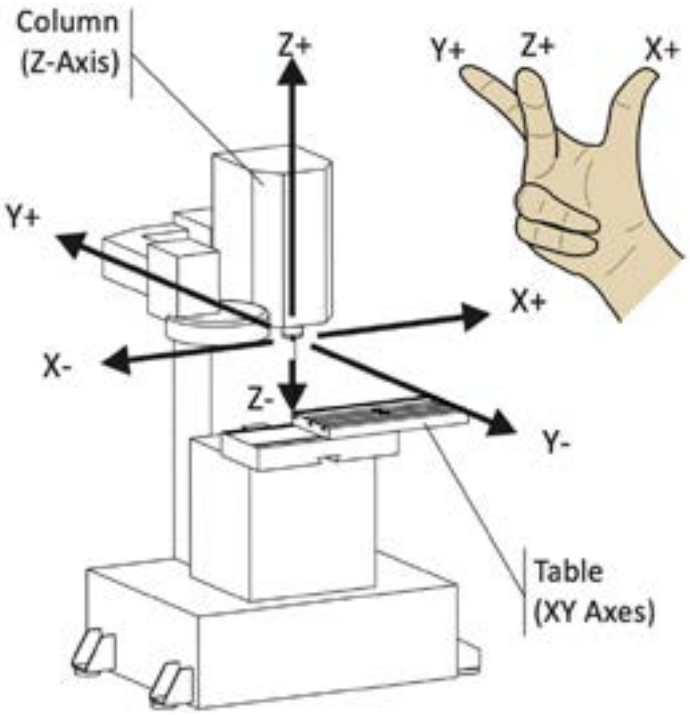


Figure 53: *Right-Hand Rule for CNC machine axes*

https://www.opmtlaser.com/wp-content/uploads/2025/01/3-Axis-CNC-Machining.png

The right-hand rule is a helpful technique for identifying the correct axes and directions of rotation on a CNC machine. By pointing your thumb outward to represent the X, Y, or S axis, and curling your fingers, you can visualise the positive or clockwise rotary motion about each respective axis. These rotary motions are designated as A, B, and C, corresponding to rotations about the X, Y, and S axes, respectively. This intuitive approach aids in understanding both linear and rotational movements, ensuring accurate programming and operation of CNC machinery.

19.5.2 G-Code

G-code is the most widely used programming language for CNC (Computer Numerical Control) machines. It is sometimes referred to as RS-274, named after an early standard designation. The "G" in G-code stands for "preparatory code," which indicates that these commands prepare or set a mode of operation for the machine. A G-code file consists of a list of instructions that guide the CNC machine on how to move its cutting tool or workpiece, specifying precise positions and motions. Developed at MIT in the 1950s and standardised by the Electronics Industry Association, G-code has become a universal language for CNC machinery across various types. Modern CNC controllers, whether used in milling machines, lathes, or routers, all understand a version of G-code. This standardised language translates digital designs into precise machine movements and operations. Each command line, referred to as a block, provides specific instructions regarding tool paths, spindle speeds, movement direction, and other essential parameters for the machining process. Operators must grasp both the syntax and the purpose of various G-code commands. For example, commands for linear movement (G01), rapid positioning (G00), and tool changes (M06) are critical for ensuring accurate machining tasks. Mastery of G-code enables the programming of complex machining sequences, such as drilling, cutting, and contouring, while also allowing for customisation and troubleshooting. This mastery significantly enhances productivity, efficiency, and the quality of finished components in modern manufacturing environments.

19.5.2.1 G-Code Programming Commands and Format

A G-code programme is written as a series of **blocks** (or lines). Each block contains one or more instructions represented by letter addresses followed by numbers. For example, in a typical line N50 G01 X100.0 Y50.0 F150, the structure might be:

- **N50**: Line number or sequence number (optional in many systems, used for reference).
- **G01**: A G-code command (here, G01 means a linear feed move).
- **X100.0 Y50.0**: Coordinate positions (telling the tool to move to X = 100.0, Y = 50.0).
- **F150**: A feed rate (speed of the tool movement).

Each letter corresponds to a specific type of instruction:

- **N** is a sequence **Number** for the block.
- **G** codes set the mode or type of motion (like rapid move, feed move, arc move, etc.).
- **X, Y, S** are coordinate positions along axes.
- **F** is feed rate (how fast to move the tool during cutting).
- **S** is spindle speed (how fast the cutting spindle rotates).
- **T** is tool selection (which tool to use, in machines with tool turrets or changers).
- **M** codes are miscellaneous functions (such as turning the spindle on/off, coolant on/off, programme stop, etc.).

19.5.2.2 Modal vs. Non-Modal Commands

Many G-codes are modal, meaning once set, they remain in effect for subsequent blocks until changed. For example, if G01 (linear move) is active, every subsequent block with coordinates will be a linear move until another motion code (like G00 for rapid move) appears. Other codes are non-modal, applying only to the block they're in.

19.5.2.3 Units and Coordinate System

G-code instructions can specify units and coordinate modes as below:

1. **G20/G21:** select inches or millimetres, respectively, as units.
2. **G90/G91:** set **absolute** or **incremental** positioning modes:
    a. *Absolute positioning (G90)* means coordinates are interpreted from a fixed origin (usually the part zero or workpiece datum).
    b. *Incremental positioning (G91)* means each coordinate is relative to the current position (the machine moves relative to where it last was).
3. **Common G-Codes:** While the exact list of G-codes can vary slightly by machine or controller, some common **milling** G-codes include:
4. **G00:** Rapid traverse (fast, non-cutting movement to position the tool).
5. **G01:** Linear interpolation (straight cutting move at set feed rate).
6. **G02:** Circular interpolation clockwise (arc move).
7. **G03:** Circular interpolation counterclockwise.
8. **G17, G18, G19:** Select the plane for arcs (XY plane, XS plane, YS plane, respectively).

9. **G40, G41, G42:** Cutter radius compensation (off, left, right).
10. **G43/G44:** Tool length offset apply (+ or -).
11. **G54 (and G55-G59):** Work coordinate system selection (offsets for part zero positions).
12. **G80:** Cancel canned cycle.
13. **G81, G82... G89:** Canned drilling cycles (common drilling, peck drilling, boring cycles, etc.).
14. **G92:** Set a new work coordinate origin or preset position.
15. For **turning (lathe)** operations, common G-codes might include G00, G01, G02, G03 as well (for moves), and other lathe-specific cycles (like G71 for roughing cycle, G70 finishing, etc.), though this explanation focuses on general concepts applicable to both milling and turning.
16. **Common M-Codes:** M-codes handle various machine functions:
17. **M00:** Programme stop (pause until operator intervention, often).
18. **M01:** Optional stop (stops if the optional stop is enabled on the machine).
19. **M03:** Spindle on clockwise (for milling; on lathes, M03 might mean spindle forward).
20. **M04:** Spindle on counterclockwise (or spindle reverse).
21. **M05:** Spindle stop.
22. **M06:** Tool change command (tells the machine to swap to a new tool number).
23. **M08:** Coolant on.
24. **M09:** Coolant off.
25. **M30:** Programme end and reset (often rewinds to programme top).

Note for facilitators

Explain to students that **learning Gcode** is about understanding the *principles* of how CNC machines move and operate, but in industry, **writing Gcode manually** is rare – most complex parts are programmed using CAM software that automatically generates the code from a 3D model. The goal is to read and debug code, not to write long programs by hand. **Never run studentwritten Gcode on a real CNC machine without first simulating it** – a single mistake can crash the tool or damage the machine. Use free online simulators for practice. Always require students to simulate and dryrun their code before any real machine contact.

19.6 Programming Techniques

G-code programming encompasses a variety of approaches that empower operators to efficiently translate design intent into precise machine instructions. Manual programming allows users to write G-code line-by-line, granting complete control over each operation and enabling quick adjustments for unique or complex machining requirements. Computer-Aided Manufacturing (CAM) software streamlines this process by automatically converting Computer-Aided Design (CAD) models into G-code, significantly reducing programming time and minimising the potential for human error. For advanced applications, parametric programming introduces variables, conditional logic, and subroutines, fostering flexible, reusable code that can adapt to different part dimensions or production scenarios with minimal rework. Mastery of these techniques enables machinists to optimise tool paths, enhance part consistency, and boost

overall productivity in modern CNC environments, ensuring both accuracy and efficiency in manufacturing workflows. While knowing individual G-code commands is essential, effective CNC programming also involves techniques and best practices to ensure programmes run safely, efficiently, and produce accurate parts

Key programming techniques include:

1. Absolute vs. Incremental Programming: As noted with G90/G91, a programmer must decide whether to use absolute coordinates (all positions from a fixed origin) or incremental moves (each position relative to last). In practice, absolute mode (G90) is common for clarity – every coordinate refers to a known datum on the part. Incremental (G91) can be useful inside repeated structures or subroutines where relative moves are easier to repeat. Many programmers stick to absolute mode for most programming to avoid confusion, switching to incremental only when needed for particular tasks (like certain canned cycles or loops).
2. Planning Toolpaths and Safety: Before writing code, a programmer plans the machining steps and toolpath:
    a. Approach and Retract Moves: Always include safe approach moves (rapid positioning to a safe start point above the part) and safe retract moves. For instance, using G00 (rapid) to position the tool clear of the work before and after cutting prevents collisions with the workpiece or fixtures.
    b. Avoiding Singularities: Plan paths to avoid sudden sharp turns or over-travel. Use appropriate radii for corners if needed.
    c. Order of Operations: Typically, perform roughing cuts first, then finishing cuts for accuracy. Also, if multiple tools are involved, group operations by tool to minimise tool changes.
3. Cutter Radius Compensation and Tool Offsets: CNC programming often uses cutter compensation (G41/G42) for milling so that the programmer can specify the path of a part's geometry while the machine offsets the path to account for the cutter's radius. For example, if milling a contour, using G41 (left compensation) or G42 (right compensation) with a known cutter diameter allows the same programme to be used even if the tool size changes slightly, by adjusting an offset in the controller.

Notes for Facilitators: Explain that:

a. G41/G42 are invoked typically just before a contour, and G40 cancels the compensation after finishing the contour.

b. Proper lead-in and lead-out move (usually linear moves) are needed when using cutter compensation so the tool can offset properly without gouging the part.

c. Similarly, tool length compensation (G43/G44) is used on mills for the Z-axis to account for different tool lengths. The programme references a standard reference point (like tool tip at some plane), and the machine adjusts based on stored length offset for each tool to achieve correct depth. Usually G43 with an H offset (H1, H2 matching the tool number) is used to apply a tool's length offset.

4. Canned Cycles and Subroutines: To simplify programming common operations, CNC controls offer canned cycles (these are shorthand commands for repetitive tasks like drilling holes, tapping, or boring). For example:

a. G81: Standard drilling cycle (drill down to a certain Z depth at feed rate, then retract).

b. G83: Peck drilling cycle (drill with periodic retractions to break chips).

c. G84: Tapping cycle (feeds in and reverses out for threads). Using canned cycles reduces the number of lines and chances for error, as the machine handles the motion pattern internally. Teachers can illustrate how a single G81 line can replace several lines of explicit motion code.

d. Subroutines and Loops: Many CNC controls allow subprogrammes or looping to repeat code blocks. A section of code like a pocketing routine can be written once, then executed multiple times at different locations via a loop or subroutine call (often using M98 to call a subprogramme, or G91 with a loop count in some controllers). Utilising subroutines makes the programme shorter and easier to modify, which is an advanced technique but valuable when teaching good programming habits.

5. Using CAM vs. Manual Coding

6. It is worth mentioning that in industry, CAM (Computer-Aided Manufacturing) software often generates G-code automatically from CAD models. However, understanding manual G-code is fundamental:

   a. It helps in verifying and troubleshooting CAM output.

   b. It's essential for making quick edits or writing simple programmes without full CAM software. Educators can stress that while students might use CAM in projects, knowing the G-code language provides insight into what the machine is actually doing, and is important for debugging machining issues.

7. Comments and Readability: Good programming practice includes commenting and formatting as below:

   a. Comments: Anything in parentheses () in a G-code programme is a comment for the human reader. Programmers use comments to label sections, describe operations, or give special instructions. Example: (Milling outer profile) as a comment header for that section of code.

   b. Readable Formatting: Although machines don't care about spacing beyond the basic word structure, programmers often write one command per line in a consistent order. A common convention is to write axis motions in X, Y, Z order, followed by feedrate (F), and have one motion (G00 or G01 etc.) per line. Consistency in ordering words in a block (e.g., always N, then G, then X,Y,Z, then F,S,T,M) makes it easier for others to read and understand the code.

8. Verification and Simulation: While not part of coding itself, a critical step in CNC programming is verification.

   a. Programmers often run through the code in a simulator or the machine's dry-run mode to ensure there are no crashes or mistakes.

   b. Visualising the toolpath (many CNC machine interfaces graph the path) helps catch mistakes in coordinate values or sequence.

9. Error Checking and Debugging: CNC controls are strict about formatting. Missing a decimal point or a letter can cause errors or misinterpretation. For example, writing G01 X100 Y100 without a feedrate could cause an alarm if a feedrate wasn't previously set.

Good practice is to define all necessary parameters clearly at the start (units, feedrates, spindle speeds) and check the programme for any undefined moves.

19.7 CNC Programme Structure

Every CNC programme follows a logical structure from start to finish. A well-structured programme ensures the machine operates safely and produces the desired result. Adhering to a standard programme structure is important both for safety and for other machinists or students to read the programme easily. A typical CNC programme (for one setup and part) can be broken into the following sections:

1. **Programme Start and Safety Block**
    a. The beginning of a programme may have a start sentinel (like % in some controls) and a programme number (e.g., O1234).
    b. A safety block (or startup block) is then used to set default modes and ensure no old settings carry over. This usually includes:
        i. Unit selection (G20 for inch or G21 for mm).
        ii. Modal cancellations (cancel any tool offsets, cutter comp, or canned cycles with G40, G49, G80).
        iii. Plane selection (often G17 for XY plane on mills).
        iv. Default to absolute mode (G90) unless incremental is specifically needed.
        v. Feedrate or spindle defaults if required.
    c. Example safety line: G90 G21 G17 G40 G49 G80 – which sets absolute mode, metric units, XY-plane, and cancels tool radius comp, tool length comp, and canned cycles.
2. **Tool Selection and Setup**
    a. Issue a tool change command (e.g., T1 M06 for Tool #1). The machine will prepare Tool 1.
    b. Set spindle speed and turn on spindle (e.g., S1500 M03 to rotate at 1500 RPM clockwise).
    c. Activate coolant if needed (M08).
    d. Move to a safe position to start machining, often using a combination of G54 (work offset) and a rapid move. For example:

    G54 G00 X... Y... to position laterally, and G43 Z... H1 to move the tool to a safe height while applying the tool length offset (H1 corresponds to Tool 1's length offset).
3. **Machining Operations**
    a. This section contains the main sequence of machining commands. Depending on complexity, it might be divided into subsections for each feature or each tool.
    b. For each operation (or each tool if multiple tools are used), you would typically:
        i. Approach: Rapid move close to the cut start point.
        ii. Possibly use a canned cycle (for drilling) or explicit moves (for milling contours, pockets, etc.).
        iii. Execute the necessary G-code moves to perform the cutting.

iv. Retract: Rapid away from the work at the end of the operation.

c. If multiple tools are used, after finishing with one tool, turn off coolant (M09), stop spindle (M05), then move back to a safe location (often home or a tool change position), and command the next tool change (T2 M06, etc.), repeating the cycle for the next tool's operations.

4. **Programme Ending**

   a. After all operations are done, ensure the spindle is off (M05) and coolant is off (M09) if not already.

   b. Some programmes move the tool away to a safe location or machine home. A common practice is using G28 (return to reference home) with G91 (temporary incremental) to send axes home safely, e.g.,G91 G28 Z0; G91 G28 X0 Y0; G90 which returns Z axis to machine zero, then X and Y, and finally switches back to absolute mode.

   c. End the programme with an end-of-programme code. For many machines, **M30** signifies programme end and reset (rewind to start). Older controllers or certain contexts might use M02 (programme end without rewind), but M30 is common.

   d. End-of-file is often indicated by another % or just the file end.

5. **Programme Comments and Documentation**

   a. Optionally, many programmes include an initial comment block describing the programme's purpose, the part name, the programmer, the date, etc. For example:

      (PART: Bracket_12345)

      (MATL: Aluminium 6061)

      (PROG: John Doe, 01-Jan-2025)

   b. Throughout the programme, comments can mark sections or give hints, as discussed in *Programming Techniques.*

6. **Multiple Tool Programmes:** In more complex programmes that use multiple tools, the structure repeats the cycle of *tool change -> machine with that tool -> end operations for that tool* as needed. Each tool usage might be considered a sub-section of the programme. For instance:

   a. Programme Start and Safety (with first tool setup).

   b. Operations with Tool 1.

   c. Prepare for Tool 2 (stop spindle, coolant off, tool change to Tool 2, spindle on, etc.).

   d. Operations with Tool 2.

   e. and so on for all tools.

   f. Final programme end.

Each tool section itself often follows a structure:

a. Tool Change and Spindle/Coolant On (begin tool section).

b. Approach moves (get into position).

c. Cutting moves (do the work).

d. Retraction moves (leave the part safely).

e. (Maybe a brief dwell or coolant off if needed between certain operations).

f. Then move to prepare for next tool or end.

19.8 Structured Example Explanation: To illustrate the structure, consider a scenario where a CNC milling programme first mills a profile with an endmill (Tool 1) and then drills a hole with a drill (Tool 2).

The structured flow would be:

1. **Start/Safety:** Set modes (absolute, units, cancel any old modes).
2. **Tool 1 (End Mill) Operations**
    a. Tool change to T1, spindle on, coolant on.
    b. Rapid above first cut position.
    c. Perform milling (G-code moves for contour).
    d. Retract and coolant off, spindle off.
3. **Tool 2 (Drill) Operations**
    a. Tool change to T2, spindle on, coolant on.
    b. Rapid above hole position.
    c. Drill hole using a canned cycle (e.g., G81).
    d. Retract, cancel canned cycle (G80), coolant off, spindle off.
4. **End:** Return to home, programme end (M30).

Notes for Facilitators

1. This structure helps students and educators see the logical sequence; it mirrors how one might explain the process verbally: first set everything up, then do this cut, then change tool, do that cut, finally wrap up safely.
2. *Safety Considerations in Structure: Emphasise that the structured approach is not only for organisations but also for safety:*
    a. Always ensure the machine is in a known state at the start (so no unexpected motion or mode).
    b. Always end in a safe state so the next programme or manual move starts safely (for instance, ensuring the tool is retracted and spindle off at the end prevents accidents).
    c. The strict ordering of motions in each block (only one movement command per line, etc.) and sequence of operations is intended to minimise mistakes that could cause tool crashes.

19.9 Example of a Simple CNC Programme

```
%
O1001 (Sample Programme)
G90 G21 G17 G40 G49 G80        (Safety startup: absolute, metric, XY-plane, cancel offsets)
```

```
G54                     (Select work coordinate system 1)
T1 M06                  (Tool change to Tool #1)
S1500 M03               (Spindle on clockwise at 1500 RPM)
G00 X50.0 Y50.0         (Rapid move to XY start position)
G43 Z5.0 H1             (Apply tool length offset #1, move Z to 5.0 above part)
M08                     (Coolant on)
G01 Z0.0 F100           (Feed to Z0 at 100 mm/min – start cutting)
X100.0 Y50.0 F200       (Cut in X direction to X100 at 200 mm/min)
Y100.0                  (Cut in Y direction to Y100)
X50.0                   (Cut back to X50, forming a square path)
Y50.0                   (Cut back to start Y, closing the square)
G00 Z100.0              (Rapid retract to safe Z height)
M09                     (Coolant off)
M05                     (Spindle stop)
G28 X0 Y0 Z0            (Return to machine home position)
M30                     (End programme)
%
```

In this annotated example, you can see how G-codes (like G90, G00, G01) designate motion modes, coordinates specify positions, and M-codes control the machine's hardware (spindle, coolant, tool changes, etc.). The percent signs % (at start and end) and the programme number (O1001) are typical in many CNC controllers to denote the beginning and end of a programme file and its ID. Lines in parentheses () are comments for human readers, ignored by the machine.

Notes for Facilitators

1. **Clarifying Concepts:** Demystify G-code. It is not a complex programming language; it is just a set of instructions. Use the analogy: You are instructing a taxi driver. G00 is go to this location as fast as possible (rapid). G01 is go to this location at a specific speed (feed). M03 is start the engine (spindle on).
2. **Common Misconceptions:** Students may think CNC machines are fully automatic and require no skill. Emphasise that they still require a highly skilled operator who knows how to set up the machine, choose the right tools and speeds, write the programme, and troubleshoot when things go wrong.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Simulate G-code:** On the board, write a simple G-code programme for a shape (like the square from the example). Walk through it line by line, using the taxi driver analogy. Have students be the machine and move a marker across a piece of paper following the code.
    b. **Local Industry:** Discuss how a local metal fabrication shop might use a CNC plasma cutter to quickly and accurately cut complex shapes from sheet metal for a construction project. This is a practical Ghanaian application.

Learning Tasks

1. Learners review the functions and uses of basic manufacturing tools, safety conventions, measuring instruments, and fundamental processes such as cutting, filing, and drilling to build on their previous knowledge from earlier years.
2. Watch a short video clip of a CNC milling machine and a manual milling machine in action. Write a 150-word response answering: How does the CNC machine's operation as a machine tool differ from the manual machine in terms of programming, accuracy, and speed? Justify which tool would be better for producing a precise wooden mould, based on your observations from the video.
3. After watching a video of a CNC machine in operation, learners research how CNC machines function as machine tools compared to a traditional tool (e.g., manual lathe or drill press) used in local industries.
4. Learners Write a CNC programme that machines a 50 mm × 50 mm square starting at X30 Y30, to a depth of Z = −3 mm, using Tool #3 (12 mm end mill), spindle speed 2000 RPM, and feed rate 150 mm/min.

Pedagogical Exemplars

Experiential learning

a. Teacher shows learners a video demonstration of a CNC machine in operation to illustrate its real-world industrial application.

b. Learners conduct guided research on CNC machines and present how they differ from conventional machine tools commonly used in local industries.

c. Learners in mixed ability groups write the programme using a worksheet or whiteboard to complete the full CNC code for the square path

d. Learners exchange, and simulate a G-code programme to machine a 50 mm × 50 mm square starting from X30 Y30, using a 12 mm end mill (Tool #3), and cutting to a depth of –3 mm.

e. Each learner then responds to a structured written assessment question based on the learning indicator.

Key Assessment Level 4: Homework

1. Explain the difference between CNC milling and CNC turning in terms of tool movement and workpiece orientation.
2. Design a CNC programme to mill a 50 mm × 30 mm pocket, 3 mm deep, starting at X10 Y10. Include key G-code commands and explain their function.

PLC Session 19

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is homework. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the homework (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 20

Learning Indicator: Understand the operation and application of a computer numerically controlled (CNC) machine

Focal Area: Operation and application of CNC machine

20.1 Introduction

CNC (Computer Numerically Controlled) machines are advanced tools used in modern manufacturing to automate machining processes. Unlike manual machines, CNC machines follow programmed instructions to perform precise operations such as cutting, drilling, turning, and milling. Understanding how these machines operate and where they are applied is essential for students preparing for careers in manufacturing and engineering, as CNC machines are programmable and repeatable, improving productivity, accuracy, and safety. Operators must be familiar with both the software aspects, such as programming, and the hardware requirements, including machine setup and operation.

