Pearson
BTEC

Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining)
(Development Technical Knowledge)

Specification

BTEC Specialist qualification

First registration January 2023

Issue 3

About Pearson

We are the world's leading learning company operating in countries all around the world. We provide content, assessment and digital services to learners, educational institutions, employers, governments and other partners globally. We are committed to helping equip learners with the skills they need to enhance their employability prospects and to succeed in the changing world of work. We believe that wherever learning flourishes so do people.

This specification is Issue 3. Key changes are summarised on the next page. We will inform centres of any changes to this issue. The latest issue can be found on our website.

References to third-party material made in this specification are made in good faith. Pearson does not endorse, approve or accept responsibility for the content of materials, which may be subject to change, or any opinions expressed therein. (Material may include textbooks, journals, magazines and other publications and websites).

All information in this specification is correct at time of publication.

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Summary of changes to Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge) Specification Issue 3

Summary of changes made between previous issue and this issue	**Section**	**Page number**
Updated wording from, 'For assessment criteria 2.10, learners must use **three** different types of material' to, 'For assessment criteria 2.10, learners must show they can **use three different** work holding devices'.	Essential information for tutors and assessors	32
Re-formatting of the section, 'Learning outcome 2: Understand how to prepare for advanced manual turning operations' Updated wording of 'Types of tooling required' to include reference to work holding devices.	Unit 6: Advanced Manual Turning Techniques	78
Re-formatting of the section, 'Learning outcome 2: Understand how to prepare for advanced manual milling operations'	Unit 7: Advanced Manual Milling Techniques	86
Numbering of Pass assessment criteria updated, P3 to be changed to P2, P4 to P3, P5 to P4, P6 to P5.	Unit 15: Engineering Inspection and Quality Control	158
Missing assessment criteria D1 added to the assessment and grading grid.	Unit 17: Computer Aided Manufacturing	178
Updating of Assessment table to include criteria for, P7, M4, D4.	Unit 29: Industry 4.0	318

If you need further information on these changes or what they mean, please contact us via our website at: qualifications.pearson.com/en/support/contact-us.html.

Contents

1 Introducing the qualification

What are BTEC Specialist qualifications?

BTEC Specialist qualifications are work-related qualifications available from Entry to Level 3. The qualifications put learning into the context of the world of work, giving learners the opportunity to apply their research, skills and knowledge in relevant and realistic work contexts. This applied, practical approach means learners build the knowledge, understanding and skills they need for career progression or further study.

Sizes of BTEC Specialist qualifications

For all regulated qualifications, Pearson specifies a total estimated number of hours that learners will need to complete in order to show achievement for the qualification – this is the Total Qualification Time (TQT). The TQT value indicates the size of a qualification.

Within the TQT, Pearson identifies the number of Guided Learning Hours (GLH) we estimate a centre delivering a qualification might provide. Guided learning means activities, such as lessons, tutorials, online instruction, supervised study and giving feedback on performance, that directly involve tutors and assessors in teaching, supervising and invigilating learners. It also includes the time required for learners to complete external assessment under examination or supervised conditions.

In addition to guided learning, other required learning directed by tutors or assessors includes private study, preparation for assessment and undertaking assessment when not under supervision, such as preparatory reading, revision and independent research.

As well as TQT and GLH, qualifications can also have a credit value – equal to one tenth of the TQT, rounded to the nearest whole number.

TQT and credit values are assigned after consultation with the employers and training providers delivering the qualifications.

Qualification purpose

The Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge) is for learners who are working in, or are intending to work in, the engineering sector.

The Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge) is suitable for learners to:

- achieve a qualification to prepare for employment
- study mandatory units, including the following topics:
  - communication for engineering technicians
  - mathematics for engineering technicians
  - health and safety in the engineering workplace
- develop the knowledge, understanding and skills required in Apprenticeship Frameworks and Standards in England, Wales and Northern Ireland
- develop a range of positive attitudes and professional attributes that support successful performance in the manufacturing engineering work environment
- achieve a nationally-recognised Level 3 qualification
- develop own personal growth and engagement in learning.