20.2 CNC machine operation and setup

The successful use of CNC (Computer Numerical Control) machines relies on a systematic approach to both preparation and operation. Proper machine setup, precise operational procedures, and strict adherence to safety protocols are essential to achieve accurate results, maintain equipment longevity, and protect operators from hazards. This section provides an overview of the essential steps involved in CNC machine operation and setup, from initial preparation of workpieces and tooling to the execution of machining cycles and crucial safety considerations that must be observed throughout the process.

20.3 Safety Considerations in CNC Machine Operation

1. Personal Protective Equipment (PPE): Always wear safety glasses or face shields, and use hearing protection where needed. Gloves and aprons may be used during setup and cleanup, but never wear gloves near moving equipment.
2. Attire and Personal Safety: Wear fitted clothing, remove jewellery, and tie back long hair. Steel-toed shoes are recommended in workshops. Never wear gloves near rotating spindles or chucks during operation.
3. Machine Guards and Enclosures: Always use machine guards and keep safety doors closed. Never disable safety interlocks or guards.
4. Pre-Operational Safety Checks: Inspect the machine and workspace for hazards, ensuring E-stop buttons are accessible and the area is clear of tools, spills, and obstructions.
5. Safe Operation Practices: Stay alert, keep clear of moving parts, and never reach into the machine while it is running. Use emergency stops if unexpected events occur.
6. Handling of Materials and Tools: Handle tools with care, making sure the spindle is stopped for any changes or adjustments. Use correct lifting techniques for heavy items.
7. Emergency Preparedness: Know where emergency stops and power cut-offs are located. Be familiar with fire protocols and first aid procedures.

8. Training and Supervision: Only trained or supervised individuals should operate CNC machines. Emphasise attentive and sober operation at all times.
9. Maintenance for Safety: Perform regular maintenance and cleaning to ensure machine reliability. Remove chips and debris frequently, and check all safety systems and interlocks.

20.4 Applications of CNC machines

CNC machines offer remarkable versatility across various manufacturing processes, including milling, turning, multi-axis machining, and specialty operations. Milling involves removing material from a fixed workpiece using rotating cutters, making it ideal for creating slots, pockets, and intricate three-dimensional shapes. Turning, on the other hand, rotates the workpiece while a stationary tool shapes it, which is particularly effective for producing cylindrical parts such as shafts and bushings. For more complex geometries, multi-axis machining—using machines with four or more axes, such as five-axis CNC allows for the fabrication of highly intricate components in a single setup, a technique widely employed in aerospace, automotive, and mould-making industries. Specialty machining processes further expand CNC capabilities, with methods like CNC electrical discharge machining (EDM) for cutting hard materials, CNC laser cutting for high-precision shapes, and CNC waterjet cutting, which uses high-pressure water and abrasives to cut materials without introducing heat. Collectively, these processes underscore the adaptability and precision that CNC machines bring to modern manufacturing.

Notes for Facilitators

1. **Clarifying Concepts:** Reinforce the «Set-up, Run, Inspect» cycle. 70% of the time of a machinist is spent on set-up: choosing and measuring tools, setting the workpiece zero, and simulating the toolpath. The run is the fast part. «Inspect» is what tells you if your set-up and programme were correct.
2. **Common Misconceptions:** Students might think they can just load a programme and press «start.» Emphasise that dry runs (running the programme with the tool up in the air or without a workpiece) are mandatory. This is the final safety check to ensure the programme will not cause a crash.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Dry Run Simulation:** If a CNC machine is available, demonstrate a dry run. Show how to set the feed override to a low value, then watch the simulation on the screen or watch the machine move without cutting. This is the single most important safety and verification step.
    b. **Application Discussion:** Research and discuss the potential for CNC in Ghana. Could it be used for custom automotive parts? For prototyping agricultural equipment? For creating complex moulds for local industries? This helps students see the future relevance.

Learning Tasks

1. Learners briefly revisit key manufacturing processes studied in Years 1 and 2 (e.g., casting, forging, extrusion, machining, welding, additive manufacturing
2. Learners watch a video demonstration of a CNC machine in operation (such as a CNC router or lathe), then research the machine's operation (including G-code programming and tool movement) and its applications in manufacturing (such as cutting wood panels or metal parts).
3. Learners explore a web-based CNC simulation (such as a free emulator or Fusion 360 demo) and view a short video of a CNC milling machine in action.
4. Complete an Example Assessment Question Individually

Pedagogical Exemplars

1. **Experiential Learning:** Take learners on an educational tour to a manufacturing industry to observe the operating and application of CNC machines. (If a visit is not possible, please have the learners watch videos about the operating and application of CNC machines.)
2. **Research-based learning:** Learners in mixed-ability groups read from the library and Internet on the operation and applications of CNC machines and present their results to the class for feedback.
3. Learners discuss the operation and industrial applications of CNC machines.
4. **Independent work:** Have learners complete the assessment questions individually and then mark them as a class, using the marking scheme.

Key Assessment Level 2: Classwork

1. Discuss how CNC machines have transformed modern manufacturing. Include at least three specific applications and explain how CNC technology improves productivity and precision.
2. A student is using a CNC machine to engrave a logo on a stainless-steel plate. Identify the most suitable CNC process for this task and justify your choice based on the material and required detail.

PLC Session 20

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is classwork. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the classwork (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 5 Review

This section aims to enhance understanding of computer numerically controlled (CNC) machines and the crucial role of cutting tools in modern manufacturing. It begins with identifying and classifying cutting tools used in manufacturing, examining methods of categorisation by manufacturing type, cutting action, and materials. Through hands-on activities, learners explore both conventional and non-conventional manufacturing processes, assessing their advantages, limitations, and technological advancements.

Next, the section focuses on the safe application of these tools across various materials, including wood, metal, ceramics, and polymers. Practical tasks cover shaping, drilling, milling, and finishing, emphasising safety protocols and proper tool handling.

The principles and operations of CNC machines are then introduced, covering subsystems, programming in G-code, and key concepts like absolute and incremental positioning and tool compensation. This segment highlights the transformative impact of CNC technology across industries, including aerospace and medical devices, while also examining specialty processes like laser engraving.

Throughout the journey, experiential learning and collaborative projects encourage critical evaluation of tool choices and problem-solving in real-world scenarios. By the end, learners should be able to select appropriate tools, effectively programme and operate CNC machines, and produce accurate, industry-compliant components, laying a solid foundation for technical excellence in engineering and manufacturing.

SECTION 6: PRINCIPLES OF MATERIAL REMOVAL PROCESSES AND APPLICATIONS OF THE CENTRE-LATHE MACHINE

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Sub-Strand: Manufacturing Processes

Learning Outcome: Explain the working principles of a centre-lathe machine and use the lathe machine to perform a simple material removal process

Content Standards

1. *Demonstrate understanding of material removal processes using conventional machining processes. (Week 21)*
2. *Demonstrate understanding of material removal processes using abrasive processes. (Week 22)*

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the fundamental principles of material removal processes with a focus on conventional machining operations using the centre-lathe machine**.** Learners will explore how materials are shaped and formed by removing excess material through cutting, turning, drilling, and facing processes. Emphasis is placed on understanding how these methods are applied in real manufacturing environments to achieve precision and surface quality.

Through experiential and practice-based learning, learners will examine the structure, components, and working principles of the centre-lathe machine, including how the machine rotates the workpiece against a cutting tool to perform various operations. Learners will also identify different types of lathe machines—such as engine lathes, toolroom lathes, and CNC lathes, and understand their roles in industry.

Again, learners will actively engage in setting up the lathe machine**,** including mounting the workpiece, selecting appropriate cutting tools, and applying proper cutting parameters like spindle speed, feed rate, and depth of cut. These activities will be supported with practical demonstrations and group-based learning tasks.

Additionally, learners will explore turning, drilling, and basic milling operations using the centre-lathe machine. They will observe and practice these operations safely, apply quality checks, and reflect on the importance of tool selection and machine setup in achieving accurate results. Safety protocols and personal protective equipment (PPE) will also be emphasised throughout the section to promote responsible workshop practice.

By the end of this section, learners will gain a hands-on understanding of how conventional machining processes are used in the manufacturing industry**.** They will also build foundational skills in lathe operation, process planning, and workplace safety**.**

The weeks and the indicators covered by the section are:

Week 21

1. Discuss the fundamentals of material removal processes and principles of operation of the centre-lathe machine.
2. Recognise and gain understanding of turning, drilling and milling operations using the centre-lathe machine

Week 22

1. Recognise and gain understanding of grinding operations
2. Perform a material removal process using a lathe machine

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. **Talk for Learning**
    a. **Tool Matching and Peer Teaching**: In small groups, learners handle real workshop tools and match them to specific machining tasks. Videos are used to spark discussions, and learners explain safety and measurement procedures to peers.
    b. **Brainstorming and Sample Analysis**: Learners brainstorm how materials are removed in milling and turning. Sample components are displayed (e.g., turned vs. ground), and learners discuss observable differences in finish and accuracy.
    c. **Operation Classification and Review**: In groups, learners recall machining operations learned previously and categorise tasks best suited for the lathe.
2. **Research-Based Learning**
    a. **Historical and Technological Evolution**: Learners research the history and modern significance of material removal techniques using library and online resources. Findings are presented via a timeline or short report.
    b. **Process Comparison Study**: Individually or in mixed-ability groups, learners research one conventional and one non-conventional machining process, comparing their working principles, tools, and applications using comparison tables or presentations.
    c. **Visual Labelling and Presentation**: Learners observe lathe operations (live or recorded), take notes, label diagrams of centre lathe machines, and present their findings on posters.
3. **Experiential Learning**
    a. **Demonstration and Diagram Study**: Learners study labelled diagrams of lathe machines and watch demonstration videos of lathe use in manufacturing.
    b. **Industrial Field Trips**: Visits to manufacturing companies where learners observe live machining processes including turning, milling, drilling, and grinding, focusing on setup, sequence, and safety practices.

c. **Hands-on Machining Practice**: Under supervision, learners practice operations like turning, drilling, and grinding, applying feed/speed control, tool alignment, and dimensional measurement techniques.

d. **Design and Tolerance Task**: Learners design and machine precision parts (e.g., shaft or gear blank) with specified tolerances (±0.05 mm), demonstrating their understanding of process control.

e. **Grinding Operation Practice**: In groups, learners perform grinding operations using school equipment. Activities include setup, execution, and quality inspection.

f. **Structured Assessment and Feedback**: After practice sessions, learners complete structured written assessments aligned with learning indicators. Responses are marked using rubrics to evaluate mastery and provide feedback for improvement

ASSESSMENT SUMMARY

To effectively evaluate learners' comprehension of the principal themes in this section, a diverse range of assessment modes is utilised. These modes ensure that learners across all proficiency levels have opportunities to demonstrate their understanding. Oral responses are encouraged through engaging class discussions, allowing learners to articulate their insights and participate in critical discourse. Additionally, written responses of varying difficulty levels are solicited to assess learners' understanding of major concepts.

Research and experiential learning are key components, providing learners with opportunities to explore Principles of material removal processes and applications of the centre-lathe machine comprehensively. These approaches encourage practical application and innovation, enabling learners to develop a nuanced understanding of the working principles of a centre-lathe machine illustrated by turning, drilling and milling operations using the centre-lathe machine. This multidimensional assessment approach ensures that learners not only acquire theoretical knowledge but also apply their learning to real-world scenarios, enhancing their critical thinking and problem-solving abilities. Table 12 is a summary of the assessment used against the indicator.

Table 12 Assessment summary for Section 6

Indicators	DOK Level	Assessment Strategy and/or Mode
Discuss the fundamentals of material removal processes and principles of operation of the centre-lathe machine.	2	1. Research, presentation, group discussion
Recognise and gain understanding of turning, drilling and milling operations using the centre-lathe machine	3	1. Practical experience, group project
Recognise and gain understanding of grinding operations	3	1. Individual research project, case study analysis with reports 2. Socratic seminar with reflective discussion
Perform a material removal process using a lathe machine	4	1. Individual research and report writing, research project 3. Think-pair-share discussion

WEEK 21

Learning Indicators

1. *Discuss the fundamentals of material removal processes and principles of operation of the centre-lathe machine*
2. *Recognise and gain understanding of turning, drilling and milling operations using the centre-lathe machine*

Recap weeks

Year 1	**Week 7:** Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials

Focal Area 1: Fundamentals of material removal processes

21.1 Introduction

(Refer to Year 1, section 2, week 7: Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials

Material removal processes are a group of manufacturing techniques used to cut, shape, or finish materials by removing unwanted portions from a workpiece. This is usually done in the form of chips or fine particles. These processes are essential in the manufacturing industry because they help in shaping raw materials into finished products with precise dimensions and surface finishes. Without these techniques, it would be difficult to produce parts with the required accuracy for machines, tools, and consumer products.

The importance of material removal processes cannot be overstated. First, they enable the production of complex shapes and features such as holes, grooves, slots, and threads. Second, they are vital in improving the surface quality and dimensional accuracy of parts. In many cases, even after casting or forming a product, material removal is needed to meet tight tolerances. Third, these processes are key to various industries such as automotive, aerospace, electronics, and medical device manufacturing, where high precision is required.

Generally, material removal processes work by using a tool that comes in contact with the workpiece to chip away the undesired material. The tool may move in different directions, and the material may also be moved depending on the machine setup. During these operations, forces, temperature, and vibrations are generated, so it is important to control the process properly to avoid damaging the tool or the workpiece.

21.2 Classification of Material Removal Processes

Material removal processes can be grouped into two broad categories: conventional and non-conventional processes.

21.2.1 Conventional material removal processes

Conventional material removal processes are those that rely on mechanical energy to remove material in the form of chips. These include processes such as turning, milling, drilling, grinding, and sawing. In these methods, a sharp cutting tool is used to remove material from a

workpiece. The cutting tool usually has a specific geometry and is harder than the material being cut. These processes are widely used in workshops and industries because they are cost-effective and produce good surface finishes. For example, turning on a lathe involves rotating the workpiece while a single-point cutting tool removes material along its length. Drilling involves creating a hole using a rotating drill bit, and milling uses a rotating multi-point tool to remove material from a flat or contoured surface.

These conventional methods are mostly done using machines such as lathes, milling machines, drilling machines, and grinding machines. They require physical contact between the tool and the workpiece and often involve the use of cutting fluids to cool and lubricate the tool and workpiece.

21.2.2 Non-conventional material removal processes

Non-conventional material removal processes are modern methods that do not necessarily use a sharp cutting tool. Instead, they use other forms of energy such as electrical, chemical, thermal, or light energy to remove material. These processes include Electrical Discharge Machining (EDM), Laser Beam Machining (LBM), Water Jet Cutting, Ultrasonic Machining (USM), and Electrochemical Machining (ECM). These methods are particularly useful when the material is very hard, very thin, or when very complex shapes are needed that are difficult to produce with conventional methods. For example, in EDM, material is removed by spark erosion between a tool and the workpiece immersed in a dielectric fluid. There is no direct contact between the tool and workpiece, making it suitable for machining delicate or heat-sensitive materials.

The main difference between conventional and non-conventional processes lies in the type of energy used and whether or not there is direct physical contact between the tool and the workpiece. Conventional processes are usually more straightforward and suitable for general purposes, while non-conventional processes are more specialised and used when high precision, special materials, or unusual shapes are required.

Focal Area 2: Principles of operation of the centre-lathe machine

21.3 Introduction

A centre-lathe machine, commonly called an engine lathe, is a machine tool used mainly for shaping metal or wood by rotating the workpiece against a cutting tool. The lathe machine is very important in manufacturing because it allows precise turning, drilling, and boring operations. It is often referred to as the “mother of all machines” because many other machines are created using parts made on a lathe. A lathe works by holding and rotating the workpiece on its spindle while a stationary cutting tool removes material to shape the workpiece into the desired form.

The basic components of a lathe include the bed, which serves as the base; the headstock, which houses the main spindle and motor; the tailstock, which supports the other end of the workpiece; the carriage, which moves the cutting tool; and the lead screw, used for thread cutting. Understanding how each part works helps students appreciate how the lathe operates as a system.

21.4 Engine Lathe Machine

The engine lathe machine is versatile and suitable for general machining. It is manually operated and found in most workshops. Figure 54 shows a well labelled engine lathe machine The bench lathe is a smaller version that sits on a workbench. It is ideal for light-duty work and small parts, making it useful for education and training. The toolroom lathe is more precise and has additional features for producing accurate parts, especially for jigs and tools. The CNC lathe machine (Computer Numerical Control) is a modern type operated by a computer. It can automatically perform complex operations with high precision and is used in industries where speed and accuracy are important.

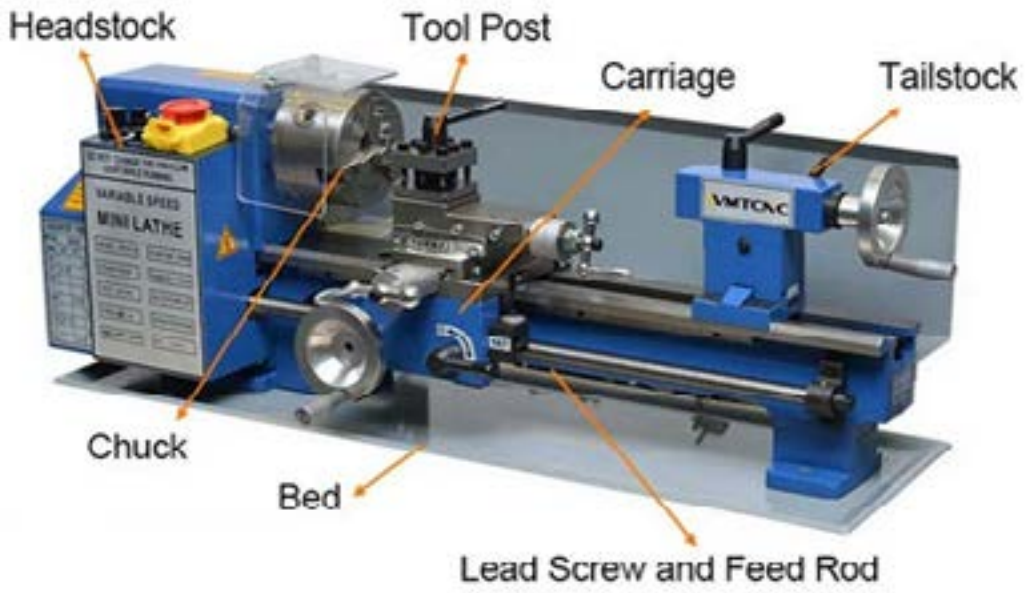


Figure 54: *Picture of a centre-lathe machine showing the bed, headstock, tailstock, carriage, lead screw and other parts*

https://cncwmt.com/qa/how-do-i-operate-a-lathe-machine-as-a-beginner/

21.5 The Three-Jaw Chuck

The most commonly used device is the chuck. The three-jaw chuck is a common work holding device. It is self-centring and is used for holding round or hexagonal workpieces, while a four-jaw chuck is independently adjustable and is used for square or irregularly shaped workpieces. Figure 55 shows a 4-jaw chuck and 3-jaw chuck. Other work holding devices include faceplates, lathe centres, and collets. Lathe centres are used to hold long workpieces between the headstock and tailstock to ensure balance and support during turning.

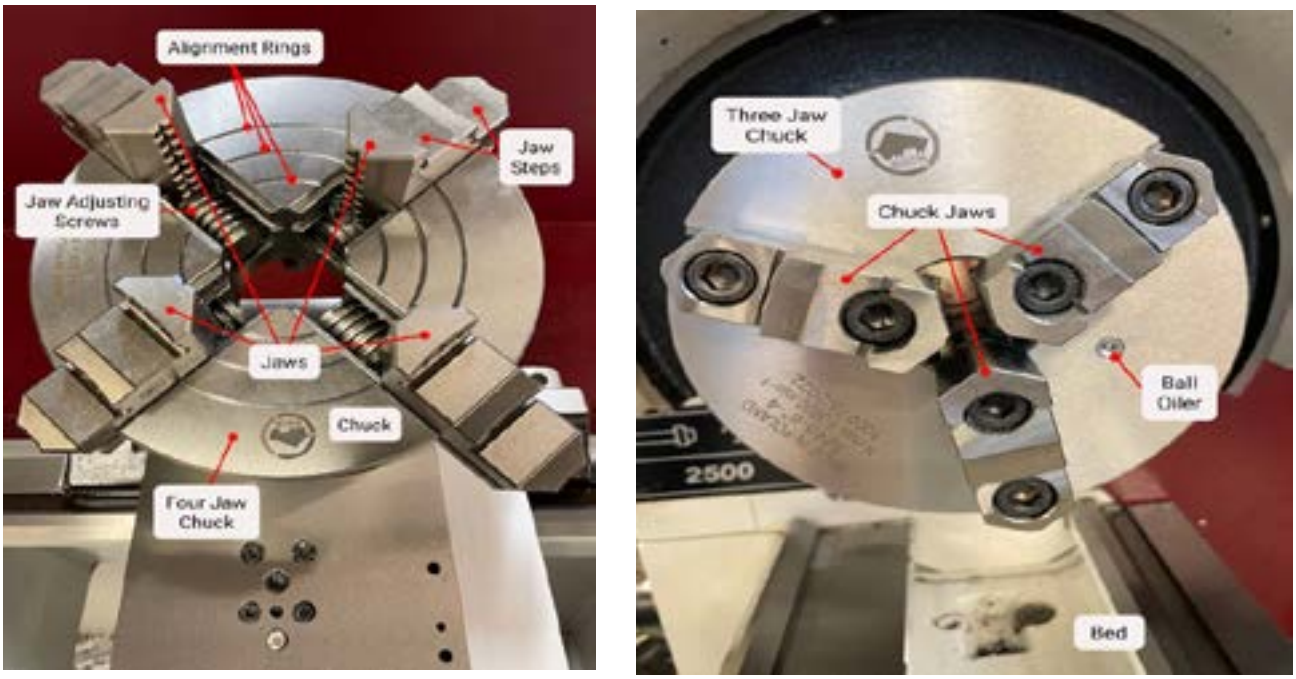


Figure 55: *Work holding devices, a 4 – jaw chuck and 3-jaw chuck*

https://openwa.pressbooks.pub/machining1/chapter/10pt2/

21.6 Lathe Cutting Tools

Lathe cutting tools are made of hard materials like high-speed steel or carbide, and they come in different shapes depending on the type of cutting operation. The main types include turning tools, boring tools, parting tools, facing tools, and thread cutting tools. These tools are mounted on the tool post and must be set at the correct height and angle to produce smooth and accurate cuts. Each tool is designed to perform a specific operation, and students must learn to identify them by shape and use.

21.7 Parameters of the Lathe Machine

The effectiveness of any machining operation depends on key cutting parameters. These include spindle speed, feed rate, and depth of cut. Spindle speed refers to how fast the workpiece rotates and is measured in revolutions per minute (RPM). Feed rate is how fast the cutting tool moves along the surface of the workpiece and is usually measured in mm/revolution. Depth of cut refers to how deep the tool cuts into the material on each pass. Choosing the right values for these parameters depends on the type of material being machined, the type of tool, and the desired surface finish. If the speed is too high, it may overheat the tool, and if the feed is too fast, the surface may become rough. Therefore, learning how to set these parameters correctly is important for good machining results.

21.8 Setting Up the Lathe Machine

Before using the lathe machine, proper setup is necessary to ensure safety and accuracy. The first step is mounting the workpiece securely using a chuck or between centres. Next, the operator must align the centres of the headstock and tailstock to make sure the workpiece rotates evenly. The cutting tool must be installed and adjusted at the correct height and angle using the tool post. Once everything is in place, the operator sets the cutting parameters, such as spindle speed, feed rate, and depth of cut, based on the material and tool type. Finally, the machine is tested at low speed to ensure everything is working properly before starting full operations.

21.9 Safety Precautions

Working on the lathe requires strict safety procedures to avoid accidents. Learners must always wear protective gear, including safety glasses and aprons. Loose clothing, long hair, and jewellery should be secured or avoided because they can get caught in the rotating parts. The chuck key must always be removed before turning on the machine, and students should never touch a moving workpiece or tool. Hands should be kept away from the cutting area, and tools must be handled carefully and stored properly after use. The workspace should be kept clean and free from oil spills to prevent slips. The teacher must always supervise students during machine operations.

Note for Facilitators

Let learners understand that these safety precautions are non-negotiable

Focal Area 3: Turning, drilling and milling operations using centre-lathe machine

21.10 Understanding Turning, Drilling and Milling Operations

Turning, drilling, and milling are three of the most common material removal processes that can be performed on a centre-lathe machine. These operations allow a machinist to shape raw material into a finished part with specific dimensions and surface quality. In a centre-lathe machine, the workpiece is usually rotated while a cutting tool removes material from its surface.

Turning is the process of removing material from the external surface of a rotating workpiece using a single-point cutting tool. It is mainly used to produce cylindrical shapes, such as rods, shafts, and pipes. In turning, the tool moves in a straight line either along the axis of rotation (longitudinal turning) or across it (facing). This operation can also be used to create tapers and grooves. A turning operation typically results in a smooth surface and precise diameters, which are important in mechanical components.

Drilling on the centre-lathe is done by feeding a rotating drill bit into the workpiece, which is held in the chuck and rotated. The drill is mounted in the tailstock, and the operator moves it forward using the tailstock handwheel. This operation is used to make round holes in the centre of the workpiece. After drilling, other operations such as reaming or boring may be carried out to increase the accuracy of the hole.

Milling on a lathe is not as common as turning or drilling, but it can be done by holding a milling cutter in the tool post and rotating the workpiece. This process is called lathe milling or milling on the lathe. It is used to create flat surfaces, slots, or keyways on round parts. In this case, the cutter remains stationary while the workpiece rotates, and the carriage moves the cutter into the workpiece.

21.11 Performing Turning, Drilling and Milling Operations

To perform turning, drilling, and milling operations on the centre-lathe machine, the operator must follow a step-by-step procedure that ensures accuracy, safety, and proper machine use.

21.11.1 Turning

Turning, the first step is to secure the workpiece in the chuck and make sure it is tightly clamped and centred. The appropriate cutting tool is selected and mounted in the tool post. The

operator then sets the cutting parameters such as spindle speed, feed rate, and depth of cut based on the material and desired finish. The tool is moved parallel to the axis of the rotating workpiece to reduce the diameter. The operator must frequently stop to measure the diameter with a calliper or micrometre until the required size is achieved.

21.11.2 Drilling

In drilling, the drill bit is installed in the tailstock and aligned with the centre of the workpiece. The workpiece continues to rotate, but the drill bit does not. Instead, the tailstock is moved forward using the handwheel, and the drill cuts into the rotating workpiece to form a hole. The drill is withdrawn occasionally to clear chips and allow cooling. Once the desired depth is reached, the drill is retracted, and the hole may be cleaned or finished with another tool.

21.11.3 Milling

Milling on the lathe is more advanced and requires careful setup. The workpiece is clamped in the chuck and rotated. A milling cutter is installed in the tool post or special milling attachment. The carriage or cross-slide is then moved to feed the cutter into the rotating workpiece. Because the lathe is not designed primarily for milling, only light milling cuts should be performed. This operation is useful for making flats or slots on cylindrical parts, especially when a milling machine is not available.

When performing these operations, it is important to follow safety rules, including wearing safety goggles, ensuring the chuck key is removed before switching on the machine, and keeping hands away from rotating parts. Proper lubrication and chip removal help maintain the tool and workpiece.

Notes to Facilitators

1. **Clarifying Concepts:** Use the core principle: The lathe spins the workpiece; the cutting tool is stationary. This is the opposite of a drill press (spinning tool, stationary workpiece) and a milling machine (spinning tool, moving workpiece). Get this basic concept clear before moving on to specific operations.
2. **Common Misconceptions:** Students often confuse facing and turning. Clarify that facing cuts across the end of a part to make it flat, while urning cuts along the side of a part to reduce its diameter.
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Visualise the Process:** Before using the lathe, have students draw the movement of the tool relative to the workpiece for facing and turning.
    b. **Troubleshooting:** The most common beginner mistakes are: 1) Tool not set at centre height (leading to poor finish or tool breakage). 2) Not removing the chuck key before starting (a major safety hazard). Drill these two points into students.

Learning Tasks

1. Learners explain what material removal processes are and describe their significance in producing machine components.
2. Learners identify and differentiate between conventional and non-conventional material removal processes with examples.

3. Learners describe the working principles, components, and tool setups for turning, drilling, and milling using the centre-lathe.
4. Learners watch a demonstration video of turning and drilling operations. gain conceptual understanding of how turning, drilling, and milling are performed using a centre-lathe, including process parameters.
5. Learners demonstrate the ability to operate the centre-lathe by performing actual turning, drilling, and milling operations on mild steel or aluminium workpieces.
6. Learners in a mixed ability groups small groups, performing core practical operations on the centre-lathe under supervision.

Teacher Notes: *Ensure the absolute necessity of direct, constant, and experienced supervision for any hands-on lathe work. High school students should not operate such machinery unsupervised.*

Pedagogical Exemplars

1. Talk for Learning: Learners handle real tools and materials in the workshop. In small groups, they match previously learned tools to specific machining tasks. Teacher uses videos to stimulate discussion and encourages peer teaching, where students explain basic safety and measurement procedures to their group.
2. Research-based learning
    a. Learners in a mixed ability group, use library and internet resources to research the historical development and modern relevance of material removal techniques. They summarise their findings in a timeline chart or brief report.
    b. In mixed-ability groups or individually. Learners select one conventional and one non-conventional process and research their working principle, tool type, and application. Findings are shared via oral presentations or comparison tables.
    c. Learners watch a lathe operation in the workshop or from video resources, take notes, and label a diagram of a centre-lathe machine and present them on a poster
3. Experiential learning
    a. Provide learners a labelled diagram of lathe parts. Show learners videos of a lathe machine being used to manufacture a component.
    b. Take learners on a tour to a manufacturing industry where students observe live turning, drilling, and milling. If a visit is not possible, watch more videos of different components being manufactured on a centre-lathe.
    c. Learners in a mixed ability group, under supervision of the school workshop attendant, practice these operations step-by-step, applying feed and speed control, tool alignment, and measurement checks.
4. Collaborative Learning**:** Learners in pairs discuss the use of centre-lathe machines to perform turning, drilling and milling operations.
5. Experiential Learning
    a. Learners watch short curated videos on turning, drilling, and milling using centre-lathe.

b. Arrange a field trip to a nearby manufacturing machine shop to observe live turning, drilling, and milling in an industrial setting, if not possible, watch short videos on the manufacturing of different products using a lathe.

c. In a mixed ability group learners perform the following operation at the school workshop

- Facing
- Centre drilling
- External turning
- Simple milling (using milling attachment)

Key Assessment Level 2: Research and Presentation

1. Choose any one machining operation that can be performed on a lathe (e.g., facing or turning). Describe the operation and explain the step-by-step procedure involved, including safety precautions and the purpose of each step (12 marks)
2. With the aid of a labelled diagram, explain how turning between centres is performed. Describe the setup and the sequence of steps involved, and explain the purpose of using this method. (15 marks)
3. After performing an external turning operation, your part's diameter is 0.2 mm larger than the specification. **Analyse any four (4)** possible causes and recommend corrective measures. (9 marks)
4. Design a step-by-step operation sheet for producing a shaft (Ø25 mm x 100 mm) that includes drilling a centre hole, rough turning, and finishing. (20 marks)

Notes for Facilitators

The operation sheet template below can be used as a guide to answer Q4.

1. Students must fill in every column – missing parameters indicate incomplete planning.
2. For cutting parameters, approximate values are acceptable; the goal is to show understanding that speed, feed, and depth of cut vary with material and operation.
3. Emphasise that the safety notes column is not optional – students must identify at least one specific hazard per step.
4. After completing the template, students can be asked to simulate the process verbally or with a cardboard mockup before any real machine use.

Operation Sheet Template – Shaft Production (For Q4)

Student Name: _____ **Date:** _____

Component: Shaft
Material: Mild steel (or aluminium)

Final dimensions: Ø25 mm × 100 mm

Tolerance: 0.05± mm on diameter, 0.5± mm on length

Table 21.1 Operation sheet for shaft production (Q4)

Step	Operation Description	Tool / Machine	Cutting Parameters (Speed, Feed, Depth of Cut)	Safety Notes
1	Cut raw stock to approx. 110 mm length	Power hacksaw or band saw	N/A	Secure stock in vice; wear gloves and goggles
2	Mount workpiece in 3jaw chuck; face one end	Lathe, facing tool	Speed: 800 RPM (mild steel), Feed: 0.1 mm/rev, DOC: 0.5 mm	Remove chuck key before start; keep hands clear
3	Centre drill both ends	Lathe, centre drill (Ø6 mm)	Speed: 1000 RPM, manual feed	Use tailstock handwheel slowly; clear chips frequently
4	Rough turn external diameter to Ø25.5 mm	Lathe, rough turning tool	Speed: 600 RPM, Feed: 0.2 mm/rev, DOC: 1.0 mm (multiple passes)	Stop machine to measure; do not touch rotating part
5	Measure diameter with vernier calliper	Calliper	N/A	Ensure machine is stopped before measuring
6	Finish turn to Ø25.0 mm (±0.05)	Lathe, finishing tool	Speed: 1000 RPM, Feed: 0.05 mm/rev, DOC: 0.25 mm	Use light cut; apply cutting fluid for better finish
7	Cut to final length (100 mm) by facing second end	Lathe, facing tool	Speed: 800 RPM, Feed: 0.1 mm/rev, DOC: 0.5 mm	Remount workpiece with end protruding from chuck
8	Chamfer edges (45°, 1 mm)	Lathe, chamfering tool	Speed: 800 RPM, manual feed	Light pressure; check chamfer size visually
9	Deburr and clean	File, emery cloth, brush	N/A	Use file with a handle; brush away chips
10	Final inspection – measure diameter, length, surface finish	Micrometre, steel rule, visual check	N/A	Record measurements on inspection sheet

PLC Session 21

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to

a. explain the week's concepts in a practical way that will make it easier for learners to understand

b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).

3. Use your subject specific app to plan your lesson. Ask the app to

a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.

b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)

c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).

Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app

a. The key assessment for the week is research and presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then

a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)

b. all teachers in the group work through a similar problem individually for 3–4 minutes

c. the group then works through the problem together step by step

d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.

- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 22

Learning Indicators

1. *Recognise and gain understanding of grinding operations*
2. *Perform a material removal process using a lathe machine*

Focal Area 1: Understanding grinding operations

22.1 Introduction

Grinding is a material removal process that uses a rotating abrasive wheel to smooth, shape, or finish a workpiece by removing very small amounts of material. It is classified as a finishing operation, meaning it is often performed after other machining processes like turning or milling to improve surface quality and accuracy. Grinding can also be used as a primary machining method for very hard or brittle materials that are difficult to cut with regular tools.

The importance of grinding in manufacturing cannot be overstated. It allows for the production of very precise dimensions and excellent surface finishes, often with tolerances of less than 0.01 mm. Grinding is essential in industries such as automotive, aerospace, and toolmaking, where high precision is required. It is also used to sharpen cutting tools, remove material from hardened surfaces, and create smooth edges.

There are different types of grinding processes depending on the type of surface, the workpiece material, and the desired outcome. The most common is surface grinding, which produces flat surfaces. Cylindrical grinding is used to grind round parts, such as shafts. Centreless grinding is used for mass production of cylindrical parts without using a centre to hold the workpiece. Other forms include internal grinding and tool and cutter grinding.

22.2 Principles and Steps of Grinding Operations

The basic principle of grinding is simple: an abrasive wheel rotates at high speed, and the surface of the wheel comes into contact with the workpiece, removing tiny particles in the form of chips. The grinding wheel is made of small, sharp abrasive grains held together by a bonding material. As the wheel spins, these abrasive grains cut into the workpiece surface. As some grains become dull or break off, new sharp grains are exposed, allowing the wheel to continue cutting effectively.

The grinding process is usually carried out on a grinding machine, which has several main parts: the grinding wheel, the workpiece holding device (like a magnetic chuck for flat workpieces or a rotating fixture for round ones), the machine bed, and controls for adjusting speed and feed. In surface grinding, the grinding wheel moves back and forth over the surface of the stationary workpiece. In cylindrical grinding, the workpiece rotates while the grinding wheel moves across it.

The steps involved in grinding operations generally follow this sequence. First, the workpiece is prepared and mounted securely on the grinding machine. For flat pieces, a magnetic chuck is often used. Next, the grinding wheel is selected based on the hardness of the material and the type of finish required. The wheel must then be dressed, a process that sharpens it and removes any clogged particles to ensure effective cutting.

Once everything is set up, the operator adjusts the cutting parameters, including the wheel speed, feed rate, and depth of cut. These settings must be carefully controlled to prevent overheating, surface damage, or tool wear. After this, the machine is turned on, and the grinding operation begins. The grinding wheel is slowly fed into the workpiece, making several passes to achieve the desired surface finish or dimension. Coolant is usually applied during the process to keep the workpiece and wheel cool and reduce friction.

When the final surface is achieved, the operator stops the machine, checks the part with measuring tools like a micrometre or surface roughness tester, and cleans the machine to remove grinding dust. Grinding can also produce sharp edges, so de-burring may be done as the final step.

Focal Area 2: Perform a material removal process using a lathe machine

22.3 Performing a Material Removal Process Using a Lathe Machine

Performing a material removal process using a lathe machine involves a step-by-step procedure that transforms a raw material, such as a metal bar or plastic rod, into a finished component with accurate dimensions and a smooth surface. This is done by rotating the workpiece and bringing a cutting tool into contact with it to remove excess material. The process requires careful planning, setup, and operation to ensure safety and precision. It is one of the most fundamental skills in manufacturing engineering and forms the basis for making cylindrical parts such as shafts, bushings, bolts, and pins.

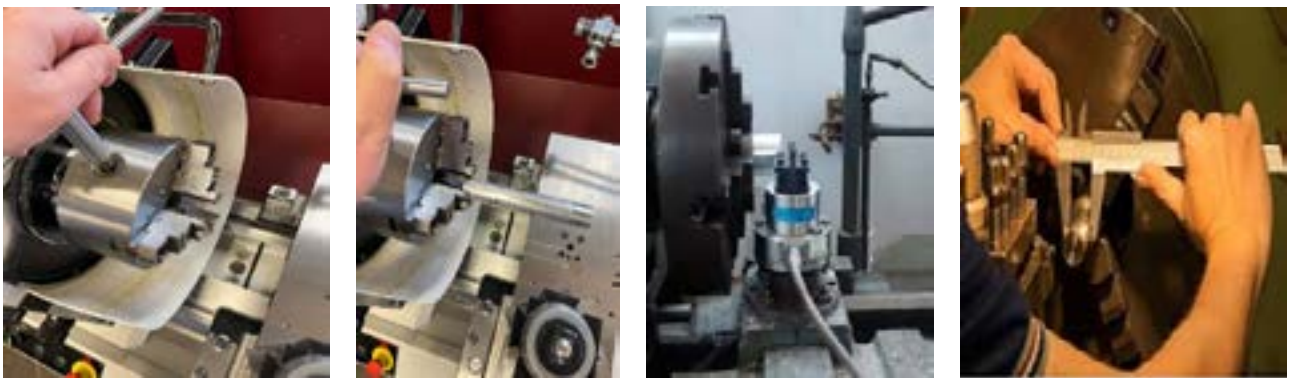
The process begins with selecting a suitable workpiece, usually a round rod or bar of a machinable material like mild steel, aluminium, or plastic. The workpiece is cut to a manageable length and mounted securely into the chuck of the lathe machine. The chuck is then tightened to hold the workpiece firmly. Before the machine is turned on, the operator ensures that the cutting tool**,** such as a turning or facing tool, is properly installed on the tool post and aligned at the correct height, usually the centre of the workpiece. This is important for ensuring smooth cutting and avoiding damage to the tool or material.

Once everything is securely mounted, the cutting parameters are set. These include spindle speed, which controls how fast the workpiece rotates; feed rate, which determines how quickly the tool moves along the surface of the workpiece; and depth of cut, which is the amount of material removed in one pass. These values depend on the type of material being machined and the desired surface finish. For beginners, slower speeds and shallower cuts are recommended to maintain control.

With all settings in place, the lathe is turned on, and the cutting operation begins. If performing a facing operation**,** the tool is moved from the edge of the workpiece toward the centre to create a flat surface. If turning is being performed, the tool moves along the length of the rotating workpiece to reduce its diameter. The operator watches carefully, making small adjustments to keep the tool steady and ensure a consistent cut. Throughout the operation, a coolant may be applied to reduce heat and help with chip removal.

Once the desired shape or dimension is achieved, the machine is stopped, and the part is measured using tools such as a vernier calliper or micrometre to check accuracy. If necessary, additional passes are made with finer cuts to achieve a better finish. After completing the operation, the tool is retracted, and the workpiece is carefully removed from the chuck. The machine and surrounding area are then cleaned to remove chips and debris, and the tools are stored properly.

Performing a material removal process on a lathe machine teaches students essential skills such as precision measurement, hand-eye coordination, machine setup, and safe working habits. It also helps them understand how raw materials are transformed into useful mechanical parts through controlled machining operations. Fig. 56 shows the process of performing material removal process using the lathe machine.



(a) (b) (c) (d)

Figure 56: *(a) setting up a workpiece in the chuck (b) tool being aligned to centre height, (c) cutting tool performing a turning or facing operation (d) finished part with measurement being taken using a calliper.*

https://openwa.pressbooks.pub/intromachining1/chapter/wa10-5/

Notes for Facilitators

1. **Clarifying Concepts:** Explain that grinding is the final touch. It is used after turning to achieve a very precise size (tolerance) or a very smooth surface (finish). It is like sanding a piece of wood after cutting it with a saw.
2. **Common Misconceptions:** Students may think grinding is just for removing large amounts of metal. Explain that it is a finishing process that removes very small amounts of material (a few hundredths of a millimetre).
3. **Low-Cost Demonstration and Ghanaian Examples**
    a. **Finishing Activity:** Have students take a turned piece and try to file or sand it to a perfect finish. Then, if possible, have them observe or perform a cylindrical grinding operation. Discuss the difference in effort, speed, and the resulting surface finish and accuracy.
    b. **Troubleshooting for Turning:** When students perform the turning operation for assessment, have a checklist ready. Did they face the end? Did they centre-drill? Did they check the diameter after rough turning? Did they use a light finishing pass? This systematic process ensures a successful outcome.

Learning Tasks

1. Learners create a concept map that links turning, milling, and drilling operations with grinding. They highlight tool types, material removal processes, and surface finishes.
2. Learners prepare a group poster presentation on what grinding is, its types (surface, cylindrical, centreless), and its relevance in precision manufacturing

3. Learners in a mixed ability groups small groups, simulate or demonstrate steps involved in surface grinding, using diagrams and step-wise flowcharts.
4. Learners create a comparison chart highlighting the differences in process, tools, and products of drilling, milling, and turning, focusing on where the lathe fits in.
5. Learners explain the working principle of the centre-lathe machine and describe the function of key components.
6. Learners in a mixed ability groups or individually produces a precision shaft using mild steel and present the finished component along with a report showing the stages of material removal and quality assurance checks.

Pedagogical Exemplars

1. Talk for Learning: Learners brainstorming session to recall how material is removed in milling and turning. Display sample components finished by turning and grinding and ask learners to describe the difference.
2. Experiential Learning
    a. Show learners curated videos of different grinding operations, e.g., surface and cylindrical grinding.
    b. If possible, arrange a field trip to a local manufacturing company for learners to observe: machine setup and safety procedures, sequence of grinding operations and quality checks.
    c. In a mixed ability group perform a grinding operation at the school workshop using the grinding machine.
3. Talk for Learning: Learners in mixed-ability groups recall and document differences in machining operations learned in previous years. Categorise tasks best suited for the lathe.
4. Experiential Learning
    a. Teacher demonstrates proper lathe setup on a live machine and performs lathe operations for the learner to practice.
    b. Learners design and machine a precision shaft or gear blank with a defined dimensional tolerance (e.g., ±0.05 mm).

Key Assessment Level 4: Individual Research and Report Writing

1. Evaluate the reasons why grinding is often used as a finishing operation after turning or milling. Compare its benefits to those of turning or milling, and explain in what situations grinding is most appropriate. (15 marks)
2. Study the given diagram of a grinding process. Interpret the function of the key components shown and identify at least two points in the process where errors could occur that may affect the quality of the finished part. Explain how these errors could impact the final result. (12 marks)
3. Predict the effects of incorrect tool height alignment during lathe setup. Suggest measures to correct and prevent these effects. (20 marks)

PLC Session 22

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is individual research and report writing. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    j. transfer your chats into your learning planner template.
    k. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    l. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 6 review

This section helped learners understand how material can be shaped or formed by removing parts of it using machines, especially the centre-lathe machine. It covered how different machining processes like turning, drilling, and facing are done, and how to safely and correctly operate a lathe in a manufacturing setting.

1. **Material Removal Process:** This is the method of cutting away unwanted material from a workpiece to give it the desired shape. It's used to make machine parts with accurate sizes and smooth surfaces.
2. **Lathe Machine:** A lathe is a machine that holds and spins a workpiece while a cutting tool shapes it. It is mainly used for cylindrical parts and is one of the most important machines in a workshop.
3. **Working Principle of a Centre-Lathe:** The lathe rotates the material (called the workpiece) while the cutting tool stays still or moves along its surface. The tool removes thin layers of material as the workpiece turns.
4. **Headstock:** Contains the motor and spindle; it rotates the workpiece.
5. **Tailstock:** Supports the other end of the workpiece; also holds tools like drill bits.
6. **Carriage:** Holds and moves the cutting tool along the workpiece.
7. **Chuck:** Clamps and holds the workpiece firmly in place.
8. **Types of Lathe Machines:** Learners discovered different lathes like engine lathes (most common), toolroom lathes (for high precision), bench lathes (small and simple), and **CNC lathes** (computer-controlled and very accurate).
9. **Turning:** This is the process of removing material from the outer surface of a rotating workpiece to make it smooth, round, or to reduce its diameter. It is the most common lathe operation used to create cylindrical parts.
10. **Facing:** This operation involves cutting across the end of a rotating workpiece to make its surface flat and smooth. It is used to square off the ends of a part.
11. **Drilling:** In this process, a drill bit is fed into the rotating workpiece to create a hole along its axis. The tailstock usually holds the drill bit for this operation.
12. **Lathe Parameters:** These include spindle speed (how fast the workpiece spins), feed **rate** (how fast the tool moves), and depth of cut (how deep the tool cuts into the material). Adjusting these settings affects the surface finish and the accuracy of the part.
13. **Work Holding Devices:** These are used to keep the workpiece steady while it is being machined. Examples include the chuck, faceplate, and centres.