Purpose of the Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge)

The Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge) has been designed to meet the minimum requirements of the Development phase of many of the Trailblazer Standards in Engineering. Learners will complete a number of mandatory and additional optional units to allow employers to select learner requirements for entering the workplace. The achievement of this qualification is part of the gateway process towards End-Point Assessment and contributes to learners achieving their Apprenticeship Standard.

Industry support and recognition

These qualifications are supported by the Engineering Technician Apprenticeship Group for Machining Technicians led by GTA England. The employers include Jaguar Land Rover, Rolls Royce, JCB, Babcock

Funding

Qualifications eligible and funded for post-16 year olds can be found on the funding Hub. The Apprenticeship funding rules can be found at www.gov.uk

2 Qualification summary and key information

Qualification title	**Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge)**
Qualification Number (QN)	610/1771/1
Regulation start date	14/12/2022
Operational start date	01/01/2023
Approved age ranges	16–18 19+ Please note that sector-specific requirements or regulations may prevent learners of a particular age from taking this qualification. Please refer to *Section 7: Recognising prior learning and achievement.*
Total Qualification Time (TQT)	980
Guided Learning Hours (GLH)	720
Assessment	Internal assessment.
Grading information	Unit 1 is a competency unit and graded Pass only. Units 2-34 are graded Pass/Merit/Distinction. Please refer to *Section 12: Understanding the qualification grade* for further information on claiming the qualification grade.

Qualification title	Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge)
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification. In order to optimise success. learners will typically have four GCSEs at Grade C/4 or equivalent, including Mathematics, English and a Science. Where this qualification is offered as part of an Apprenticeship, employers who recruit candidates without English or Mathematics at Grade C/4 or above must ensure that a candidate achieves this standard before completing the Apprenticeship. Centres must also follow the *Pearson Access and Recruitment policy* (see *Section 6: Access to qualifications*).

3 Qualification structure

Pearson BTEC Level 3 Diploma in Advanced Manufacturing Engineering (Machining) (Development Technical Knowledge)

The requirements outlined in the table below must be met for Pearson to award the qualification.

Minimum number of mandatory units that must be achieved	5
Minimum number of optional units must be achieved *A minimum 3 optional units must come from Group A* *A minimum 2 optional units must come from Group B* *A minimum 1 optional unit must come from Group C*	6

Unit number	Mandatory units	Level	Guided learning hours
1	General Machining, Fitting and Assembly Applications	2	120
2	Health and Safety in the Engineering Workplace	3	60
3	Communications for Engineering Technicians	3	60
4	Mathematics for Engineering Technicians	3	60
5	Properties and Applications of Engineering Materials	3	60

Unit number	Optional units – Group A	Level	Guided learning hours
6	Advanced Manual Turning Techniques Barred combination with *Unit 8: Advanced Milling and Turning Techniques*	3	60
7	Advanced Manual Milling Techniques Barred combination with *Unit 8: Advanced Milling and Turning Techniques*	3	60
8	Advanced Manual Milling and Turning Techniques Barred combination with *Unit 6: Advanced Manual Turning Techniques* and *Unit 7: Advanced Manual Milling Techniques*	3	60
9	CNC Programming	3	60
10	Advanced CNC Turning Techniques Barred combination with *Unit 12: Applications of Computer Numerical Control in Engineering*	3	60
11	Advanced CNC Milling Techniques Barred combination with *Unit 12: Applications of Computer Numerical Control in Engineering*	3	60
12	Applications of Computer Numerical Control in Engineering Barred combination with *Unit 10: Advanced CNC Turning Techniques and Unit 11: Advanced CNC Milling Techniques*	3	60
13	Specialist Machining	3	60
14	Precision Grinding Techniques	3	60
15	Engineering Inspection and Quality Control	3	60
16	Engineering Secondary and Finishing Techniques	3	60
17	Computer Aided Manufacturing	3	60
18	Setting and Proving Secondary Processing Machines	3	60

Unit number	Optional units – Group B	Level	Guided learning hours
19	Computer Aided Drafting in Engineering	3	60
20	Further Engineering Mathematics	3	60
21	Organisational Efficiency and Improvement	3	60
22	Manufacturing Planning	3	60
23	Mechanical Measurement and Inspection Techniques	3	60
24	Engineering Design	3	60
25	Engineering Drawing for Technicians	3	60
26	Mechanical Principles of Engineering Systems	3	60
27	Electrical and Electronic Principles in Engineering	3	60
Unit number	**Optional units – Group C**	**Level**	**Guided learning hours**
28	Additive Manufacturing Processes	3	60
29	Industry 4.0	3	60
30	Environmental Engineering and Sustainability	3	60
31	Simulation and Digital Twinning	3	60
32	Cyber Security in Engineering	3	60
33	Data Analytics/Big Data	3	60
34	Autonomous Systems	3	60

4 Assessment requirements

The table below gives a summary of the assessment methods used in the qualification.

Units	Assessment methods
All units	Internal assessment (centred-devised assessment)

Language of assessment

Learners must use English only during the assessment of this qualification.

A learner taking the qualification(s) may be assessed in British Sign Language where it is permitted for the purpose of reasonable adjustment.

Further information on the use of language in qualifications is available in our *Use of languages in qualifications policy*, available on our website, qualifications.pearson.com.

Internal assessment

Internally-assessed units are subject to standards verification. This means that centres set and mark the final summative assessment for each unit, using the examples and support that Pearson provides.

To pass each internally-assessed unit, learners must:

- achieve all the specified learning outcomes
- satisfy all the assessment criteria by providing sufficient and valid evidence for each criterion
- prove that the evidence is their own.

Centres must ensure:

- assessment is carried out by assessors with relevant expertise in both the occupational area and assessment. For the occupational area, this can be evidenced by a relevant qualification or current (within three years) occupational experience that is at an equivalent level or higher than this qualification. Assessment expertise can be evidenced by qualification in teaching or assessing and/or internal quality assurance or current (within three years) experience of assessing or internal verification
- internal verification systems are in place to ensure the quality and authenticity of learners' work, as well as the accuracy and consistency of assessment.

Learners who do not successfully pass an assignment are allowed to resubmit evidence for the assignment or to retake another assignment.

Assessment of knowledge units

To pass each knowledge unit, learners must independently complete assignment(s) that show that the learning outcomes and assessment criteria for the unit have been met.

Format of assignments for knowledge units:

- all learning outcomes and assessment criteria must be covered
- assignments can include both practical and written tasks
- assignments are independently completed as a distinct activity after the required teaching has taken place
- the brief is issued to learners with a defined start date, a completion date and clear requirements for the evidence they are required to produce
- all or parts of units can be combined into a single assignment.

Each unit contains suggested tasks that centres can use to form the basis of assignments for learners to complete. It is expected that centres will contextualise these and ensure that the final version is checked by their internal verifier.

Assessment of skills units

To pass each skills unit, learners must:

- gather evidence from their course in a portfolio showing that they have met the required standard specified in the learning outcomes, assessment criteria and Pearson's quality assurance arrangements
- have an assessment record that shows how each individual assessment criterion has been met. The assessment record should be cross-referenced to the evidence provided. The assessment record should include details of the type of evidence and the date of assessment. Suitable centre documentation should be used to form an assessment record.

Learners can use one piece of evidence to demonstrate their knowledge, skills and understanding across different assessment criteria and/or across different units. The evidence provided for each unit must reference clearly the unit that is being assessed and learners should be encouraged to signpost evidence. Evidence must be available to the assessor, the internal verifier and the Pearson Standards Verifier.

Examples of forms of evidence include observation records, reflective accounts, witness testimony and products of learner work.

Any specific evidence requirements for a unit are given in the unit's *Assessment* section.

5 Centre recognition and approval

Centres must have approval prior to delivering or assessing any of the units in this qualification.

Centres that have not previously offered BTEC Specialist qualifications need to apply for, and be granted, centre recognition as part of the process for approval to offer individual qualifications.

Existing centres will be given 'automatic approval' for a new qualification if they are already approved for a qualification that is being replaced by a new qualification and the conditions for automatic approval are met.

Guidance on seeking approval to deliver BTEC qualifications is given on our website.