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 17

Question 1 (DOK 3)

Evaluate a range of cutting tools used in modern manufacturing. Identify which would be classified as non-conventional and justify your selection based on how the tool interacts with the workpiece.

(Total: 5 marks)

1 mark – Correctly identifies laser beam cutting tool as non-conventional

2 marks – Provides a clear explanation of why it is non-conventional (e.g., uses non-mechanical energy, no physical contact)

2 marks – Compares it with at least one conventional tool and explains how it differs (e.g., mechanical vs thermal/mechanical process)

Question 2 (DOK 3)

Analyse the properties and typical applications of cutting tools made from different materials. Based on this, argue which tool would be most appropriate for high-speed machining of hardened steels, justifying your choice.

(Total: 5 marks)

1 mark – Correctly selects alumina-based lathe tool

2 marks – Justifies choice with reference to properties (e.g., hardness, heat resistance, wear resistance)

2 marks – Explains why the other materials/tools are less suitable for this specific application

Question 3 (DOK 3)

Compare and contrast classification by cutting action and by tool geometry, and evaluate how these classifications might influence tool selection in a manufacturing process. Include one real-world example for each classification method.

(Total: 6 marks)

2 marks – Clear and accurate explanation of cutting action classification

2 marks – Clear and accurate explanation of tool geometry classification

1 mark – Appropriate real-world example for cutting action

1 mark – Appropriate real-world example for tool geometry

(Bonus: +1 mark if evaluation links classification to decision-making in tool selection clearly)

Question 4 (DOK 3)

Using case examples, distinguish between conventional and non-conventional cutting tools. Evaluate the advantages and limitations of each in terms of precision, material compatibility, and production cost.

(Total: 6 marks)

1 mark – Correct definition of conventional cutting tools

1 mark – Correct definition of non-conventional cutting tools

2 marks – Two well-explained examples (one of each)

2 marks – Clear evaluation of pros/cons (precision, material range, cost)

WEEK 18

Q1. Drilling Ceramic Tile

Total: 6 Marks

Criteria	Mark Range	Scoring Guidance
a. **Identification of appropriate tool**	0–1 mark	1 mark – Correctly identifies the diamond-coated bit as the most suitable tool. 0 mark – Incorrect or missing tool selection.
b. **Justification based on material properties and tool performance**	0–2 marks	2 marks – Clearly explains that ceramics are brittle and require a hard, wear-resistant tool like diamond to prevent cracking and ensure precision. 1 mark – Partial explanation with some correct reasoning. 0 mark – No explanation or incorrect reasoning.
c. **Description of two precautions**	0–2 marks	2 marks – Accurately describes two relevant precautions (e.g., use water cooling, apply low pressure, wear goggles). 1 mark – Only one correct precaution or vague descriptions. 0 mark – No precautions or irrelevant responses.

Q2. Design a Workshop Activity

Total: 8 Marks

Material	Criteria	Mark Range	Scoring Guidance
Wood	Tool, Process, Safety	0–2 marks	**2 marks** – Correct tool (e.g., chisel), clear shaping process, and relevant safety precaution. **1 mark** – Two of the three elements correct. **0 marks** – One or none correct.
Metal	Tool, Process, Safety	0–2 marks	**2 marks** – Correct tool (e.g., twist drill), clear drilling process, and relevant safety precaution. **1 mark** – Two of the three elements correct. **0 marks** – One or none correct.
Polymer	Tool, Process, Safety	0–2 marks	**2 marks** – Correct tool (e.g., sandpaper), clear polishing process, and relevant safety precaution. **1 mark** – Two of the three elements correct. **0 marks** – One or none correct.

Overall clarity and integration of activity		0–2 marks	**2 marks** – Well-structured, logical sequence, and clear integration of all three materials. **1 mark** – Mostly clear with minor gaps. **0 marks** – Disorganised or incomplete activity design.

WEEK 19

Q1. Explain the difference between CNC milling and CNC turning in terms of tool movement and workpiece orientation

Total: 8 Marks

Criteria	Mark Range	Scoring Guidance
Explanation of CNC Milling	0–3 marks	3 marks – Clear and accurate explanation: tool rotates and moves across a stationary workpiece to remove material. 2 marks – Mostly correct explanation with minor omissions. 1 mark – Basic or partially correct explanation. 0 mark – No explanation or incorrect understanding.
Explanation of CNC Turning	0–3 marks	3 marks – Clear and accurate explanation: workpiece rotates while a stationary cutting tool removes material. 2 marks – Mostly correct explanation with minor omissions. 1 mark – Basic or partially correct explanation. 0 mark – No explanation or incorrect understanding.
Comparison and clarity	0–2 marks	2 marks – Clear, correct comparison between the two processes. – In milling, the tool rotates; in turning, the workpiece rotates. – Milling works on flat or complex shapes; turning produces cylindrical shapes. 1 mark – Attempted comparison with limited clarity. 0 mark – No comparison or unclear response.

Q2. List and explain the purpose of three G-code commands commonly used in CNC milling operations. (6 marks)

Criteria	Marks
Correct G-code listed (1 mark each, max 3)	3 marks
Correct and clear explanation of purpose (1 mark each, max 3)	3 marks

Question 1: Explain the difference between CNC milling and CNC turning in terms of tool movement and workpiece orientation **Total: 8 Marks**

Model Answer

CNC Milling

In CNC milling, the cutting tool rotates and moves along multiple axes (typically X, Y, and Z) while the workpiece remains stationary. The tool removes material by moving across the surface of the workpiece to create features such as slots, pockets, and contours.

CNC Turning

In CNC turning, the workpiece rotates while the cutting tool remains stationary or moves linearly along one or two axes. Material is removed from the rotating workpiece to produce cylindrical shapes, such as shafts or threads.

Comparison

The key difference lies in the movement: milling involves a rotating tool and stationary workpiece, while turning involves a rotating workpiece and stationary tool. Milling is ideal for complex shapes and surfaces, whereas turning is best for symmetrical, round parts.

Question 2: Examples of Acceptable Answers:

G-Code	Explanation
G00	Rapid positioning – moves the tool quickly between positions without cutting
G01	Linear interpolation – moves the tool in a straight line at controlled feed rate for cutting
G90	Absolute positioning – all coordinates are interpreted from a fixed origin point

Notes for Markers

- Partial explanations (e.g., "G01 is for moving the tool") = 0.5 mark
- Unrelated or incorrect explanations = 0 marks
- Accept equivalent G-codes from other CNC dialects if justified [e.g., G21 for metric input (mm) G20 for imperial input (inches)]

WEEK 20

Q1. Discuss how CNC machines have transformed modern manufacturing. Include at least three specific applications and explain how CNC technology improves productivity and precision.

Total: 10 Marks

Criteria	Mark Range	Scoring Guidance
Identification of three specific applications	0–3	3 marks – Three relevant and clearly described applications (e.g., aerospace parts, automotive components, medical implants). 2 marks – Two relevant applications described. 1 mark – One relevant application described. 0 mark – No valid applications mentioned.
Explanation of productivity improvements	0–3 marks	3 marks – Clear explanation of how CNC improves productivity (e.g., automation, reduced setup time, faster cycle times). 2 marks – General explanation with some relevant points. 1 mark – Vague or partially correct explanation. 0 mark – No explanation or incorrect reasoning.

Explanation of precision improvements	0–3 marks	3 marks – Clear explanation of how CNC enhances precision (e.g., tight tolerances, repeatability, reduced human error). 2 marks – General explanation with some relevant points. 1 mark – Vague or partially correct explanation. 0 mark – No explanation or incorrect reasoning.
Structure and clarity of response	0–1 mark	1 mark – Well-organised, coherent, and clearly written. 0 mark – Disorganised or unclear response.

Q2. A student is using a CNC machine to engrave a logo on a stainless steel plate. Identify the most suitable CNC process for this task and justify your choice based on the material and required detail.

Total: 10 Marks

Criteria	Mark Range	Scoring Guidance
Correct identification of CNC process	0–2 marks	2 marks – Correctly identifies CNC laser engraving or CNC milling with engraving tool as suitable. 1 mark – Partially correct or less optimal process (e.g., general CNC milling without detail). 0 mark – Incorrect or missing process.
Justification based on material (stainless steel)	0–3 marks	3 marks – Clear explanation of how the selected process handles stainless steel (e.g., hardness, heat resistance, tool wear). 2 marks – General explanation with some relevant points. 1 mark – Vague or partially correct explanation. 0 mark – No explanation or incorrect reasoning.
Justification based on required detail (engraving)	0–3 marks	3 marks – Clear explanation of how the process achieves fine detail (e.g., precision of laser, small-diameter tools). 2 marks – General explanation with some relevant points. 1 mark – Vague or partially correct explanation. 0 mark – No explanation or incorrect reasoning.
Structure and clarity of response	0–2 marks	2 marks – Well-organised, coherent, and clearly written. 1 mark – Mostly clear with minor issues. 0 mark – Disorganised or unclear response.

WEEK 21

Question 1

Choose any one machining operation that can be performed on a lathe (e.g., facing or turning). Describe the operation and explain the step-by-step procedure involved, including safety precautions and the purpose of each step. (12 marks)

Marking Guide (Detailed and Specific – For Both Facing and Turning)

Criteria	Expected Student Response Details	Marks
1. Clear Definition of Operation (either Facing or Turning)	For turning: States that it removes material from the outer diameter of a rotating workpiece to reduce size or shape it. e.g., Turning is used to reduce the diameter of a rotating cylindrical workpiece. For facing: States that it removes material from the end face of a workpiece to make it flat and smooth. e.g., Facing produces a flat surface at the end of the workpiece	4 (2 for explanation and 2 for a good reason)
2. Step-by-Step Procedure (Correct Sequence)	Includes at least 4 correct and logically sequenced steps: 1. Wear PPE and inspect lathe 2. Mount and secure workpiece in chuck 3. Select correct spindle speed and feed 4. Align and set cutting tool at centre height 5. Start the lathe and perform the cut 6. Stop machine and inspect the workpiece	4 max (1 for each step)
7. Purpose of Steps	Explains the why behind at least 2 steps: • e.g., "Setting correct speed helps avoid tool damage," or "Inspection ensures dimensional accuracy." • e.g., "Tool alignment ensures a flat face in facing or consistent diameter in turning."	2 (1 each)
8. Safety Precautions (At least two)	Lists at least 2 specific safety rules, such as: – Wear safety goggles – Remove chuck key before starting – Keep hands and loose clothing away from rotating parts – Do not touch hot or sharp workpieces	2 (1 each)
	Total	**12**

Sample answer

Either

1. Turning: Removes material from the outer diameter of the workpiece to reduce its size, smooth the surface, or shape it to the desired dimensions.

Or

2. Facing: Removes material from the end face of the workpiece to make it flat, smooth, and perpendicular to its axis.

Steps Involved (Apply to Both Turning and Facing):

1. Preparation and Safety Checks
    a. Wear safety goggles, tie back long hair, and remove jewellery.
    b. Ensure the workpiece is properly centred and tightly secured in the chuck.
    c. Confirm that the cutting tool is correctly clamped in the tool post and set at centre height.
    d. Purpose: To prevent injuries and ensure safe, accurate setup of workpiece and tool.
2. Set Spindle Speed and Feed Rate
    a. Choose spindle speed based on the material (e.g., lower speed for harder materials).
    b. Select a feed rate suited for either rough or finishing cuts.
    c. Purpose: Affects the rate of material removal, surface finish quality, and tool life.
3. Position the Tool
    a. For turning: Align the cutting tool with the side of the workpiece for horizontal movement along its length.
    b. For facing: Position the tool to contact the end face of the workpiece, moving from the outer edge toward the centre.
    c. Purpose: Proper positioning ensures that the tool performs the correct type of cut and avoids tool damage or poor finish.
4. Start the Lathe and Perform the Cut
    a. Start the machine and slowly feed the tool into the material.
    b. For turning: Feed the tool along the axis of the workpiece to reduce diameter.
    c. For facing: Feed the tool across the face toward the centre to flatten the end.
    d. Take light roughing passes, followed by finishing passes.
    e. Purpose: Shapes the workpiece precisely and safely, minimising surface defects.
5. Stop the Lathe and Inspect the Work
    a. Switch off the machine and wait for it to stop fully.
    b. For turning: Measure final diameter with callipers or micrometres.
    c. For facing: Use a square or steel rule to check flatness and perpendicularity.
    d. Purpose: Ensures the workpiece meets required dimensions and surface quality.

Question 2

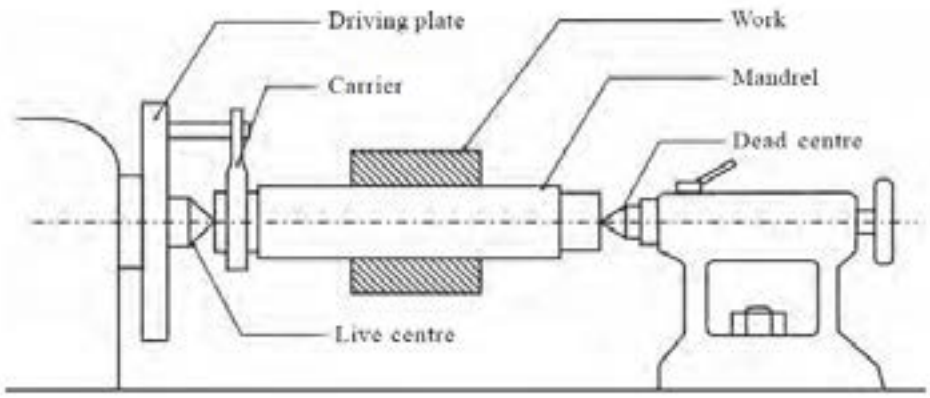
With the aid of a labelled diagram, explain how turning between centres is performed. Describe the setup and the sequence of steps involved, and explain the purpose of using this method. (15 marks)

Marking Guide: Turning Between Centres

Total: 15 Marks

Criteria	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0 marks)
Labelled Diagram	Diagram is clearly drawn and accurately labelled with headstock, tailstock, centres, workpiece, tool post, cutting tool, and lathe dog/faceplate.	Diagram is mostly accurate with at least 5 correct labels; some minor details missing.	Diagram is present with 3–4 correct labels; unclear in some parts.	No diagram provided, or diagram is irrelevant or incorrectly labelled.
Preparation (Centre Drilling)	Clearly states that centre holes are drilled at both ends of the workpiece using a centre drill to allow accurate support.	Mentions centre holes at both ends but doesn't fully explain the purpose.	Refers to preparing or drilling ends, but explanation is vague or missing tools.	No mention of preparation or incorrect description (e.g., talks about chucking instead).
Mounting Between Centres	Accurately explains that the workpiece is supported by the live centre in the headstock and the dead centre in the tailstock.	Identifies both centres correctly but gives an incomplete explanation.	Mentions that the workpiece is mounted between two centres but lacks names or clarity.	No or incorrect explanation of how the workpiece is mounted.
Driving Mechanism (Lathe Dog and Faceplate)	Clearly explains that the lathe dog is attached to the workpiece and engaged with the faceplate to transmit motion from the spindle.	Mentions lathe dog or faceplate but explanation is somewhat unclear or incomplete.	States that the workpiece rotates, but does not explain how or misses correct terminology.	No mention of how the workpiece is driven or completely incorrect explanation.
Cutting Process and Purpose of Method	Describes tool setup and turning action clearly. Accurately explains the benefits of turning between centres (e.g., concentricity, full-length support, better precision for long shafts).	Explains cutting and gives one clear benefit of the method.	Gives some information about cutting or purpose but lacks clarity or completeness.	Cutting process and purpose not explained or completely missed out

Sample answer



Setup and Sequence

- Prepare the Workpiece:

A centre hole is drilled at both ends of the workpiece using a centre drill.

Purpose: Allows the centres to locate and support the workpiece accurately.

- Mount the Workpiece Between Centres:

One end of the workpiece is supported by the live centre in the headstock (which rotates with the spindle), and the other by the dead centre in the tailstock (which remains stationary).

Purpose: Supports the workpiece at both ends for stability during turning.

- Use a Lathe Dog and Faceplate:

A lathe dog is attached to the workpiece and engages with the faceplate on the headstock spindle.

Purpose: Transfers rotary motion from the spindle to the workpiece.

- Adjust Tool and Begin Turning:

A single-point cutting tool is positioned correctly on the tool post and set to the centre height.

The lathe is started, and the tool is fed along the length of the rotating workpiece to remove material.

Purpose: Reduces the diameter and shapes the cylindrical surface evenly.

Question 3

After performing an external turning operation, your part's diameter is 0.2 mm larger than the specification. **Analyse any four (4)** possible causes and recommend corrective measures. (9 marks)

Marking scheme: Award 1 mark for each any relevant point (9 marks).

A. Analysis of Possible Causes (5 marks total)

Possible Cause	Marks
Incorrect tool setting or zero reference point	1 mark
Insufficient depth of cut	1 mark

Tool wear or deflection	1 mark
Improper tool geometry (e.g., nose radius, angle)	1 mark
Loose work holding or vibration	1 mark

B. **Corrective Measures (4 marks total)**

Award 1 mark for each any relevant point (4 marks).

Corrective Action	Marks
Reset tool zero or reference point	1 mark
Take correct depth of cut on finishing pass	1 mark
Ensure tool is sharp and correctly aligned	1 mark
Verify secure work holding (e.g., in chuck)	1 mark

Sample answer

1. A diameter larger than the specified value in external turning can result from several factors:

   Possible Causes:

   - Incorrect tool setting – The tool may not have been properly zeroed against the workpiece surface.
   - Insufficient depth of cut – The final pass may not have removed the correct amount of material.
   - Tool deflection or wear – A worn or deflecting tool may not cut to the intended diameter.
   - Improper tool geometry – Incorrect tool nose radius or approach angle could affect cutting accuracy.
   - Loose work holding – Vibration or misalignment in the chuck or fixture can cause dimensional errors.

2. Recommended Corrective Measures:

   - Recheck and reset the tool's zero reference point.
   - Measure the part accurately with callipers or micrometres after each roughing pass.
   - Perform a final finishing pass with a proper depth of cut.
   - Ensure the tool is sharp and correctly aligned with the workpiece centre.
   - Check that the workpiece is securely clamped in the chuck to prevent slippage.

Question 4

Design a step-by-step operation sheet for producing a shaft (Ø25 mm x 100 mm) that includes drilling a centre hole, rough turning, and finishing. (20 marks)

Marking scheme (Total: 20 Marks)

Assessment Area	Criteria	Marks
1. **Work Preparation and Setup**	Correct stock selection and initial preparation (cut to length, mounting method)	2 marks
	Facing one end and centre drilling both ends	2 marks
2. **Rough Turning Process**	Identifies roughing stage with appropriate tool and process	2 marks
	Approaches rough turning with correct technique (multiple passes, excess material)	2 marks
3. **Finishing Operation**	Selects appropriate finishing tool	1 mark
	Specifies correct technique (low feed rate, final pass to size)	2 marks
	Tolerances stated or implied (e.g., ±0.05 mm)	1 mark
4. **Measurement & Inspection**	Includes steps for measurement (micrometre/vernier)	2 marks
	Inspection and deburring steps clearly stated	1 mark
5. **Logical Sequencing and Clarity**	Operations are arranged in correct logical order	2 marks
	Clear and technically accurate descriptions throughout	2 marks
6. **Safety & Notes**	Mentions safety precautions or handling care	1 mark

Sample answer

1. Design a step-by-step operation sheet for producing a shaft (Ø25 mm × 100 mm) that includes:
    a. Drilling a centre hole
    b. Rough turning
    c. Finishing turning

Step-by-Step Operations

Step	Operation	Tool Used	Details / Notes
1	**Prepare workpiece**	Power hacksaw machine	Cut raw bar stock to approx. 120 mm to allow for facing and holding
2	**Mount workpiece between centres**	Live centre, drive dog, and faceplate or 3-jaw chuck for initial setup	Ensure proper alignment
3	**Face one end**	Facing tool	Clean the face for accurate length reference

4	**Centre drill**	Centre drill (60° tip)	Drill shallow conical hole on both ends for support with centres
5	**Rough turning**	Roughing tool	– Take successive cuts to reduce diameter close to 25.5 mm – Use high feed and depth of cut
6	**Measure**	Vernier calliper or micrometre	Check diameter after rough turning
7	**Finish turning**	Finishing tool	– Reduce to final diameter of 25.00 ± 0.05 mm – Use lower feed and speed for good surface finish
8	**Chamfer ends (optional)**	Chamfering tool	Chamfer edges for safety and aesthetics
9	**Deburr and inspect**	File, emery paper, micrometre	Clean edges and check final dimensions and surface quality

Safety Notes

1. Always wear eye protection.
2. Ensure tool is properly aligned and tightened.
3. Stop machine before measuring or adjusting.

WEEK 22

Question 1

Evaluate the reasons why grinding is often used as a finishing operation after turning or milling. Compare its benefits to those of turning or milling, and explain in what situations grinding is most appropriate. (15 marks)

Marking Scheme

Criteria	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0 marks)
1. Purpose of Grinding	Clearly explains that grinding is a finishing operation used after turning/ milling to achieve superior surface finish and tight dimensional tolerance.	Explains that grinding is a finishing process and improves either surface finish or dimensional accuracy, but not both.	Mentions that grinding is used to improve finish or accuracy but without clear relation to turning/milling.	No valid explanation of why grinding is used or provides unrelated info.

2. Surface Finish and Accuracy	States that grinding achieves Ra 0.2–0.8 µm and ±0.002 mm tolerance, and contrasts these with turning's rougher finish and wider tolerances.	Mentions that grinding achieves finer finishes and tighter tolerances, but without precise values.	Makes vague statement about grinding being "more accurate" or "smoother" without explanation.	No mention of finish or tolerance, or incorrect information.
3. Grinding for Hard Materials	Explains that grinding is ideal for hardened materials (e.g., after heat treatment) which are difficult to machine using turning or milling.	States that grinding is used on hard materials but does not link to machining difficulty or heat treatment.	Refers to hard materials without showing why grinding is better.	No mention or inaccurate claim (e.g., turning is better for hardened parts).
4. Comparison with Turning/ Milling	Provides at least three accurate comparisons in terms of removal rate, finish, accuracy, and tool life, using a clear structure (e.g., table or bullet points).	Gives two correct comparisons with general clarity but not well-structured.	Gives one accurate comparison with limited clarity or detail.	No clear or correct comparison given.
5. Appropriate Applications	Lists at least two relevant cases (e.g., shafts, heat-treated gears) and explains why grinding is ideal in those contexts.	Lists one relevant application with a short or unclear justification.	Gives one vague or general application (e.g., "when a good finish is needed") without explaining why.	No relevant application or justification provided.

Sample answer

Grinding is a finishing operation used to improve surface quality and dimensional accuracy after primary machining processes like turning or milling. Unlike turning or milling, which remove larger amounts of material, grinding removes very small amounts with high precision.

Reasons for Using Grinding After Turning or Milling

1. Improved Surface Finish

a. Grinding produces a much smoother surface than turning or milling.

b. For example, surfaces with a finish of Ra 0.2–0.8 µm are achievable with grinding, whereas turning may leave Ra 1.6–3.2 µm.

2. Greater Dimensional Accuracy

a. Grinding achieves tight tolerances, often in the range of **$0.002\pm$ mm**, which is difficult with turning or milling alone.

b. This is essential for parts like shafts, gears, or bearing surfaces.

3. Hard Material Machining

a. Grinding is ideal for hard materials such as hardened steel or ceramics that are difficult to cut with conventional tools.

b. After heat treatment, grinding is used to bring parts to final dimensions.

4. Removal of Tool Marks and Burrs

a. Turning and milling may leave tool marks or burrs; grinding smooths out these imperfections for both functional and aesthetic reasons.

Comparison to Turning or Milling

Aspect	Turning/Milling	Grinding
Material Removal Rate	High (used for rough shaping)	Low (used for fine finishing)
Surface Finish	Moderate to rough	Very smooth
Accuracy	Good for most jobs	Excellent for precision components
Tool Wear	Cutting tools dull quickly on hard metals	Grinding wheels last longer with proper use

Question 2

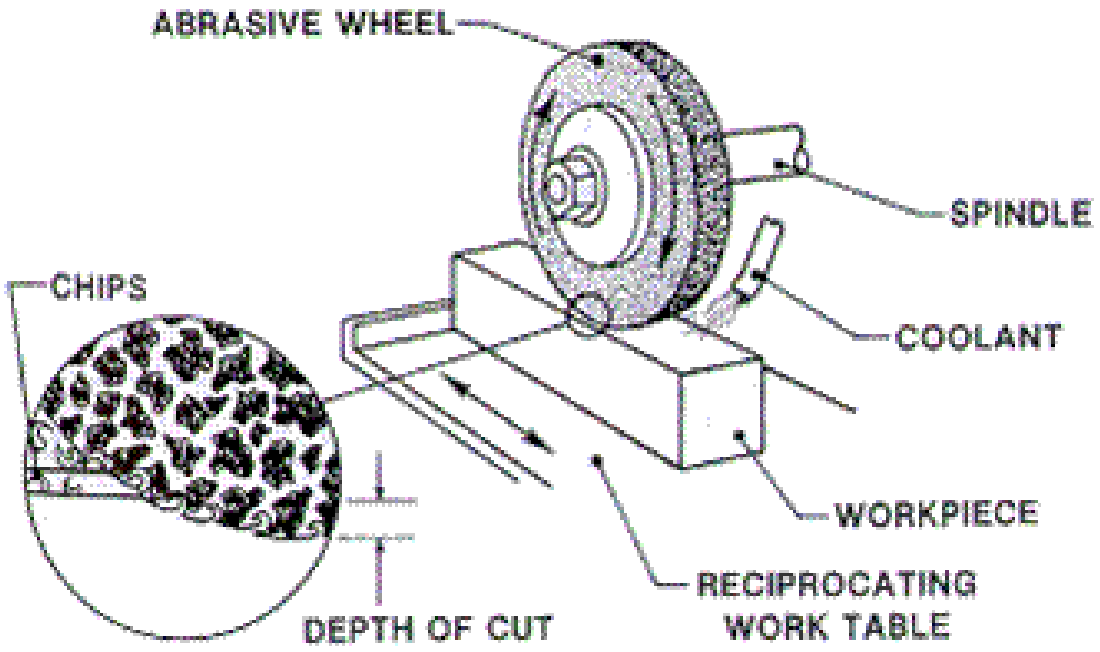
Study the given diagram of a grinding process. Interpret the function of the key components shown and identify at least two points in the process where errors could occur that may affect the quality of the finished part. Explain how these errors could impact the final result. (12 marks)

Marking Scheme

Criterion	Excellent (3 marks)	Very Good (2 marks)	Satisfactory (1 mark)	Needs Improvement (0 marks)
Identification of Key Components (e.g., grinding wheel, workpiece, wheel dresser, coolant nozzle)	Identifies and labels at least 4 key components correctly, referring to the diagram clearly.	Identifies 3 components correctly, with reference to the diagram.	Identifies 2 components, with some unclear link to diagram.	Identifies 1 or no component, or mislabels items in the diagram.

Explanation of Component Functions	Gives accurate and specific functions of at least 3 components (e.g., coolant prevents overheating and surface burns, grinding wheel removes material).	Explains 2 components clearly, one may be missing detail.	Gives general idea for 1 component, or partial explanation for more than one.	No valid explanation, or incorrect/misleading functions.
Identification of Two Error Points (e.g., incorrect wheel dressing, poor coolant application, loose clamping)	Identifies 2 specific points in the grinding process where errors may occur and directly relates them to the diagram/ process.	Identifies 2 possible errors, one may be slightly general or partially related.	Identifies 1 valid error point, second is vague or incorrect.	No clear or relevant error points identified.
Explanation of Impact on Part Quality (e.g., thermal damage, poor surface finish, dimensional inaccuracy)	Accurately explains how each error affects part quality using specific technical effects.	Provides a clear impact for one error and partial or general explanation for the second.	States that errors affect quality, but gives little or no explanation of how.	No explanation of impact or explanations are irrelevant

Sample answer



Interpretation of Key Components in the Grinding Diagram

a. Grinding Wheel

- A rotating abrasive tool that removes small amounts of material from the workpiece surface.
- Must be balanced, dressed, and run at the correct speed.

b. Workpiece

- The part being machined. It is held steady and moved past the grinding wheel during operation.

c. Wheel Dressing Unit

- Removes debris and reshapes the grinding wheel to maintain its cutting effectiveness and surface shape.

d. Coolant Nozzle

- Directs cutting fluid to the grinding sone to reduce heat and prevent surface damage.

e. Worktable/Chuck

- Holds the workpiece securely during grinding. In surface grinding, this is often magnetic; in cylindrical grinding, it may rotate.

Points Where Errors May Affect Part Quality

a. Incorrect Wheel Dressing

- If the grinding wheel is not dressed properly, it may become glazed or lose its shape.
- Impact: This can result in poor surface finish, uneven material removal, or loss of dimensional accuracy.

b. Improper Coolant Application

- If the coolant is not directed correctly or the flow is too low, overheating may occur.
- Impact: Excessive heat can cause thermal damage, such as burns or microcracks, and may distort the workpiece.

c. Loose Work holding (optional third point if needed)

- If the workpiece is not properly clamped to the table or chuck, it may move slightly during grinding.
- Impact: Leads to vibration marks, poor surface accuracy, or even unsafe working conditions.

Question 3

Predict the effects of incorrect tool height alignment during lathe setup. Suggest measures to correct and prevent these effects. (20 marks)

Marking Scheme: (Total: 20 marks)

Section	Expected Points	Marks
A. Prediction of Effects (10 marks)	Candidate should state and explain the following:	
• Poor surface finish (rubbing or tearing)	2	
• Dimensional inaccuracy (undersize or taper)	2	
• Tool wear or breakage due to uneven forces	2	
• Increased cutting forces and vibration	2	
• Conical/tapered parts instead of true cylinders	2	
(1 mark for point, 1 mark for explanation – partial credit possible)		/10
B. Corrective and Preventive Measures (10 marks)	Candidate should suggest and explain the following:	
• Use of centre gauge or tailstock for alignment	2	
• Use of tool height setter	2	
• Perform trial/test cut and inspect result	2	
• Use shims to adjust tool height	2	
• Periodic checking and operator training	2	
(1 mark for point, 1 mark for explanation)		/10

Sample answer

If the cutting tool is not aligned with the centre height of the workpiece during lathe operation, the following negative effects can occur:

1. Poor Surface Finish
   - Too high: The tool may rub against the surface instead of cutting, causing chatter marks.
   - Too low: The tool may dig in, leading to rough or torn surfaces.
2. Dimensional Inaccuracy
   - Inconsistent cutting forces due to misalignment cause tapering or undersized diameters.
3. Tool Wear and Breakage
   - Off-centre tools face uneven force distribution, leading to premature wear or chipping.
4. Increased Cutting Forces and Vibration
   - Misaligned tools increase friction and reduce cutting efficiency, causing machine vibration.

5. Conical/Tapered Cuts
    - Improper tool height may result in the tool not cutting uniformly across the length, creating a taper instead of a true cylinder.

Suggested Measures to Correct and Prevent These Effects

1. Use a Centre Gauge or Tailstock Centre**:** Align the tool tip with the lathe centre using a centre gauge or visually align it with the tailstock centre point.
2. Use a Tool Height Setter: Employ a height-setting tool to set the cutting edge exactly at centre height, especially for insert tools.
3. Perform a Test Cut and Inspect: Make a light cut on a trial piece and observe the chip formation and cutting pattern. Adjust as necessary.
4. Use Shims for Adjustment: If the tool is below centre, insert shims under the tool to raise it to the correct height.
5. Check and Re-check Alignment: Before and during machining, periodically check the tool height to ensure it hasn't shifted.
6. Training and Setup Procedures: Train operators to routinely verify tool height during setup as part of standard operating procedure (SOP).

SECTION 7: SAFETY AND QUALITY MANAGEMENT IN MANUFACTURING

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Sub-Strand: Safety, Quality and the Environment

Learning Outcomes

1. *Explain regulations and compliance issues and procedures for the manufacturing industry. (Week 23)*
2. *Apply quality control and quality assurance practices for efficient and effective manufacturing processes. (Week 24)*

Content Standards

1. *Demonstrate an understanding of manufacturing industry safety regulations and compliance. (Week 23)*
2. *Demonstrate an understanding of the use of quality assurance and quality control in manufacturing. (Week 24)*

INTRODUCTION AND SECTION SUMMARY

This section introduces learners to the critical role of regulations, compliance, and safety standards in the manufacturing industry, with a strong focus on safety, quality, and the environment. Learners will explore the regulatory framework that governs modern manufacturing operations, both at the national and international levels, including the roles of agencies such as the Ghana Standards Authority (GSA) and the Environmental Protection Agency (EPA).

Through case studies, interactive discussions, and project-based learning, learners will examine key safety procedures, environmental policies, and worker protection measures. They will be guided to understand not just what the rules are, but why they exist, and how they contribute to sustainable, ethical, and efficient production systems.

In parallel, learners will investigate how quality assurance (QA) and quality control (QC) systems function in manufacturing processes. This includes understanding inspection routines, documentation protocols, and the role of certifications such as ISO 9001 in ensuring consistent product quality. Learners will engage in activities such as simulating QC checks, analysing production errors, and evaluating quality reports to deepen their grasp of quality principles.

By the end of this section, learners will be able to explain the relevance of regulatory compliance, identify safety protocols, and apply basic quality control techniques. They will gain confidence in recognising the importance of regulation, compliance, and quality as pillars of modern

manufacturing. This section supports the curriculum's broader goals by developing learners' critical thinking, ethical awareness, and industry readiness, laying the groundwork for responsible participation in the manufacturing sector.

The weeks and the indicators covered by the section are:

Week 23

1. Analyse relevant safety tests based on national and international guidelines and principles.
2. Examine the regulatory agency penalties, and criteria for corrective actions

Week 24

1. Describe the role of quality control in manufacturing processes.
2. Explain the various functions of quality control and quality assurance in the manufacturing process.
3. Analyse and utilise quality control data to make decisions

SUMMARY OF PEDAGOGICAL EXEMPLARS

1. **Talk for Learning**
    a. Learners engage in discussions to understand product quality features, standards bodies, material failure types, and the interpretation of quality data to improve products.
    b. Guided discussions help learners understand how quality data is interpreted to improve products.
2. **Research-Based Learning**
    a. Learners research Ghanaian product testing standards, compare them with international benchmarks (ISO/ASTM), present posters on EPA rules, role-play as EPA officials, and complete self-assessed written tasks.
    b. All learners complete a written task and assess their own work using a student-friendly rubric.
3. **Collaborative Learning**
    a. Mixed-ability groups research the roles of quality control in factories and share findings with the class.
4. **Experiential Learning**
    a. Learners visit a local factory to observe quality checks and assurance in real-time.
    b. They watch factory videos showing quality control tools and testing methods, noting key processes.
5. **Project-Based Learning**
    a. Learners design and apply quality control systems in the school workshop, simulating real manufacturing environments.
6. **Practice-Based Learning**
    a. Using sample data, learners work in groups to calculate averages and analyse quality control results with charts and graphs.

ASSESSMENT SUMMARY

To assess learners' understanding of safety regulations, quality assurance, and compliance procedures in the manufacturing industry, a **blended and inclusive assessment approach** is employed. This ensures that learners with diverse strengths and learning styles can effectively engage with the content and demonstrate mastery.

Talk for Learning activities promote oral expression, enabling learners to communicate their understanding through structured group discussions, debates, and guided reflections. These tasks assess learners' ability to explain regulations and compliance issues using relevant vocabulary and real-life examples.

Written assessments of varying complexity are used to evaluate individual understanding of key concepts such as environmental standards, material failure, and the roles of quality assurance and quality control. Self-assessment rubrics are integrated to encourage reflection and responsibility for learning.

Research-based and experiential learning tasks offer authentic opportunities for learners to engage with practical aspects of safety and quality. Projects such as investigating standards from the Ghana Standards Authority (GSA) or simulating an Environmental Protection Agency (EPA) panel provide deeper insight into compliance procedures and encourage active participation.

Collaborative and project-based activities support teamwork and critical thinking, particularly in analysing case studies, designing quality control systems, or exploring the effects of manufacturing violations on communities.

This multifaceted assessment design ensures that learners do not merely recall information but also apply, analyse, and evaluate manufacturing practices in relation to real-world standards and regulations. The approach cultivates critical thinking, collaboration, and ethical awareness—key competencies for future industry practitioners. **Table** 13 summarises the types of assessment strategies used in alignment with the content standards and learning outcomes

Table 13 Summary of assessment for Section 7

Indicators	DOK Level	Assessment Strategy and/or Mode
Describe the role of quality control in manufacturing processes.	3	Research and class presentation
		Collaborative poster design
Examine the regulatory agency penalties and criteria for corrective actions.	3	Group discussion and mind mapping
		Case study analysis with panel simulation
Describe the role of quality control in manufacturing processes.	3	Individual research project and written report
		Socratic seminar with reflective discussion

Explain the various functions of quality control and quality assurance in the manufacturing process.	3	Individual research and report writing
		Think-pair-share discussion
		Group concept mapping
Analyse and utilise quality control data to make decisions.	4	Data interpretation using real-world samples
		Practice-based activity (charts, graphs, statistical tools)
		Peer-assessed written summary with rubric

WEEK 23

Learning Indicators

1. *Analyse relevant safety tests based on national and international guidelines and principles*
2. *Examine the regulatory agency penalties, and criteria for corrective actions*

Recap weeks

Year 2	**Week 22:** Analyse the effects that various manufacturing activities have on the environment (e.g., the effects of waste disposal, power consumption, processing of raw materials.)

Focal Area 1: Safety tests based on National and International guidelines and principles

23.1 Introduction

In manufacturing, **quality control** is a process that ensures that the final products meet specific standards of safety, performance, and reliability. One key part of quality control is conducting **safety tests** to confirm that materials, components, and finished products are safe to use and free from defects. These safety tests are based on both **national and international guidelines**, which are created by regulatory bodies to protect workers, consumers, and the environment. Understanding how safety tests are applied and the principles behind them is important for students who are preparing to work in the manufacturing industry.

(Refer to Year 2, section 7, week 22: Analyse the effects that various manufacturing activities have on the environment (e.g., the effects of waste disposal, power consumption, processing of raw materials.)

In many countries, including Ghana, national safety and quality standards are enforced by government agencies such as the **Ghana Standards Authority (GSA)** and related ministries. These agencies set regulations to guide how manufacturing companies test the quality and safety of their products and operations. National guidelines often require manufacturers to test raw materials for strength and purity, check machines for safe operation, and inspect finished products for any harmful effects before they are released to the public.

Some common safety tests based on national guidelines include **mechanical strength tests**, which check if materials like metals and plastics can withstand pressure without breaking; **electrical safety tests**, which ensure machines and tools do not pose shock or fire hazards; and **chemical tests**, which confirm that materials do not release harmful substances. For example, in a Ghanaian manufacturing company making cooking pots, the material may be tested to ensure it does not contain high levels of lead or other toxic metals.

In addition to product testing, national safety guidelines emphasise **workplace safety.** Manufacturers must regularly inspect machines, enforce the use of personal protective equipment (PPE), and train workers to follow safe operating procedures. These tests and inspections form part of a broader system known as **Occupational Health and Safety (OHS)**, which helps prevent workplace accidents.

23.2 Safety Tests for Manufacturing Processes Based on International Guidelines and Principles

Manufacturers who export goods or want to meet global quality levels must also follow international safety standards developed by organisations such as the International Organisation for Standardisation (ISO), the American Society for Testing and Materials (ASTM), and the International Electrotechnical Commission (IEC). These standards help ensure that products made in one country can be safely used in another, without causing harm or failing to perform as expected.

One of the most important international quality standards is ISO 9001, which focuses on quality management systems and includes guidelines for testing product safety. Another is ISO 45001, which deals with workplace health and safety. International safety tests may include impact tests, flammability tests, and durability tests. For instance, a manufacturer producing helmets must ensure that they pass impact resistance tests according to ISO standards to protect users from head injuries.

Following international safety guidelines also involves documentation and traceability. Manufacturers must keep records of the materials used, the safety tests conducted, and the outcomes. This information helps in product recalls, troubleshooting, and continuous improvement. Many international standards also require third-party inspections, where independent testing labs verify the quality and safety of products before they can be sold globally.

Notes for Facilitators

1. **Clarifying Concepts:** Explain that safety tests are not just about passing; they are about building a quality culture. A company that tests every batch of cement before use (Ghanaian standard) is demonstrating a commitment to safety, not just compliance. Link national standards (GSA) to international ones (ISO) by explaining that ISO 9001 certification is often a requirement for a Ghanaian company to export its products or supply large multinationals. Furthermore, a fine for pollution must be high enough that it is cheaper for the company to install proper waste treatment than to pay the fine repeatedly. Corrective actions are not just "clean up the mess"; they are a process to identify the root cause and implement a system to prevent recurrence (the Corrective Action Plan or CAP).
2. **Common Misconceptions:** Students may think standards are just bureaucratic hurdles. Explain that standards like GSA for electrical plugs prevent fires, and ISO standards ensure that a bolt made in Accra will fit a nut made in Germany. They are about safety, reliability, and trade. Students may think the EPA only fines big companies. Explain that the EPA also regulates small-scale operations, like a local quarry or a small paint workshop, and can apply sanctions to them as well.
3. **Low-Cost Demonstrations and Ghanaian Examples**
    a. **GSA Certification:** Show a local product with a GSA certification mark (e.g., a packaged food item, an electrical extension cord). Explain that this mark means the product has passed certain safety and quality tests.
    b. **Mechanical Testing Demo:** If you have a tensile testing machine from Week 6, use it to test a small metal sample to failure. Explain that this is a destructive safety test used to certify steel for building construction in Ghana. The result ensures the steel won›t snap under load.

c. **Case Study Analysis:** Use the EPA notice to a real Ghanaian company as an example. Have students read the notice and identify: 1) The violation. 2) The penalty. 3) The corrective action required.

d. **Role-Play:** Divide the class into groups. One group plays the EPA; another plays a manufacturing company that has violated a regulation. The EPA must explain the violation, propose a penalty, and outline a CAP. The company must agree to the CAP or propose an alternative. This builds negotiation and problem-solving skills.

Learning Tasks

1. Learners identify and discuss relevant national and international regulatory agencies for manufacturing processes.
2. Learners in mixed ability groups **analyse a defective product sample** and identify which quality characteristics are compromised. They link the defect to lapses in control or inspection.
3. In mixed ability, research **Ghanaian manufacturing safety guidelines**, list the mandatory tests applied to a local product (e.g., bolts, protective gear, or food-grade packaging), and explain how these tests help ensure quality.
4. In groups, learners create a class presentation comparing **national and international safety test standards**, using a case study product (e.g., suture, helmet, or machine part).
5. Each learner demonstrates independent understanding of the role of quality control in manufacturing processes.

Pedagogical Exemplars

Talk for Learning

1. Learners engage in a structured group discussion, identifying various **product quality dimensions** (tolerance, durability, reliability, accuracy) and how inspection tools (vernier callipers, gauges) ensure these qualities.
2. Facilitate a class discussion where learners identify and discuss the major regulatory agencies for manufacturing processes, both nationally and internationally. Use mind maps to organise thoughts.

Research-Based Learning

1. In a mixed ability research group, each team selects a product manufactured in Ghana and investigates the **required safety and quality tests**, using resources from local standards bodies like Ghana Standard Authority (GSA) or **Council for Scientific and Industrial Research** (CSIR). Each ability group provides a brief summary poster or slides on relevant national safety tests for manufacturing processes.
2. Learners compare Ghanaian standards with *International Standard Organisation (*ISO) or *American Society for Testing and Materials* (ASTM) for a selected product. They research mechanical testing (e.g., tensile test, fatigue test) and environmental tests (e.g., corrosion, thermal resistance).. Groups present findings through a short oral presentation and submit a one-page failure summary report.

3. Each learner receives a structured written assessment questions on the learning indicator after completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback

Key Assessment Level 3: Research and Class Presentations

1. A manufacturer discovered that final inspections of precision bearings were rushed, resulting in several units with dimensional errors being shipped. Analyse how this oversight could affect the safety and performance of automotive engines. Support your answer with specific mechanical consequences and suggest one inspection practice to prevent this issue. (10 marks)
2. An undersized shaft was installed in a high-speed machine after passing through inspection unnoticed. Evaluate the mechanical effects of this installation on the machine's performance. Identify at least two potential failure modes and explain how tighter inspection controls could have detected the issue earlier. (10 marks)
3. Compare the current safety testing procedures of Ghana with those used in countries known for high safety standards, such as Germany, Japan, or the United States. Based on your comparison, suggest two realistic improvements Ghana can make. Explain how each improvement would help increase safety and public confidence in locally made products. (20 marks)

Focal Area 2: Penalty and criteria for corrective actions

Recaps

Year 1	**Week 24:** Describe the social and economic consequences that a manufacturing activity can have or has had on individuals and society
Year 2	**Week 22:** Analyse the effects that various manufacturing activities have on the environment (e.g., the effects of waste disposal, power consumption, processing of raw materials.).

23.3 Introduction

In manufacturing, companies must follow rules and guidelines to protect the environment, workers, and public health. These rules are often enforced by government bodies called regulatory agencies. In Ghana, one of the main environmental regulatory agencies is the Environmental Protection Agency (EPA). The EPA monitors how companies handle waste, use chemicals, and control pollution. When a company breaks the rules or harms the environment, the EPA has the power to apply penalties or require the company to take **corrective actions**. These actions help fix the problem and prevent it from happening again. Understanding these penalties and actions is important for students learning how manufacturing should operate responsibly and lawfully.

23.4 Criteria for Corrective Actions According to EPA Standards

(Refer to Year 2, section 6, week 22, Analyse the effects that various manufacturing activities have on the environment (e.g., the effects of waste disposal, power consumption, processing of raw materials.).

Corrective actions are steps that a manufacturing company must take to fix a problem when they violate environmental laws or regulations. The Environmental Protection Agency (EPA)

of Ghana, like many similar agencies around the world, has clear **criteria** for deciding what corrective actions are needed. These criteria help ensure that the actions taken are fair, effective, and based on the level of environmental harm caused.

One key criterion is the severity of the violation. If a company releases toxic waste into a water body or pollutes the air with dangerous gases, the corrective action must be more serious and immediate than if the company simply failed to keep proper records. Another criterion is the potential harm to human health or the environment. For example, if a chemical spill could affect a nearby community, the EPA will require faster and stronger corrective actions.