Approvals agreement

All centres are required to enter into an approval agreement with Pearson, in which the head of centre or principal agrees to meet all the requirements of the qualification specification and to comply with the policies, procedures, codes of practice and regulations of Pearson and relevant regulatory bodies. If centres do not comply with the agreement, this could result in the suspension of certification or withdrawal of centre or qualification approval.

Centre resource requirements

As part of the approval process, centres must make sure that the resource requirements below are in place before offering the qualification:

- appropriate physical resources (for example IT, learning materials, teaching rooms) to support the delivery and assessment of the qualification
- suitable staff for delivering and assessing the qualification (see *Section 4: Assessment requirements*)
- systems to ensure continuing professional development (CPD) for staff delivering and assessing the qualification
- health and safety policies that relate to the use of equipment by learners
- internal verification systems and procedures (see *Section 4: Assessment requirements*)
- any unit-specific resources stated in individual units.

6 Access to qualifications

Access to qualifications for learners with disabilities or specific needs

Equality and fairness are central to our work. Our *Equality, diversity and inclusion policy* requires all learners to have equal opportunity to access our qualifications and assessments, and that our qualifications are awarded in a way that is fair to every learner.

We are committed to making sure that:

- learners with a protected characteristic (as defined by the Equality Act 2010) are not, when they are taking one of our qualifications, disadvantaged in comparison to learners who do not share that characteristic
- all learners achieve the recognition they deserve from their qualification and that this achievement can be compared fairly to the achievement of their peers.

For learners with disabilities and specific needs, the assessment of their potential to achieve the qualification must identify, where appropriate, the support that will be made available to them during delivery and assessment of the qualification.

Centres must deliver the qualification in accordance with current equality legislation. For full details of the Equality Act 2010, please visit www.legislation.gov.uk

Reasonable adjustments and special consideration

Centres are permitted to make adjustments to assessment to take account of the needs of individual learners. Any reasonable adjustment must reflect the normal learning or working practice of a learner in a centre or a learner working in the occupational area.

Centres cannot apply their own special consideration – applications for special consideration must be made to Pearson and can be made on a case-by-case basis only.

Centres must follow the guidance in the Pearson document Guidance for reasonable adjustments and special consideration in vocational internally assessed units.

7 Recognising prior learning and achievement

Recognition of Prior Learning (RPL) considers whether a learner can demonstrate that they can meet the assessment requirements for a unit through knowledge, understanding or skills they already possess and so do not need to develop through a course of learning.

Pearson encourages centres to recognise learners' previous achievements and experiences in and outside the workplace, as well as in the classroom. RPL provides a route for the recognition of the achievements resulting from continuous learning.

RPL enables recognition of achievement from a range of activities using any valid assessment methodology. If the assessment requirements of a given unit or qualification have been met, the use of RPL is acceptable for accrediting a unit, units or a whole qualification. Evidence of learning must be sufficient, reliable and valid.

Further guidance is available in our policy document *Recognition of prior learning policy and process*, available on our website.

8 Quality assurance of centres

For the qualification in this specification, the Pearson quality assurance model will consist of the following processes.

Centres will receive at least one visit from our Standards Verifier, followed by ongoing support and development. This may result in more visits or remote support, as required to complete standards verification. The exact frequency and duration of Standards Verifier visits/remote sampling will reflect the level of risk associated with a programme, taking account of the:

- number of assessment sites
- number and throughput of learners
- number and turnover of assessors
- number and turnover of internal verifiers
- amount of previous experience of delivery.

Following registration, centres will be given further quality assurance and sampling guidance.

For further details, please see the work-based learning quality assurance handbooks, available in the support section of our website:

- *Pearson centre guide to quality assurance – NVQs/SVQs and competence-based qualifications*
- *Pearson delivery guidance and quality assurance requirements – NVQs/SVQs*; *competence-based qualifications and BTEC Specialist qualifications.*

9 Units

This section of the specification contains the units that form the assessment for the qualification.

For explanation of the terms within the units, please refer to *Section 14: Glossary.*

It is compulsory for learners to meet the learning outcomes and the assessment criteria to achieve a Pass. Content is compulsory unless it is provided as an example and is therefore marked 'e.g.'. All compulsory content must be delivered, but assessments may not cover all content.