Other factors include the past behaviour of the company (whether they have broken the rules before), their willingness to cooperate, and whether the violation was intentional or accidental. Based on these criteria, the EPA may require the company to clean up pollution, stop using harmful substances, install better waste treatment equipment, or provide environmental education to workers. Sometimes, the company must also prepare a written Corrective Action Plan (CAP) that explains how and when the problem will be fixed.

23.5 Penalty According to EPA Standards

Penalties are punishments given to companies that break environmental laws. The purpose of these penalties is not just to punish but also to encourage companies to follow the rules and avoid repeating the same mistake. According to **EPA's Environmental Sanctions Regulations of Ghana [Legislative Instrument (L.I.) 2251 of 2016]**, companies can face different types of penalties depending on the type and seriousness of the violation.

One common type of penalty is a monetary fine, which is an amount of money the company must pay. For example, if a manufacturing company discharges untreated waste into a river, the EPA may fine them based on the quantity of waste, the level of pollution, and the environmental damage caused. In Ghana, fines can range from hundreds to thousands of Ghana cedis depending on the violation. The EPA may also charge the company for the cost of cleaning up the pollution, which can be very expensive.

In serious cases, the EPA has the power to suspend or revoke the environmental permit of the company, which means the company must stop its operations until the issue is resolved. If the violation involves criminal activity, such as illegal dumping of hazardous waste, the case may be taken to court, and the officials of the company may face legal prosecution or even imprisonment.

Penalties may also include public exposure, where the name of the company and its violation is published in newspapers or announced publicly, which can damage the reputation of the company.

Notes for Facilitators

1. **Clarifying Concepts:** Frame penalties not as punishment but as economic deterrence. A fine for pollution must be high enough that it's cheaper for the company to install proper waste treatment than to pay the fine repeatedly. Corrective actions are not just "clean up the mess"; they are a process to identify the root cause and implement a system to prevent recurrence (the Corrective Action Plan or CAP).
2. **Common Misconceptions:** Students may think the EPA only fines big companies. Explain that the EPA also regulates small-scale operations, like a local quarry or a small paint workshop, and can apply sanctions to them as well.

3. **Low-Cost Demonstrations and Ghanaian Examples:** Divide the class into groups. One group plays the EPA; another plays a manufacturing company that has violated a regulation. The EPA must explain the violation, propose a penalty, and outline a CAP. The company must agree to the CAP or propose an alternative. This builds negotiation and problem-solving skills.

Learning Tasks

1. Learners in mixed ability **identify typical violations** in manufacturing (e.g., pollution, improper waste disposal, unsafe work conditions). They **link** these to previously discussed regulatory bodies like Environmental Protection Agency (EPA), Ghana Standard Authority (GSA), Council for Scientific and Industrial Research (CSIR).
2. In mixed ability research a **real or hypothetical case** where EPA intervened in a factory's operations. They identify the violations, actions recommended, and criteria used by the EPA for corrective measures (e.g., severity of hazard, frequency, environmental damage).
3. In groups, learners compare **financial penalties**, shutdowns, revocations of operating licenses, or legal prosecution imposed by EPA for breaches. They analyse how penalties vary by type and scale of offense.
4. Each learner demonstrates independent understanding of the types and implications of penalties imposed by the EPA for non-compliance in manufacturing processes.

Pedagogical Exemplars

1. **Talk for Learning**
   a. Learners engage in a structured group discussion to brainstorm on what types of violations are common in manufacturing industries and discuss the various criteria for corrective actions. How do these affect the community or environment? Which agencies intervene and why?
   b. Facilitate a class discussion on the various fines and penalties imposed by regulatory agencies like the EPA for non-compliance in manufacturing processes. Use case studies to illustrate real-world examples.
2. **Research-Based Learning**
   a. Learners work in mixed ability research teams. Each team is assigned one EPA criterion (e.g., environmental impact, health risk, waste management failure). They present a **poster** illustrating the issue, EPA criteria for intervention, and a recommended corrective action.
   b. Learners are given case studies of actual manufacturing violations (either Ghanaian or international). They **simulate an EPA panel** to determine appropriate penalties using Ghana's EPA guidelines.
3. Each learner receives a structured written assessment questions on the learning indicator after completing their responses, they use a self-assessment rubric aligned with the teacher's marking guide to evaluate their own work before submitting for feedback

Key Assessment Level 3: Research and Individual Presentation

1. Analyse the rationale behind escalating penalties for repeat environmental offenders. How does this approach support both environmental policy enforcement and long-term compliance? Use examples or case scenarios to support your explanation. (10 marks)
2. Examine the structured process the EPA should follow after detecting illegal chemical waste disposal. Justify each step in the sequence and explain how it ensures both accountability and environmental restoration. (10 marks)
3. Develop a corrective action plan for a manufacturing plant that emits gaseous waste above acceptable environmental limits. In your response, explain the steps to identify the source of the problem, reduce emissions, and prevent it from happening again. (9 marks)

PLC Session 23

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
   a. explain the week's concepts in a practical way that will make it easier for learners to understand
   b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
   a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
   b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
   c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
   a. The key assessment for the week is research and individual presentation. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the presentation (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
   a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
   b. all teachers in the group work through a similar problem individually for 3–4 minutes
   c. the group then works through the problem together step by step
   d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
   a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
   b. After the enactment, ask for structured feedback from the group
      i. was the concept explained in a way that a learner with no prior knowledge could follow?
      ii. were the examples grounded in contexts familiar to Ghanaian learners?
      iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).

9. Remember to

    a. transfer your chats into your learning planner template.

    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).

    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

WEEK 24

Learning Indicators

1. *Describe the role of quality control in manufacturing processes*
2. *Explain the various functions of quality control and quality assurance in the manufacturing process*
3. *Analyse and utilise quality control data to make decisions*

Recap weeks

Year 2	**Week 23:** Explain the benefits of using environmentally friendly processes and products in the manufacturing process.

Focal Area 1: Role of quality control in manufacturing

24.1 Introduction

Quality control is an important part of the manufacturing process that focuses on making sure products meet certain standards of quality. These standards may relate to the product's size, shape, appearance, strength, or safety. In simple terms, quality control is the practice of checking and improving a product to ensure that it is fit for use. Without quality control, products might have defects or errors that could lead to customer dissatisfaction, safety problems, or wasted materials. Therefore, quality control helps companies reduce mistakes, maintain reputation, increase customer trust, and ensure safety in the use of their products.

24.2 Fundamental Concepts of Quality Control

(Refer to Year 2, section 7, week 23: Explain the benefits of using environmentally friendly processes and products in the manufacturing process

The main idea behind quality control is to make sure that every product made in the factory meets the same high standard. One key concept is conformance to requirements, which means the product must match the set design and specification. Another important idea is prevention over inspection, meaning it is better to prevent problems before they happen rather than fixing them later. Quality control also involves the use of data to make decisions. By measuring and recording product features during production, companies can quickly identify problems and take action to solve them. This is called data-driven decision-making.

An image of a product inspection line showing workers checking for defects can be used here to help students understand the real-world application of these concepts.

24.3 Quality Control Processes

Quality control is not just a single step in production - it is a process made up of several stages. It usually begins with setting quality standards based on customer needs, company policies, or national standards. The next step is measuring the product during and after production using tools and instruments. After that, the measured data is compared with the required specifications. If there is a difference, it is called a deviation or non-conformance, and corrective action is taken. The final step involves feedback and continuous improvement, where the results of quality checks are used to improve the overall manufacturing process.

24.4 Quality Control Tools and Techniques

There are several tools and techniques used in quality control to help detect and solve problems. Some of the basic tools include the check sheet, used to collect and record data; the histogram, which shows data distribution; and the control chart, which tracks changes in quality over time. Another useful tool is the cause-and-effect diagram (also called a fishbone diagram), which helps find the root causes of a problem. These tools are often used during meetings or investigations when a defect or error occurs, and they help teams understand the problem better before making corrections.

24.5 Quality Standards and Certifications

To maintain trust in products, many companies follow recognised quality standards and obtain **certifications**. One of the most common international standards is ISO 9001, which provides a framework for setting up a quality management system. In Ghana, local standards are set by the Ghana Standards Authority (GSA). A company that meets these standards can be certified, which means their quality system has been reviewed and approved by experts. Certified companies are more trusted by customers and have access to larger markets. Standards ensure that products are consistently good, safe, and reliable.

24.6 Quality Control in Manufacturing

In the manufacturing environment, quality control is applied at every stage - from raw materials to the finished product. Workers inspect materials before they are used, machines are checked to ensure they are operating correctly, and finished products are tested before being packaged. This continuous checking helps catch problems early and reduces the chance of producing large quantities of defective goods. In many factories, there are quality control inspectors whose job is to monitor the production line, collect samples, and report on product quality. Quality control ensures that manufacturing processes are efficient and that customers receive what they expect.

24.7 Quality Control Systems and Technologies

Modern factories use advanced quality control systems and technologies to improve accuracy and speed. These systems include automated inspection machines, sensors, and software that collect data in real-time. For example, a sensor can measure the diameter of a part during production and send the data to a computer for analysis. If something goes wrong, the system can alert the operator immediately. Some companies use Statistical Process Control (SPC) software that draws control charts and calculates whether a process is going out of control. Technology allows manufacturers to detect problems faster and make quick decisions to fix them, reducing waste and cost.

Focal Area 2: Functions of quality control and quality assurance in manufacturing

24.8 Introduction

In the manufacturing process, quality is not just about making a product that works, it is about making products that meet customer expectations consistently and safely. This is achieved through two important systems: **Quality Control (QC)** and **Quality Assurance (QA)**. Quality

control involves the **inspection and testing** of products to identify defects, while quality assurance involves the **planning and improvement of processes** to prevent those defects from happening in the first place. Both QC and QA play different but equally important roles in making sure that manufactured goods are of high quality, reliable, and safe for use. Together, they help reduce waste, save time, improve customer satisfaction, and ensure compliance with standards and regulations.

24.9 Quality Control Metrics and Criteria

Quality control relies on **measuring specific features** of a product and comparing them with set standards. These features are called **quality metrics**, and they can include measurements like length, diameter, weight, strength, or surface finish. The criteria used to judge these measurements are known as **tolerances** - acceptable ranges of values. For example, if a shaft is supposed to be 20 mm in diameter, the tolerance might be ± 0.1 mm, which means the part is acceptable if it measures anywhere from 19.9 mm to 20.1 mm. If the measurement falls outside this range, the product is considered defective. These metrics and criteria help manufacturers make objective decisions about whether to keep or reject a product. Consistent use of quality metrics ensures fairness, accuracy, and reliability in production.

24.10 Quality Control Functions and Techniques

The main function of quality control is to **detect defects in products** and ensure that only good-quality items reach the customer. To do this, manufacturers use a variety of inspection and testing techniques. One common technique is **visual inspection**, where trained workers look for surface defects such as cracks, dents, or scratches. Another is **dimensional inspection**, which involves using tools like callipers, gauges, and micrometres to measure the size of parts. For more advanced needs, manufacturers may use **non-destructive testing** methods such as ultrasonic or magnetic testing, which can detect internal defects without damaging the part. Quality control also includes **sampling methods**, where only a few pieces from a batch are tested to represent the quality of the whole group. These techniques ensure that defects are caught early, reducing waste and customer complaints.

24.11 Quality Assurance Functions and Methodologies

While quality control focuses on identifying defects after they occur, quality assurance works **before and during production** to prevent problems. The key function of quality assurance is to **design and manage systems** that ensure quality is built into every stage of the manufacturing process. This includes creating **standard operating procedures (SOPs)**, training workers, selecting the right materials, and designing workflows that reduce errors. One common QA methodology is the **Plan-Do-Check-Act (PDCA) cycle**, which promotes continuous improvement by encouraging regular review and refinement of processes as shown in Fig. 57. Another important QA method is **Total Quality Management (TQM)**, which involves every department and employee in maintaining quality. Quality assurance provides confidence that products will meet standards without relying only on inspection at the end.

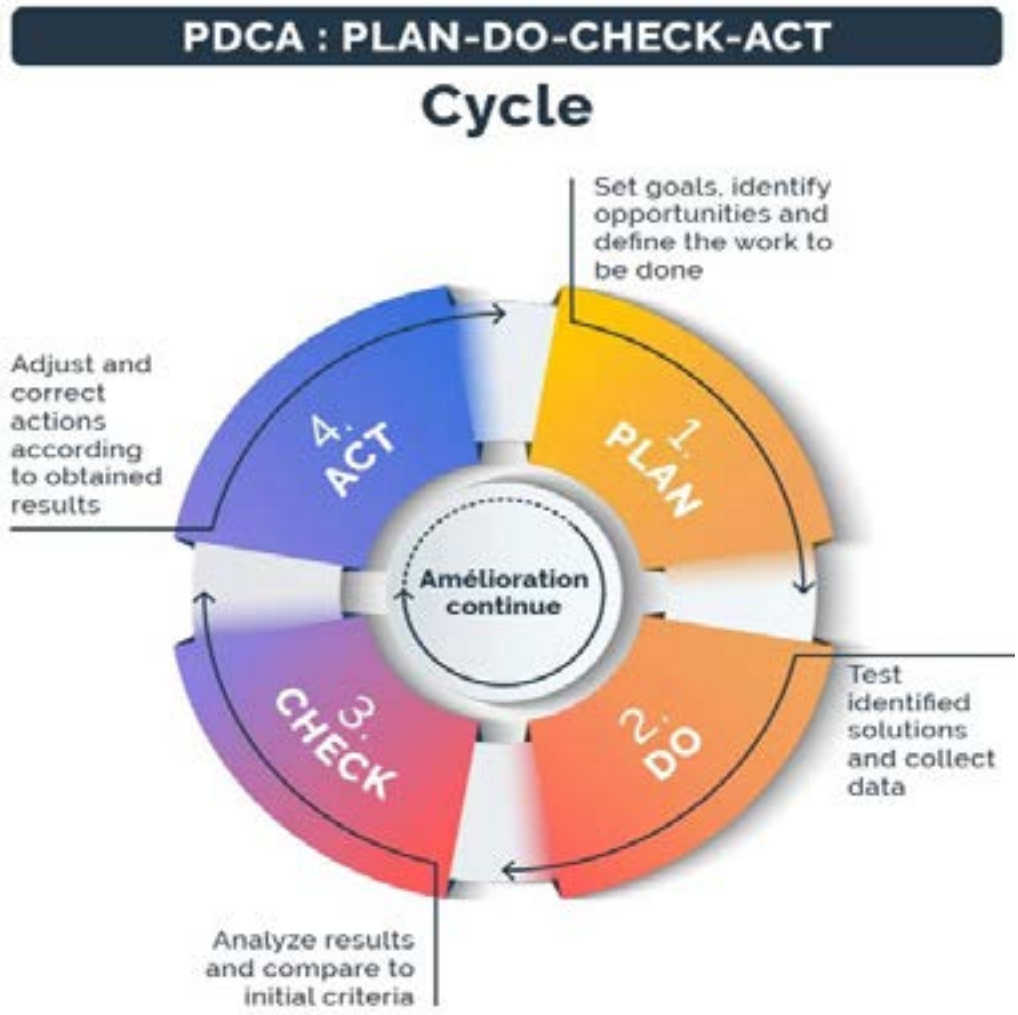


Figure 57: *A diagram of the PDCA cycle*

https://blog.proactioninternational.com/en/pdca-method-complete-guide-lean

24.12 Human Factors in Quality Control and Quality Assurance

People play a central role in both quality control and quality assurance. Even with advanced machines and software, human decision-making, skills, and behaviour can affect the quality of products. In quality control, human inspectors must be trained to notice small defects and follow procedures exactly. In quality assurance, the success of systems and improvements depends on whether workers follow instructions, communicate problems, and give feedback. Poor working conditions, lack of training, and low motivation can increase errors and reduce product quality. That is why manufacturers invest in **worker education, proper lighting, ergonomic tools, and a safety-focused environment** to improve human performance in quality-related tasks. Respecting and empowering the human element in quality systems leads to better results.

24.13 Role of Technology in Quality Control and Quality Assurance

Technology has transformed how manufacturers manage quality. In quality control, **digital measuring instruments, optical scanners**, and **automated inspection systems** allow for faster and more accurate checks. These machines can detect tiny flaws that the human eye might miss. In quality assurance, technologies such as **Enterprise Resource Planning (ERP)** software, **Statistical Process Control (SPC)** systems, and **real-time data tracking** help

monitor and manage production processes. These tools alert managers to unusual patterns or errors so they can respond quickly. For example, if a machine starts producing parts that are slightly too big, a sensor can detect the change immediately and stop the machine before hundreds of defective parts are made. Technology also allows manufacturers to **store and analyse quality data,** leading to better decision-making and long-term improvement.

Quality control and quality assurance are two important parts of the manufacturing process that work together to make sure products meet standards and satisfy customers. Quality control focuses on detecting and fixing problems by inspecting and testing products. Quality assurance focuses on preventing problems by managing systems, training people, and designing better processes. Both systems use tools, techniques, and technologies to maintain high standards and improve production. Human effort, accurate measurement, and continuous improvement are all key to delivering quality in manufacturing.

Focal Area 3: Decision making with quality control data

24.14 Quality Control Data

Quality control data refers to the information collected during the manufacturing process that shows how well products or processes meet required standards. These data points include measurements such as length, weight, diameter, hardness, temperature, or time. For example, if a company is making metal rods, data may be collected on the diameter of each rod. This data is essential because it allows manufacturers to **monitor consistency, detect defects, and improve product quality**. Without collecting and analysing this data, companies would have no reliable way to check whether products are within acceptable limits or to make informed decisions.

24.15 Statistical Foundations

Statistics is the branch of mathematics used to organise, analyse, and interpret data. In quality control, statistics help manufacturers **understand variation**, which refers to the natural differences that occur in materials or processes. Two common statistical terms are **mean**, which is the average value, and **standard deviation**, which tells us how spread out the data is. For example, if the average diameter of rods is 20 mm, and most rods are very close to this size, the process is under control. However, if the measurements vary widely, there may be a problem. Understanding basic statistics allows students to know when variation is normal and when it signals a deeper issue that needs to be addressed.

Notes for Facilitators

In a factory, the mean (average) tells you if your production line is hitting the target size – for example, if you are making 25 mm shafts and the mean is 25.02 mm, you are very close. However, the mean alone does not tell you about consistency. That is what standard deviation measures. A low standard deviation means every shaft is nearly identical (e.g., all between 24.98 mm and 25.02 mm). This is ideal because the parts will fit together reliably, and very few will be rejected. A high standard deviation means the shafts vary widely (e.g., some 24.85 mm, some 25.15 mm). Even if the average is perfect, many parts will be out of tolerance, causing assembly problems, waste, and customer complaints. So, when a manufacturer says they want "consistent quality," they really mean they want a low standard deviation – not just a good average.

24.16 Data Collection and Measurement

Collecting accurate data is the first step in effective quality control. In manufacturing, data can be collected using tools like **vernier callipers, micrometres, pressure gauges, or thermometers.** These instruments are used by trained workers or machines at different points in the production line. It is important to collect data regularly and consistently to track the performance of processes over time. The quality of the decision made depends on how accurate and complete the collected data is. If the data is wrong or missing, decisions based on it can lead to more defects and higher costs. Therefore, students must understand the importance of careful measurement, calibration of instruments, and proper recording of results.

24.17 Data Visualisation and Interpretation

Once data is collected, it needs to be organised and displayed in a way that makes it easy to understand. This is where **data visualisation** comes in. Charts and graphs such as **bar charts, line graphs, histograms, and control charts** help identify patterns, trends, and outliers. For example, a line graph can show how product quality changes over time, while a control chart can indicate whether the process is stable or needs attention. Interpreting these visuals correctly helps identify whether a process is working well or needs adjustment. Teaching students to read and analyse these charts improves their ability to make smart and timely decisions in manufacturing settings.

Special causes of variation are detected on control charts by noticing certain types of patterns that appear on the control chart. The point beyond the control limits is one such pattern.

24.18 Statistical Process Control (SPC)

Statistical Process Control (SPC) is a method used to monitor and control a process using statistics. It uses **control charts** to track process behaviour and helps determine whether a process is operating consistently or if there are special causes of variation. For instance, if a measurement goes above or below certain control limits on the chart, it signals that something unusual is happening, such as tool wear or material defects. SPC helps reduce waste, prevent defects, and maintain a high level of quality. High school students learning about SPC develop a better understanding of how data can be used in real time to keep manufacturing operations efficient and under control.

24.19 Decision Making Frameworks

Making good decisions using quality control data involves following a structured approach. One popular decision-making framework is the **PDCA cycle**; Plan, Do, Check, Act. In this model, manufacturers plan an improvement, carry it out, check the results using quality data, and act on what they learn. Another model is the **DMAIC framework** used in Six Sigma (Define, Measure, Analysse, Improve, Control), which is especially helpful for solving complex quality problems. These frameworks help guide teams through each step of the improvement process and make sure that decisions are well thought out and backed by data.

Notes for Facilitators

1. **Clarifying Concepts:** The simplest distinction: QA is about planning and designing the process to prevent defects («Do things right»). QC is about inspecting the product to find defects («Did we do things right?»). QA is proactive; QC is reactive. Use the analogy of a student writing an exam: QA is studying the syllabus and practicing past questions; QC is checking your answers before submitting the paper.

2. **Common Misconceptions:** Students often use QA and QC interchangeably. Force a clear distinction by having them create a two-column table with headers «Quality Assurance (Process-focused)» and «Quality Control (Product-focused)».
3. **Low-Cost Demonstrations and Ghanaian Examples**
   a. **Classroom Example:** When making a simple product in class (e.g., a paper airplane), QA would be: using a standard template, checking the fold instructions, and ensuring everyone uses the same paper. QC would be: measuring the wingspan, checking the nose point, and test-flying a sample from each batch.
   b. **Local Industry Example:** In a Ghanaian bakery, QA is ensuring the oven temperature is calibrated, the mixing time is standardised, and the flour is from an approved supplier. QC is weighing a sample of loaves, checking their colour, and tasting a sample for quality.

Learning Tasks

1. Learners discuss quality assurance (QA) and quality control (QC), and prepare a chart showing their similarities and differences in the context of manufacturing.
2. Learners do a role-play an inspection team performing a mock quality control process using sample machined parts.
3. Each learner demonstrates independent understanding on the role of quality control in manufacturing processes.
4. Recap the basic concepts of quality control and its significance in manufacturing. Learners review previously learned concepts on product quality, inspection, defects, and tolerance.
5. Learners in a mixed ability groups discusses different quality standards and certifications. ISO certifications, Six Sigma, and their importance in manufacturing.
6. Examine how technology enhances quality control and assurance. and discuss technologies such as automation, real-time monitoring, and data analytics
7. Each learner demonstrates independent understanding on the role of quality control in manufacturing processes.
8. Learners recap core concepts from previous years, including definitions and purposes of quality control, types of data, and basic statistical terms such as mean, median, mode, range, and variation.
9. Learners interpret raw quality data by calculating and analysing mean, median, mode, standard deviation, and range, and apply these to make judgments on production consistency.
10. Learners in a mixed ability groups design and carry out a basic measurement activity using a calliper or micrometre to collect real data from manufactured items (e.g., rods or bolts). They analyse variability due to measurement or process errors.

11. Learners represent quality data using bar charts, line graphs, and control charts. They will analyse trends, shifts, or patterns.
12. Each learner demonstrates independent understanding on the analyse and utilise quality control data to make decisions

Scenario for role-play

You are the quality control (QC) team at "Precision Parts Ltd.," a company that manufactures steel shafts for bicycle axles. The production department has just finished a batch of 50 shafts. Each shaft must have a diameter of 10.00 mm ± 0.05 mm and a length of 50.00 mm ± 0.10 mm. Any shaft outside these tolerances must be rejected.

Your job is to inspect a sample of 10 shafts from this batch, record your measurements, decide which parts are acceptable (pass) or unacceptable (fail), and present your findings to the "Production Manager" (your teacher). You must also identify the most common defect and suggest one possible cause. Table 14 is a sample student role-responsibilities to guide the scenario role-play.

Table 14 Scenario role-play

Role	Responsibility
Inspector 1	Measures diameter using a vernier calliper or micrometre. Calls out each measurement.
Inspector 2	Measures length using a steel rule or calliper. Calls out each measurement.
Recorder	Writes measurements on the checklist and calculates pass/fail.
Quality Engineer	Reviews the data, identifies the most common defect, and prepares a short oral report.
Production Manager (Teacher)	Receives the report, asks questions, and decides if the process needs adjustment.

Materials Needed

- *10 sample "shafts" (real machined parts, wooden dowels, or even marked pencils – clearly labelled 1 to 10).*
- *Vernier calliper or micrometre.*
- *Steel rule (150 mm).*
- *Checklist template (below).*

Inspection Checklist Template

Batch:*Bicycle Axle Shafts*

Nominal Diameter: *10.00 mm* ***Tolerance:*** *0.05± mm (9.95 mm – 10.05 mm)*

Nominal Length: *50.00 mm* ***Tolerance:*** *0.10± mm (49.90 mm – 50.10 mm)*

Inspectors: _____ ***Date:*** _____

Part No.	Diameter (mm)	Pass/Fail (Diameter)	Length (mm)	Pass/Fail (Length)	Overall Pass/Fail
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Summary:

- *Total parts inspected:* ____
- *Parts passing both diameter and length:* ____
- *Parts fail*ing (rejected): ____

Most common defect (circle one): *Diameter too large / Diameter too small / Length too long / Length too short*

Possible cause (suggest one):

Pedagogical Exemplars

1. **Talk for Learning:** Lead a discussion where learners identify and discuss the major differences between quality assurance and quality control, using historical examples to illustrate the evolution of quality control.
2. **Collaborative Learning:** In mixed-ability groups, learners research and discuss the major roles of quality control in the manufacturing process, presenting their findings to the class.
3. **Experiential Learning**
    a. Learners visit a nearby local manufacturing industry to observe and discuss quality assurance and quality control actions and stages where quality checks are performed.
    b. Show learners a video of a quality control (QC) laboratory and activities in a quality control process in a typical manufacturing industry, such as using micrometres, vision systems, and destructive testing equipment. Learners note tools and QC steps observed.
4. **Talk for Learning**
    a. Organise a guided discussion where learners discuss the various functions of quality assurance and quality control in the manufacturing process. Use concept maps to organise thoughts.

   b. Facilitate a discussion where learners identify and discuss various tools for analysing and interpreting quality data for decision making in a manufacturing process. Use concept maps to organise thoughts
   c. Learners interpret raw quality data by calculating and analysing mean, median, mode, standard deviation, and range, and apply these to make judgments on production consistency.

5. **Practice-Based Learning:** Provide learners with a sample set of quality control data from a typical manufacturing process. In think-pair-share groups, learners analyse and interpret the data using charts, measures of central tendencies, and linear relationships for decision making.

Key Assessment Level 4: Practice-Based Assessment

1. In the manufacturing process, both quality assurance (QA) and quality control (QC) are important for maintaining product quality. Analyse how QA and QC differ in their roles. Then, create a table that clearly compares and contrasts three (3) key differences between quality assurance and quality control in terms of when they occur in the product lifecycle, what they focus on, and how they are implemented. Evaluate the role of quality control in enhancing manufacturing efficiency and product reliability. (10 marks)
2. In a manufacturing company, sampling is used to check product quality without testing every item. Analyse how different sampling methods such as random sampling, systematic sampling, and stratified sampling can affect the results of quality control. In your response, explain how the sampling method chosen can influence how accurate the quality check is, how easily defects are detected, and how decisions are made. (10 marks)
3. In manufacturing, companies aim to keep product quality consistent. Using your understanding of standard deviation:
   a. Explain how standard deviation can be used to measure the consistency of product quality.
   b. Use a specific product (e.g., bolts, rods, screws, bottles) as an example.
   c. Compare two situations: one with low standard deviation and one with high standard deviation.
   d. Explain what these differences mean for quality control in the production process. (10 marks)
4. You are working in a screw-making company and have been asked to check the quality of the screws being produced. Design a measurement activity for quality control. In your response:
   a. Describe the tools you would use to measure the screws.
   b. Explain the type of data you would collect.
   c. Describe how you would organise and analyse the data to check for consistency or defects. (10 marks)

PLC Session 24

45 minutes	Planning & Reviewing the Learning Plan

1. Begin the session by recapping lessons from the previous year/session/week, focusing on how learning was applied.
2. Use your subject specific app to explore the content before planning. Ask the app to
    a. explain the week's concepts in a practical way that will make it easier for learners to understand
    b. identify two or three common misconceptions learners may have on the week's content and how to address them using contexts familiar to Ghanaian learners. (NTS 3a, 3g and 3m).
3. Use your subject specific app to plan your lesson. Ask the app to
    a. suggest the most effective method for teaching the week's concepts to learners with diverse backgrounds.
    b. suggest learning activities, differentiation and essential questions based on the method of teaching (NTS 3a-3q)
    c. review your prepared learning plan and address any challenging issues you may have identified in your subject area (NTS 3a-3c).



Note

- Take note of the recap topics linked to Years 1 and 2 while preparing for your lesson.
- Refer to the Values Learning Community Handbook and link the values for the week in your lesson to ensure that learners are applying what they learn.

4. Plan the week's key assessment with your app
    a. The key assessment for the week is practice-based assessment. Chat with your app to plan this assessment, indicating what you and your learners will do before, during and after the assessment (NTS 3k-3q).

10 minutes	Content Exploration

5. As a subject group, select one problem or idea/term in the week's content that is challenging (not a routine procedural question, but one that requires conceptual understanding) and then
    a. use the app, ask it to solve the problem step by step and explain the reasoning behind each step (you may be assisted by a teacher who is strong in the content area)
    b. all teachers in the group work through a similar problem individually for 3–4 minutes
    c. the group then works through the problem together step by step
    d. highlight the most common errors made at each step and discuss (NTS 1c, 1e, 2c, 2e, 3e-3j).

Note

- This part is not just about 'How do I teach this?' but how do I teach it for learners to understand?
- If the group still shares the same content gap, use the app: ask it to solve the problem step by step and explain the reasoning behind each step.
- Problems/ideas discussed should be sourced from the Teacher Manual content, not invented separately. This keeps the content exploration directly connected to what teachers will deliver.

30 minutes	Enactment

6. Enact a teaching activity based on your learning plan (NTS la-1b, 1e-lg, 2c, 2e, 2f, 3c-3j and 3o).
    a. Colleagues observe with specific attention to clarity of concept explanation, use of familiar Ghanaian examples and how misconceptions are handled if they arise.
    b. After the enactment, ask for structured feedback from the group
        i. was the concept explained in a way that a learner with no prior knowledge could follow?
        ii. were the examples grounded in contexts familiar to Ghanaian learners?
        iii. did any misconceptions surface and if so, how were they addressed?

5 minutes	Reflection

7. Reflect and share your views on the session. One thing that worked well, what did not work well and what you will do differently. (NTS 1a, 1b).
8. Identify a critical friend to observe and provide feedback on your lesson in relation to the PLC Session conducted (NTS 1f, 1g).
9. Remember to
    a. transfer your chats into your learning planner template.
    b. read your Teacher Manual and related Learner Material in preparation for the next session. Take note of the recap weeks, which are linked to Years 1 and 2 (NTS 3a).
    c. integrate National Values, GESI, SEL, and 21st century skills into your learning activities, assessment tasks, and rubrics/mark schemes.

Section 7 Review

This section teaches learners how to use quality control data to make smart decisions in manufacturing. It covers how to collect, analyse, and use data to improve quality, reduce mistakes, and ensure products meet standards. Here are the key lessons and terms explained:

1. Quality Control Data – This is the information (like size, shape, weight, or colour) collected during production to check if the product is made correctly.
2. Decision Making with Data – Using the collected data to choose what to do - whether to continue, stop, or change something in the manufacturing process.
3. Statistics – A branch of math that helps us understand numbers. In manufacturing, statistics are used to spot changes or problems in production by looking at averages and differences in data.
4. Data Collection – The process of measuring products using tools like callipers or gauges to get the right information for decision-making.
5. Data Visualisation – Turning numbers into pictures like graphs and charts so that trends, errors, or patterns can be seen more easily.
6. Control Charts – Special graphs used in factories to see if a process is working as expected or going out of control.
7. Statistical Process Control (SPC) – A method that uses data and control charts to keep a process steady and fix it before problems happen.
8. Root Cause Analysis – A way to find out why a problem happened, not just what happened. It helps fix the real issue so it doesn't happen again.
9. Check Sheet – A simple form used to record how often something happens, like how many products have defects.
10. Pareto Chart – A type of bar chart that shows which problems happen most often, so you can focus on fixing the biggest ones first.
11. Scatter Plot – A graph that shows the relationship between two things—like temperature and defects—to see if they're connected.
12. PDCA Cycle (Plan, Do, Check, Act) – A four-step method for solving problems and improving processes. First, you plan what to fix, then try it, check the results, and make changes if needed.
13. DMAIC (Define, Measure, Analysse, Improve, Control) – A five-step process used in Six Sigma projects to fix big problems in a detailed way.
14. Six Sigma – A system used by companies to reduce errors and improve quality through careful data analysis and process control.
15. Technology in Quality Control – Computers, sensors, and software are used to collect and analyse quality data automatically and more accurately.
16. Quality Improvement – The ongoing process of making products and services better by using the data to fix problems.

17. Compliance – Following rules and standards (like safety and environmental laws) set by government or industry to make sure manufacturing is safe and fair.
18. Teamwork in Quality Decisions – Working in groups helps people share ideas, understand data better, and make the right choices together

MARKING SCHEMES FOR THE KEY ASSESSMENTS

WEEK 23

FOCAL AREA 1

Question 1

A manufacturer discovered that final inspections of precision bearings were rushed, resulting in several units with dimensional errors being shipped.

Analyse how this oversight could affect the safety and performance of automotive engines. Support your answer with specific mechanical consequences and suggest one inspection practice to prevent this issue. (10 marks)

Marking Scheme

- Explanation of how dimensional errors affect engine safety/performance (4 marks)
- Mechanical consequences (e.g. overheating, failure, misalignment) (3 marks)
- Suggestion of a realistic quality control improvement (2 marks)
- Clear and structured response (1 mark)

Sample Answer

Dimensional errors in precision bearings can prevent them from fitting properly within the engine's housing. This can lead to misalignment of the crankshaft or camshaft, causing excessive friction and heat during operation. Over time, the engine components may wear out prematurely or even seize, resulting in engine failure.

A possible consequence is the loss of oil pressure due to improper clearances, which can compromise lubrication and increase the risk of overheating or mechanical breakdowns.

To prevent this, manufacturers should implement a digital coordinate measuring machine (CMM) inspection step before packaging to detect deviations outside tolerance limits.

Question 2

An undersized shaft was installed in a high-speed machine after passing through inspection unnoticed.

Evaluate the mechanical effects of this installation on the machine's performance. Identify at least two potential failure modes and explain how tighter inspection controls could have detected the issue earlier. (10 marks)

Marking Scheme

- Evaluation of how an undersized shaft affects performance (4 marks)
- Identification and explanation of two failure modes (e.g. vibration, wear, misalignment) (4 marks)
- Description of an inspection method to catch size deviation (2 marks)

Sample Answer

Installing an undersized shaft in a high-speed machine would result in an improper fit within the bearing or coupling. This loose fit can cause the shaft to wobble, creating unbalanced forces that lead to vibration.

Two failure modes are:

a. Premature wear – due to continuous movement and friction between loosely fitted parts.

b. Bearing damage or misalignment – which could escalate into complete machine failure or operational hazards.

Tighter inspection using a micrometre or laser measurement system with automatic rejection of parts outside tolerance could have caught this size error before installation.

Question 3

Compare Ghana's current safety testing procedures with those used in countries known for high safety standards, such as Germany, Japan, or the United States. Based on your comparison, suggest two realistic improvements Ghana can make. Explain how each improvement would help increase safety and public confidence in locally made products. (20 marks)

Marking Scheme

Criterion	What to Look For (Specific Details)	Marks
1. Description of Ghana's Current Safety Testing System	Mentions agencies (e.g., GSA, FDA), highlights at least two key challenges such as outdated equipment, weak enforcement, or delays in testing.	3
2. Description of International Practices	Refers to at least one specific country (e.g., USA, Germany, Japan), and gives two clear examples of advanced practices e.g., third-party testing, automated labs, product traceability.	3
3. Comparison (Analysis)	Shows meaningful contrast between Ghana and international systems e.g., Ghana's lack of equipment vs. automation elsewhere. Must go beyond listing to show understanding.	4
4. Improvement 1 Suggested	Suggests a realistic, applicable improvement (e.g., require third-party testing in Ghana). Idea should directly connect to issues discussed.	2
5. Justification of Improvement 1	Clearly explains how it would improve product safety (e.g., neutral testing) and increase public trust.	2
6. Improvement 2 Suggested	Suggests a second, different and realistic improvement (e.g., upgrade testing labs).	2

7. Justification of Improvement 2	Explains how it would lead to better testing results, faster services, or support for exports.	2
8. Conclusion / Final Summary	Ends with a clear summary or reflection on how both suggestions together improve the system.	2

Sample Answer

Ghana's current safety testing procedures are often limited by a lack of modern equipment, low enforcement of standards, and limited coordination between regulatory bodies. Agencies like the Ghana Standards Authority (GSA) and the Food and Drugs Authority (FDA) are responsible for ensuring safety, but due to funding and technical constraints, testing is sometimes delayed, incomplete, or not repeated regularly.

In contrast, countries like Germany, Japan, and the United States use more advanced and structured safety testing systems. For example, in the United States, the Consumer Product Safety Commission (CPSC) requires manufacturers to conduct **third-party testing**, follow detailed **product traceability rules**, and recall unsafe products quickly. They also use **automated lab testing systems** to check mechanical strength, toxicity, and fire resistance in a wide range of products.

Two Realistic Improvements for Ghana

1. **Introduce Mandatory Third-Party Testing**

Instead of relying only on internal company tests or irregular inspections, Ghana can require manufacturers to send samples to independent, accredited laboratories for testing — as is done in Germany and the USA. This reduces bias and ensures that testing is trustworthy.

Justification

This would increase product credibility and reduce the risk of unsafe goods reaching the market. Consumers would feel safer knowing that products have passed tests done by neutral experts.

2. **Upgrade Testing Labs with Modern Equipment**

Ghana should invest in automating its safety testing facilities with modern tools such as robotic testing arms, digital calibration machines, and software for tracking test results over time.

Justification

Better equipment means more accurate and faster testing. It would also allow the country to test a wider range of products and comply with international export requirements, which would benefit local industries and encourage quality manufacturing

FOCAL AREA 2

Question 1

Analyse the rationale behind escalating penalties for repeat environmental offenders. How does this approach support both environmental policy enforcement and long-term compliance? Use examples or case scenarios to support your explanation. (10 marks)

Marking Scheme

- Clear explanation of rationale (deterrence, accountability) (3 marks)

- Discussion of how it supports policy enforcement and compliance (3 marks)
- Use of a relevant example or case scenario (2 marks)
- Logical structure, clarity, and reasoning (2 marks)

Sample Answer

Escalating penalties for repeat offenders reinforce the seriousness of environmental laws and encourage long-term compliance.

When companies repeatedly violate regulations, it suggests that previous penalties were not effective deterrents.

Higher penalties apply pressure by increasing the cost of non-compliance. For example, in the U.S., the EPA issues larger fines for companies that continue illegal waste dumping after initial warnings.

This approach ensures accountability and shows that the system rewards corrective behaviour while punishing disregard for regulations.

Over time, it builds a culture of responsibility within industries and protects public health and the environment.

Question 2

Examine the structured process the EPA should follow after detecting illegal chemical waste disposal. Justify each step in the sequence and explain how it ensures both accountability and environmental restoration. (10 marks)

Marking Scheme

- Identification of logical step-by-step process (4 marks)
- Justification of each step's role in accountability (3 marks)
- Explanation of how steps contribute to environmental restoration (2 marks)
- Clarity, coherence, and critical reasoning (1 mark)

Sample Answer

The EPA's response should begin with a notice of violation, informing the company of the breach and initiating legal and corrective procedures.

Next, the company must conduct an environmental assessment to determine the extent of the damage.

Once the results are reviewed, the EPA should recommend corrective actions with a clear timeline and penalties for failure to comply.

This process holds the violator accountable from the beginning, prevents further harm, and facilitates remediation.

For example, in 2021, an industrial plant in Ghana was forced to install new waste treatment units after a structured EPA response, leading to improved compliance and environmental recovery.

Question 3

Develop a corrective action plan for a manufacturing plant that emits gaseous waste above acceptable environmental limits. In your response, explain the steps to identify the source of the problem, reduce emissions, and prevent it from happening again. (9 marks)

Marking Scheme

Component	Marks	Specific Details Expected
1. **Identifying the Source of the Problem**	2	– **1 mark**: Mentions conducting an audit, inspection, or monitoring to trace emission sources. *Example: Using gas sensors or checking combustion equipment.* – **1 mark**: Notes identifying faulty equipment, poor fuel mix, or leakages.
2. **Emission Reduction Measures (Short-Term Actions)**	2	– **1 mark**: Suggests practical reduction methods like adjusting temperature, fuel mix, or operating conditions. *Example: Reducing burner temperature to limit NOx.* – **1 mark**: Recommends installing or upgrading control equipment like scrubbers, filters, or catalytic converters.
3. **Long-Term Prevention Strategy**	3	– **1 mark**: Includes staff training or awareness of environmental standards. – **1 mark**: Mentions regular monitoring, maintenance, or SOP development. – **1 mark**: References collaboration with regulatory bodies (e.g., EPA) or compliance programmes.
4. **Evaluation and Continuous Improvement**	2	– **1 mark**: States the need to compare data before and after implementation to assess progress. *Example: Emission logs or data analysis.* – **1 mark**: Suggests revising or updating the plan based on performance and new technologies.

Sample answer

To address excessive gaseous emissions from a manufacturing plant, a structured corrective action plan is necessary. The plan should focus on identifying the source, reducing emissions, and preventing future violations.

1. **Identify the Source of the Problem**

   a. Conduct an **environmental audit** to assess where emissions are coming from (e.g., boilers, chemical processes, combustion).

   b. Use **gas detection sensors** and **emission monitoring equipment** to measure the type and amount of gases (e.g., CO_2, NOx, SO_2).

   c. Check for **equipment malfunctions**, **leaks**, or improper use of raw materials.

   Example: Detecting that outdated burners are releasing high NOx gases due to incomplete combustion.

2. **Implement Immediate Reduction Measures**
    a. Adjust production settings to operate within safe limits (e.g., control temperature or fuel mix).
    b. Install or upgrade **air pollution control devices** such as:
        i. Scrubbers (to remove harmful gases)
        ii. Filters or **electrostatic precipitators** (to trap particles)
        iii. Catalytic converters (to reduce toxic emissions)
    c. Use **eco-friendly raw materials** or **alternative fuels** if possible.

    Example: Installing wet scrubbers on exhaust stacks to reduce sulphur dioxide emissions.

3. **Develop a Long-Term Prevention Strategy**
    a. Train staff on **environmental compliance** and **sustainable operation practices**.
    b. Set up a **regular monitoring and maintenance schedule** for emission-related equipment.
    c. Develop and enforce **Standard Operating Procedures (SOPs)** for safe handling and processing.
    d. Work with the **Environmental Protection Agency (EPA)** or local authorities to ensure standards are met.

    Example: Conducting monthly emissions checks and keeping a compliance log.

4. **Evaluate and Adjust the Plan**
    a. After implementation, compare emission levels before and after corrective action.
    b. Adjust equipment or processes if targets are not met.
    c. Update the plan as needed based on feedback and technological improvements.

Conclusion

Monitoring, training, and equipment upgrades are essential steps to ensure sustainable manufacturing.

WEEK 24

Question 1

In the manufacturing process, both quality assurance (QA) and quality control (QC) are important for maintaining product quality. Analyse how QA and QC differ in their roles. Then, create a table that clearly compares and contrasts three (3) key differences between quality assurance and quality control in terms of when they occur in the product lifecycle, what they focus on, and how they are implemented. Evaluate the role of quality control in enhancing manufacturing efficiency and product reliability. (10 marks)

Marking scheme

Component	Marks	Details Required
1. Introduction/Explanation of QA vs QC	2	1 mark: Clearly explains the purpose of QA (e.g., preventing defects by improving the process). 1 mark: Clearly explains the purpose of QC (e.g., detecting defects in the final product).
2. Table Format and Organisation	1	1 mark: Uses a clear and correct table format for comparison (headings, rows, logical structure).
3. Comparison 1 – When it occurs	2	1 mark: QA is correctly identified as occurring before/during production. 1 mark: QC is correctly identified as occurring after production.
4. Comparison 2 – Focus of each	2	1 mark: QA focuses on process improvement/ prevention. 1 mark: QC focuses on product inspection/defect detection.
5. Comparison 3 Implementation methods	2	1 mark: QA methods include audits, procedures, training, documentation. 1 mark: QC methods include testing, inspection, measurements.
6. Conclusion/Summary	1	1 mark: Presents a clear concluding sentence that reinforces the difference and importance of both QA and QC. (Award if well stated.)

Sample answer

Quality Assurance (QA) and **Quality Control (QC)** are two different approaches used in manufacturing to ensure that products meet required quality standards. QA focuses on preventing defects by improving the process, while QC focuses on detecting defects in the final product. Both are essential but serve different purposes and occur at different stages in the product lifecycle. QA and QC work together to ensure that manufacturing processes produce reliable, high-quality products. QA builds quality into the process, while QC ensures that the end product meets specifications. Both are important for customer satisfaction and compliance with industry standards.

Comparison Table

Aspect	Quality Assurance (QA)	Quality Control (QC)
When it occurs	Before and during production (planning and process setup stages)	After production (during final inspection and testing)
What it focuses on	Preventing defects by improving processes and systems	Detecting and fixing defects in finished products
How it is implemented	Through standard procedures, training, audits, and documentation	Through inspection, testing, measurements, and rejection of bad items

Question 2

In a manufacturing company, sampling is used to check product quality without testing every item. Analyse how different sampling methods such as random sampling, systematic sampling, and stratified sampling can affect the results of quality control. In your response, explain how the sampling method chosen can influence how accurate the quality check is, how easily defects are detected, and how decisions are made. (10 marks)

Marking guide scheme for question 2 (Total 10 marks)

Component	Marks	Specific Answers Expected
1. Explanation of Random Sampling	2	- 1 mark: Defines random sampling (e.g., every product has an equal chance of being chosen). Example: Selecting screws randomly throughout the day. - 1 mark: Explains its impact (e.g., unbiased but may miss clustered defects).
2. Explanation of Systematic Sampling	2	- 1 mark: Defines systematic sampling (e.g., selecting at fixed intervals like every 10th item). Example: Checking every 20th bottle on a line. - 1 mark: Explains its risk and benefit (e.g., efficient, but might miss patterned defects).
3. Explanation of Stratified Sampling	2	- 1 mark: Defines stratified sampling (e.g., dividing batch into groups and sampling from each). Example: Sampling from different shifts or machines. - 1 mark: Explains advantage (e.g., very accurate, detects group-specific defects).
4. Comparative Analysis Across All Methods	2	- 1 mark: Clearly compares how each method affects accuracy or defect detection. Example: Stratified is most accurate for detecting source-specific defects. - 1 mark: Explains impact on decision-making (e.g., wrong sampling can lead to missed problems or poor action).
5. Conclusion and Organisation	2	- 1 mark: Logical conclusion summarising how sampling methods affect QC outcomes. Example: Choosing the right sampling method improves quality decisions. - 1 mark: Well-organised, uses correct terminology and examples throughout.