Where legislation is included in delivery and assessment, centres must ensure that it is current and up to date.

Unit 1: General Machining, Fitting and Assembly Applications

Level:	2
Unit type:	Mandatory
Guided learning hours:	120

Unit Introduction

This unit covers the skills and knowledge needed to demonstrate the competences required for general machining, fitting and assembly applications. It will prepare the learner for entry into the engineering or manufacturing sector, creating a progression between education and employment, or it will provide a basis for the development of additional skills and occupational competences.

Evidence from this unit will generally come from a work environment, where learners will have opportunities to demonstrate a broad range of basic machining, fitting and assembly competences as part of their job. However, it is also acceptable for evidence to come from simulated activities where this is not possible. This may be from a training provider/college setting, or a sheltered environment in the workplace away from live engineering/machining activities or a production line. This could be due to health and safety reasons as learners develop their competence, or where there is a lack of opportunity to generate this evidence during the learner's normal working tasks.
If simulation is used, it must be under realistic conditions, i.e., using similar materials and equipment that they would encounter in the workplace.

Learning outcomes and assessment criteria

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
1	Know how to carry out general machining, fitting and assembly applications	1.1	Describe the health and safety requirements, safe working practices and procedures required for the machining, fitting and assembly activities			
		1.2	Describe the hazards associated with the activities and how they can be minimised			
		1.3	Explain how to extract and interpret information from first and third angle drawings, imperial and metric systems of measurement, workpiece reference points and system of tolerancing			
		1.4	Explain the importance of applying appropriate behaviours in the workplace and the implications for both the apprentice and the business if these are not adhered to			
		1.5	Explain how to prepare materials in readiness for marking out activities in order to enhance clarity, accuracy and safety			
		1.6	Explain how to select and establish an appropriate suitable datum, the importance of its use and the possible effects if working from a different datum			
		1.7	Describe the use of marking-out conventions when marking out a workpiece			
		1.8	Describe various fitting activities to be carried out			
		1.9	Explain how to prepare drilling machines for operations			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		1.10	Describe methods of holding a workpiece for hand fitting, turning and milling activities			
		1.11	Describe the methods, techniques and procedures used when performing an assembly activity and how the components are aligned, adjusted and positioned prior to securing them with appropriate tools and equipment			
		1.12	Describe various mechanical fastening devices that are used when performing a workpiece activity			
		1.13	Describe various turning operations that are used when performing a workpiece activity			
		1.14	Describe various milling operations that are used when performing a workpiece activity			
		1.15	Explain how to mount and secure cutting tools in tool holding devices			
		1.16	Describe the techniques required for taking trial cuts and checking dimensional accuracy; applying rough and finishing cuts, and their effect on tool life, surface finish and dimensional accuracy			
		1.17	Describe the factors that affect the selection of cutting feeds and speeds, and the depth of cut that can be taken			
		1.18	Describe the importance of applying cutting fluids and compounds to a range of different materials and why some materials do not require them			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		1.19	Explain how to check workpiece and the measuring equipment that is used			
		1.20	Describe the need to check measuring equipment before workpiece activities			
		1.21	Explain a situation when it's important to act on own initiative and when to seek help and advice from others			
		1.22	Describe the importance of leaving the work area and equipment in a safe and clean condition following the completion of machining and fitting activities			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
2	Carry out general machining, fitting and assembly applications	2.1	Work safely at all times, complying with health and safety legislation, regulations and other relevant guidelines			
		2.2	Carry out all of the following during the machining, fitting and assembly activities: • Adhere to procedures or systems in place for risk assessment, COSHH, personal protective equipment (PPE) and other relevant safety regulations • Ensure that all hand tools and equipment used are in a safe and serviceable condition • Ensure that all machine tools are correctly guarded at all times • Check that all measuring equipment is within calibration date • Return all tools and equipment to the correct location on completion of the fitting activity			
		2.3	Demonstrate the required behaviours in line with the job role and company objectives			
		2.4	Be able to plan for workplace tasks, confirming the methodology, processes undertaken equipment and steps required to complete			
		2.5	Select appropriate tools and equipment for manufacturing operations			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		2.6	Demonstrate all methods to mark out components for operations using appropriate tools and techniques: • Preparing/determining suitable datums from which to mark out • Applying a marking medium to enhance clarity of the marking out • Using an appropriate method of marking out • Using a range of marking out equipment • Marking out a range of features			
		2.7	Demonstrate how to cut and shape the materials to a required specification using appropriate tools and techniques			
		2.8	Demonstrate how to cut and shape different types of material			
		2.9	Use appropriate methods and techniques to assemble and secure components in their correct positions			
		2.10	Demonstrate how to use different workholding devices			
		2.11	Demonstrate the use of all hand fitting methods: • Cutting out the rough profile using saws • Cutting a screw thread • Filing flat and square • Filing a curved profile • Drilling holes			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		2.12	Produce mechanical assemblies, using different methods and techniques			
		2.13	Carry out turning operations: • Mounting the workpiece in an appropriate workholding device • Mounting cutting tools in tool holders to give the correct centre height • Selecting and setting appropriate feeds and speeds • Facing off • Producing parallel diameters • Producing stepped diameters • Producing tapered diameters • Centre drilling and drilling a hole • Reaming or boring a hole			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		2.14	Carry out all milling operations: • Mounting the workpiece in an appropriate workholding device • Mounting cutting tools on appropriate arbors or direct to the machine spindle • Selecting and setting appropriate feeds and speeds • Producing flat and square faces • Producing parallel faces • Producing angular faces • Producing an enclosed slot • Producing an open-ended slot			
		2.15	Measure and check all dimensional and geometrical aspects of a component that are to the specification			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		2.16	Carry out the necessary checks for accuracy: • Lengths • Depths • Internal diameters • External diameters • Flatness • Squareness • Angles • Profiles • Hole size and position • Thread size and fit • Surface finish			
		2.17	Use a range of measuring equipment during checking activities			