Model Answer

In manufacturing, sampling is used in quality control to inspect a portion of products rather than every single item. The method of sampling chosen can significantly influence the accuracy of results, the ability to detect defects, and the quality of decisions made.

1. **Random Sampling**

In **random sampling**, each product in the batch has an equal chance of being selected. This method reduces bias and gives a fair representation of the entire production.

- Accuracy: Generally high if the sample is large and truly random.
- Defect Detection: May miss patterns of defects if defects occur in clusters (e.g., one specific shift or machine).
- Decision Impact: Reliable for general trends but may not catch isolated or repeating problems.

Example: Selecting 10 screws from various boxes randomly throughout the day.

2. **Systematic Sampling**

In **systematic sampling**, products are selected at regular intervals (e.g., every 20th item off the production line).

- **Accuracy**: Can be accurate if there is no hidden pattern in the defects.
- **Defect Detection**: Might miss defects if they appear between the chosen intervals.
- **Decision Impact**: Useful for detecting long-term drift or gradual changes but risky if defect patterns align with sampling intervals.

Example: Checking every 10th bottle on a filling line.

3. **Stratified Sampling**

In **stratified sampling**, the batch is divided into groups (or strata) such as shifts, machines, or product types, and samples are taken from each group.

- **Accuracy**: Very high because it ensures all sub-groups are represented.
- **Defect Detection**: Effective in identifying problems that happen only under certain conditions (e.g., one machine or one shift).
- **Decision Impact**: Supports more targeted decisions by revealing the source of the defect.

Example: Sampling 5 items each from machines A, B, and C during morning, afternoon, and night shifts.

Conclusion

The sampling method used in quality control influences whether defects are caught early or missed. Random sampling is fair and unbiased, systematic is efficient but can be risky, and stratified sampling offers the best chance of identifying where and when defects occur. Choosing the right sampling method helps ensure accurate quality checks and better decisions for improving production.

Question 3

In manufacturing, companies aim to keep product quality consistent. Using your understanding of standard deviation:

a. Explain how standard deviation can be used to measure the consistency of product quality.

b. Use a specific product (e.g., bolts, rods, screws, bottles) as an example.

c. Compare two situations: one with low standard deviation and one with high standard deviation.

d. Explain what these differences mean for quality control in the production process. (10 marks)

Marking Scheme

Component	Marks	Details (What to look for specifically)
1. **Definition of Standard Deviation**	**2 marks**	**- 1 mark:** States that SD shows how much individual values differ from the average (mean). **- 1 mark:** Notes that SD measures variability or spread in a dataset.
2. **Role in Quality Consistency**	**2 marks**	**- 1 mark:** Explains that **low SD** means the product measurements are close to the average — indicating consistency in quality. **- 1 mark:** Explains that **high SD** means the measurements are spread out — indicating inconsistency and possible quality issues.
3. **Example from Manufacturing**	**2 marks**	**- 1 mark:** Gives a **clear example** of a product with a measurable feature (e.g., bolt, rod, bottle, screw). **- 1 mark:** Mentions the **target specification** (e.g., "10 mm diameter") or standard requirement.
4. **Comparison Using Standard Deviation**	**2 marks**	**- 1 mark:** Provides a **low SD scenario** (e.g., bolt diameters between 9.98 mm and 10.02 mm — shows tight grouping and consistent quality). **- 1 mark:** Provides a **high SD scenario** (e.g., diameters between 9.7 mm and 10.3 mm — shows wide variation and poor consistency).
5. **Conclusion or Interpretation**	**2 marks**	**- 1 mark:** Explains that SD is useful for **monitoring quality** or **process stability.** **- 1 mark:** Mentions how SD can help **identify when to take corrective action** or improve the process.

Sample answer

Standard deviation is a measure of how much individual values in a set differ from the average (mean). In manufacturing, it tells us how consistent the product quality is. Standard deviation helps manufacturers know how stable and reliable their processes are. A small standard deviation means higher quality and less waste

Low standard deviation means the measurements are close to the average — the products are very consistent.

High standard deviation means there is a wide range of measurements — the products are less consistent, and some may not meet quality standards.

Example:

Let's say a factory produces metal rods that are supposed to be 10 mm in diameter.

In Factory A, most rods measure between 9.98 mm and 10.02 mm. The standard deviation is small. This means the production is consistent, and most rods are very close to the target size.

In Factory B, rod diameters range between 9.7 mm and 10.3 mm. The standard deviation is large. This means the product quality is inconsistent — some rods may be too thick or too thin for their purpose.

Question 4

You are working in a screw-making company and have been asked to check the quality of the screws being produced. Design a measurement activity for quality control. In your response:

a. Describe the tools you would use to measure the screws.

b. Explain the type of data you would collect.

c. Describe how you would organise and analyse the data to check for consistency or defects. (10 marks)

Marking Scheme (Total: 10 marks)

- **Tools to Measure the Screws [3 marks]**

  1 mark: States a precision tool such as a vernier calliper or micrometre for measuring length/diameter.

  1 mark: Includes a thread gauge for checking thread pitch.

  1 mark: Mentions visual inspection tools (e.g., checklist, magnifier) for detecting physical defects.

- **Type of data to collect [3 marks]**

  1 mark: Clearly identifies quantitative data (length, diameter, thread pitch in mm).

  1 mark: Clearly identifies qualitative data (visual defects, pass/fail status).

  1 mark: Mentions the use of a representative sample (e.g., 10 screws per 100). |

- **Organising and Analysing the Data [4 marks]**

  1 mark: Mentions organising data into a table or spreadsheet with relevant columns.

  2 mark: States use of mean and standard deviation to assess consistency.

  1 mark: Refers to control charts (e.g., X-bar and R charts) for monitoring variation.

  1 mark: Mentions histograms or Pareto charts to visualise measurement spread or defects.

Sample answer

To check the quality of screws in a screw-making company, a well-planned measurement activity must be carried out. This includes selecting the right tools, collecting relevant data, and analysing the data to ensure product consistency and detect defects.

1. **Tools to Measure the Screws (3 marks)**

The following tools should be used to measure the screws accurately:

a. Vernier calliper or micrometre – for measuring the **diameter** and **length** of the screws with high precision.

b. Thread gauge – to verify the **thread pitch**, ensuring it matches the design specification.

c. Visual inspection tools, such as a **checklist** or **magnifying lens**, – to detect **physical defects** like bent shafts, damaged threads, or uneven heads.

2. **Type of Data to Collect (3 marks)**

Both **quantitative and qualitative data** are essential for quality assessment:

a. Quantitative data:

- **Length** of each screw (in millimetres)
- **Diameter** of each screw (in millimetres)
- **Thread pitch** (distance between screw threads)

b. Qualitative data:

- **Visual defects** such as scratches, deformed heads, missing threads
- **Pass/Fail status** based on conformity to standards

A **representative sample** from the production line, such as 10 screws per 100 produced, should be measured and recorded.

3. **Organising and Analysing the Data (4 marks)**

a. **Data Organisation**:

- All measurements and inspection results should be recorded in a **table or spreadsheet**.
- Key columns should include: Screw ID, Length, Diameter, Thread Pitch, Visual Defects, and Pass/Fail result.

b. **Data Analysis**:

- Use statistical tools to calculate the **mean** and **standard deviation** of length and diameter to determine how consistent the production is.
- Create **control charts** (such as X-bar and R charts) to track process variation over time.
- Use a **histogram** to show the spread of screw sizes and identify clustering or outliers.
- Construct a **Pareto chart** to identify the most frequent types of defects for targeted improvements.

REFERENCE

1. Adams, P. (2018). Materials Science for Engineers. London: TechBooks Publishing.
2. AGC (2024). Semiconductor, a small but significant presence that supports everyday lives. [Available online] https://www.agc.com/en/everyday/semiconductor/semiconductor.html,
3. Alamy (2009). Computer chips on a circuit board. [Available online] https://www.alamy.com/stock-photo-computer-chips-on-a-circuit-board-94836340.html?imageid=4986103D-5BF7-4C43-A261-B21D81F5DA2B&p=279792&pn=1&searchId=df510f891f96eadc054c8518c978073c&searchtype=0
4. Alomarah, A., Ruan, D., Masood, S., & Gao, S. (2019). Compressive properties of a novel additively manufactured 3D auxetic structure. Smart Materials and Structures, 28(8), 085019.
5. Al-Rukaibawi, L. S., & Károlyi, G. (2023). Through-thickness distribution of bamboo tensile strength parallel to fibres. SN Applised Sciences, 5(7), 174.
6. Ashby, M. F., & Johnson, K. (2013). Materials and design: the art and science of material selection in product design. Butterworth-Heinemann.
7. Ashby, M. F., & Jones, D. R. H. (2015). Engineering Materials 1: An Introduction to Properties, Applications, and Design. Elsevier.
8. Awalluddin, D., Ariffin, M. A. M., Osman, M. H., Hussin, M. W., Ismail, M. A., Lee, H. S., & Lim, N. H. A. S. (2017). Mechanical properties of different bamboo species. In MATEC web of conferences (Vol. 138, p. 01024). EDP Sciences.
9. Brennan, K. F. (2018). Introduction to semiconductor materials. Cambridge University Press.
10. Brown, L., & Green, T. (2015). Engineering Materials and Their Properties. Boston: Academic Press.
11. Büttgenbach, S., Constantinou, I., Dietzel, A., Leester-Schädel, M. (2020). Piezoresistive Pressure Sensors. In: Case Studies in Micromechatronics. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-61320-7_2
12. Cadu, S. (2018). General information PCM, Iolitec GmbH. [Available online] https://iolitec.de/node/608
13. Calderone L. (2018). 3D printing for surgical procedures. [Available online] https://www.manufacturingtomorrow.com/article/2018/03/3d-printing-for-surgical-procedures/11119/
14. Callister, W. D., & Rathish, D. G. (2020). Materials Science and Engineering: An Introduction. New York: Wiley.
15. Callister, W. D., & Rethwisch, D. G. (2020). Materials Science and Engineering: An Introduction, 9th Edition, John Wiley & Sons.
16. Casini, M. (2016). Smart Buildings: Advanced Materials and Nanotechnology. Woodhead Publishing.
17. Chen, H., Cheng, H., Wang, G., Yu, Z., & Shi, S. Q. (2015). Tensile properties of bamboo in different sizes. Journal of Wood Science, 61(6), 552-561.
18. Chen, M., Dai, C., Liu, R., Lian, C., Yuan, J., Fang, C., & Fei, B. (2020). Influence of cell wall structure on the fracture behaviour of bamboo (Phyllostachys edulis) fibres. Industrial Crops and Products, 155, 112787.
19. Chua, C. K., & Leong, K. F. (2014). 3D Printing and Additive Manufacturing: Principles and Applications. World Scientific Publishing.
20. Chua, C. K., & Leong, K. F. (2017). 3D Printing and Additive Manufacturing: Principles and Applications (5th ed.). World Scientific.
21. Courtney, T. H. (2013). Mechanical Behaviour of Materials. Waveland Press.

22. Diegel, O., Nordin, A., & Motte, D. (2020). A practical guide to design for additive manufacturing (p. 226). New York, NY, USA: Springer.
23. Dixon, P. G., & Gibson, L. J. (2014). "The Structure and Mechanics of Mosco Bamboo Material." Journal of the Royal Society Interface.
24. Dowling, N. E. (2012). Mechanical Behaviour of Materials: Engineering Methods for Deformation, Fracture, and Fatigue. Pearson.
25. Draftings.com.au. (2023). Importance of Accurate Manufacturing Drawings In Product Development. Retrieved from https://draftings.com.au/the-importance-of-accurate-manufacturing-drawings-in-product-development/
26. Drury, B., Padfield, C., Russo, M., Swygart, L., Spalton, O., Froggatt, S., & Mofidi, A. (2023). Assessment of the compression properties of different giant bamboo species for sustainable construction. Sustainability, 15(8), 6472.
27. Elejoste, A., Arevalillo, A., Gabilondo, N., Butron, A., & Pena-Rodriguez, C. (2021). Morphological analysis of several bamboo species with potential structural applications. Polymers, 13(13), 2126.
28. El-Hofy, H. (2018). Fundamentals of machining processes: Conventional and nonconventional processes (3rd ed.). CRC Press.
29. ElProCus – Electronic Projects for Engineering Learners. (2019). Piezoelectric Material: Types, Properties, and Characteristics.
30. Encalada-Dávila, Á., Puruncajas, B., Tutiven, C., & Vidal, Y. (2021). Wind turbine main bearing fault prognosis based solely on scada data. Sensors, 21(6), 2228.
31. Fahim, M., Haris, M., Khan, W., & Zaman, S. (2022). Bamboo as a construction material: prospects and challenges. Advances in Science and Technology. Research Journal, 16(3).
32. García, F. (2020). Bamboo and Sustainable Materials. CRC Press.
33. Gebhardt, A., Kessler, J., & Thurn, L. (2019). Additive Manufacturing: 3D Printing for Prototyping and Manufacturing (2nd ed.). Hanser Publishers.
34. Gibson, I., Rosen, D. W., & Stucker, B. (2015). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing. Springer.
35. Gibson, I., Rosen, D., Stucker, B., & Khorasani, M. (2020). Additive Manufacturing Technologies (3rd ed.). Springer
36. Gibson, I., Rosen, D., Stucker, B., & Khorasani, M. (2021). Additive Manufacturing Technologies (4th ed.). Springer.
37. Gibson, I., Rosen, D.W., & Stucker, B. (2014). Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing (2nd ed.). Springer.
38. Gielis, J. (2015). Bamboo–The plant and its uses. The Journal of the American Bamboo Society, 40.
39. Giesecke, F. E., Mitchell, A., Spencer, H. C., Hill, I. L., Dygdon, J. T., Novak, J. E., Loving, R. O., Lockhart, S., & Johnson, C. M. (2016). Technical Drawing with Engineering Graphics. Peachpit Press.
40. Groover, M. P. (2012). Fundamentals of Modern Manufacturing. Wiley, Hoboken, NJ. Chapters 6–9.
41. Groover, M. P. (2020). Fundamentals of Modern Manufacturing: Materials, Processes, and Systems (7th ed.). Wiley.
42. Groover, M. P. (2020). Fundamentals of Modern Manufacturing (8th ed.). Wiley.
43. Groover, M. P. (2021). Fundamentals of modern manufacturing: Materials, processes, and systems (7th ed., International adaptation). John Wiley & Sons.

44. Halbleiter (2020). Conductors-insulators-semiconductors. [Available online] https://www.halbleiter.org/en/fundamentals/conductors-insulators-semiconductors/
45. Hu, C. (2020). Modern semiconductor devices for integrated circuits. Wiley.
46. Husna, A., Ashrafi, S., Tomal, A. A., Tuli, N. T., & Rashid, A. B. (2024). Recent advancements in stereolithography (SLA) and their optimisation of process parameters for sustainable manufacturing. Hybrid Advances, 100307.
47. Janssen, J. J. A. (2018). Building with Bamboo: A Handbook. Intermediate Technology Publications.
48. Jariwala, D., Marks, T. J., & Hersam, M. C. (2017). Mixed-dimensional van der Waals heterostructures. Nature materials, 16(2), 170-181.
49. John, J., & Smith, A. (2017). Introduction to Material Properties. New York: Manufacturing Press.
50. Kalpakjian, S., & Schmid, S. (2014). Manufacturing Engineering and Technology (7th ed.). Pearson.
51. Kalpakjian, S., & Schmid, S. (2020). Manufacturing Engineering & Technology (8th ed.). Pearson.
52. Kalpakjian, S., & Schmid, S. R. (2016). Manufacturing Engineering and Technology (7th ed.). Pearson Education.
53. Kelkar, B. U., Shukla, S. R., Nagraik, P., & Paul, B. N. (2023). Structural bamboo composites: a review of processing, factors affecting properties and recent advances. Advances in Bamboo Science, 3, 100026.
54. Khorasani, M., Loy, J., Ghasemi, A. H., Sharabian, E., Leary, M., Mirafsal, H., ... & Gibson, I. (2022). A review of Industry 4.0 and additive manufacturing synergy. Rapid Prototyping Journal, 28(8), 1462-1475.
55. Lakkad, S., & Patel, J. (2018). Mechanical Properties of Bamboo. INBAR Technical Report.
56. Liesel, W., & Tang, T. K. H. (2015). Bamboo: The Plant and its Uses. Springer.
57. Liu, T. H., Wen, Y. L., Li, G. Q., & Nie, X. N. (2020). Optimization and Experimental Study of an Intelligent Bamboo-Splitting Machine Charging Manipulator. Journal of Robotics, 2020(1), 4675301.
58. Madsen, D. A., & Madsen, D. P. (2017). Engineering drawing & design (Sixth). Delmar Thompson Learning.
59. Manufacturing-Engineering-Curriculum. (2023). Ghana Education Service.
60. Meviy Europe. (2024). Understanding Technical Drawings for CNC Parts – Cycle 1. Retrieved from [https://de.meviy.misumi-ec.com/info/en/blog-en/design-school-en/
61. Mousavi, S. R., Zamani, M. H., Estaji, S., Tayouri, M. I., Arjmand, M., Jafari, S. H., ... & Khonakdar, H. A. (2022). Mechanical properties of bamboo fibre-reinforced polymer composites: a review of recent case studies. Journal of Materials Science, 57(5), 3143-3167.
62. Mwema, F. M., & Akinlabi, E. T. (2020). Basics of fused deposition modelling (FDM). Fused deposition modelling: strategies for quality enhancement, 1-15.
63. Narayana, K. L., Kannaiah, P., & Venkata Reddy, K. (2009). Machine Drawing (Third, pp. 1–451). New Age International.
64. Neamen, D. (2020). Semiconductor physics and devices (5th ed.). McGraw-Hill.
65. Neupane, P. (2022). Common biomaterials questions. Kathmandu, Nepal. [Available Online] https://www.pravhakar.com.np/2022/07/common-biomaterials-question.html.Top of Form
66. Oberg, E., Jones, F. D., Horton, H. L., Ryffel, H. H., & McCauley, C. J. (Eds.). (2020). Machinery's handbook (31st ed.). Industrial Press.
67. Omnifab. (2024). Manufacturing drawing: definition, role and types. Retrieved from https://omnifab.ca/en/manufacturing-drawing/

68. Pacheco-Torgal, F. et al. (2013). Nanotechnology in Eco-Efficient Construction. Woodhead Publishing.

69. Prianto, E., & Pramono, H. S. (2021). IOT-based 3D printer development for Student Competence Improvement. In Journal of Physics: Conference Series (Vol. 2111, No. 1, p. 012002). IOP Publishing.

70. Rao, P. N. (2018). Manufacturing Technology: Metal Cutting and Machine Tools (4th ed.). McGraw-Hill Education.

71. Rao, P. N. (2018). Manufacturing Technology: Metal Cutting and Machine Tools (4th ed.). McGraw-Hill Education.

72. Rashid, A. B., Haque, M., Islam, S. M., & Labib, K. R. U. (2024). Nanotechnology-enhanced fibre-reinforced polymer composites: Recent advancements on processing techniques and applications. Heliyon, 10(2).

73. Ratner, B. D., Hoffman, A. S., Schoen, F. J., Lemons, J. E., Wagner, W. R., Sakiyama-Elbert, S. E., ... & Yaszemski, M. J. (2020). Introduction—biomaterials science: an evolving, multidisciplinary endeavour. Biomaterials Science: An Introduction to Materials in Medicine; Wagner, W., Sakiyama-Elbert, S., Zhang, G., Yaszemski, M., Eds, 3-19.

74. Rieder, H., Dillhöfer, A., Spies, M., Bamberg, J., & Hess, T. (2014, October). Online monitoring of additive manufacturing processes using ultrasound. In Proceedings of the 11th European Conference on Non-destructive testing (Vol. 1, pp. 2194-2201).

75. Sabner, S. (2020). Fundamentals of Technical Drawings - Essential Information. Retrieved from https://sabner.com/fundamentals-of-technical-drawings/

76. Sekmen, K., Rehbein, T., Johlits, M., Lion, A., & Constantinescu, A. (2024). Thermal analysis and shrinkage characterisation of the photopolymers for DLP additive manufacturing processes. Continuum Mechanics and Thermodynamics, 36(2), 351-368.

77. Shakor, P., Nejadi, S., Paul, G., & Malek, S. (2019). Review of emerging additive manufacturing technologies in 3D printing of cementitious materials in the construction industry. Frontiers in Built Environment, 4, 85.

78. Simpson, T.W., Yu, J., & Jiao, J. (2020). Design for Additive Manufacturing: Guidelines and Applications for Industrial 3D Printing. CRC Press.

79. Singh, L. P., & Singh, H. (2021). Engineering Drawing. Cambridge University Press.

80. Smith, G. T. (2016). “Cutting Tool Technology: Industrial Handbook.” Elsevier

81. Smith, W. F., & Hashemi, J. (2018). Foundations of Materials Science and Engineering. McGraw-Hill Education.

82. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). Advanced Engineering Materials and Modelling. John Wiley & Sons.

83. Trujillo, D. J., & Lopez, L. F. (2020). Bamboo material characterisation. In Nonconventional and vernacular construction materials (pp. 491-520). Woodhead Publishing.

84. Walker, J. R., & Dixon, B. (2021). Machining Fundamentals (11th ed.). Goodheart-Willcox.

85. Wang, L., Shang, S., Shang, R., Tai, S., Liu, S., & Lu, B. (2024). Non-heat source forming technology of binder jetting metal powder and its post-treatment process. The International Journal of Advanced Manufacturing Technology, 132(3), 2077-2089.

86. Wen, M., Afshar, Y., Elliott, R. S., & Tadmor, E. B. (2022). KLIFF: A framework to develop physics-based and machine learning interatomic potentials. Computer Physics Communications, 272, 108218.

87. Wikipedia contributors. (2024). Engineering drawing. In Wikipedia, The Free Encyclopaedia. Retrieved from https://en.wikipedia.org/wiki/Engineering_drawing

88. Wikipedia contributors. (2024). Geometric dimensioning and tolerancing. In Wikipedia, The Free Encyclopaedia. Retrieved from https://en.wikipedia.org/wiki/Geometric_dimensioning_and_tolerancing

89. Zhang, B. T., Zheng, X., Li, H. F., & Lin, J. M. (2013). Application of carbon-based nanomaterials in sample preparation: A review. Analytica chimica acta, 784, 1-17.

90. Zhang, Y., Xu, W. Y., Shao, J. F., Zhao, H. B., & Wang, W. (2015). Experimental investigation of creep behaviour of clastic rock in Xiangjiaba Hydropower Project. Water Science and Engineering, 8(1), 55-62.

91. Živanović, S., Tabaković, S., & Randjelović, S. (2019). Rapid prototyping of art sculptural shapes according to the sample. Advanced Technologies and Materials, 44(1), 27-32.