Learning outcomes		Assessment criteria		Evidence type	Portfolio reference	Date
		2.18	Produce components that follow standards which are applicable to the process: • Components to be free from false tool cuts, burrs and sharp edges • Dimensional tolerance +/- 0.25mm or +/- 0.010” • Flatness and squareness 0.05mm per 25mm or 0.002” per inch • Angles within +/- 1 degree • Screw threads to BS Medium fit • Reamed holes within H8 • Surface finish 63µin or 1.6 µm			
		2.19	Deal with problems promptly and effectively and seek help from other relevant people if they’re unable to be resolved			
		2.20	Leave a work area in a safe and tidy condition on completion of manufacturing activities			

Learner name: Date:

Learner signature: Date:

Assessor signature: Date:

Internal verifier signature: Date:

Unit guidance

What needs to be learned
Learning outcome 1: Know how to carry out general machining, fitting and assembly applications

1.1 & 1.2 – Health and safety requirements, safe working practices and hazards, such as:
• Safe working practices and procedures:
  o wearing appropriate protective clothing and equipment (PPE)
  o using machine guards
  o keeping the work area safe and tidy
• Hazards:
  o use of power tools
  o trailing leads or hoses
  o damaged or badly maintained tools and equipment
  o using files with damaged or poor fitting handles
  o using machine tools.
1.5 – Preparing materials, such as:
• Marking out activities:
  o visually checking for defects
  o cleaning the materials
  o removing burrs and sharp edges
  o applying a marking-out medium.
1.7 – Marking-out conventions, such as:
• Marking-out:
  o datum lines
  o cutting guidelines
  o square and rectangular profiles
  o circular and radial profiles
  o angles
  o holes linearly positioned
  o boxed and on pitch circles.

1.8 – Fitting activities, such as:

- filing flat, square and curved surfaces
- filing smooth finishes
- select saw blades for different materials and operations
- produce screw threads on workpieces using hand dies
- determine the drill size for tapped holes
- using the taps in the correct sequence.

1.9 – Preparing drilling machines, such as:

- adjustment of table height and position
- mounting and securing drills in chucks or Morse taper sockets
- setting and adjusting spindle speeds
- setting and adjusting guards/safety devices.

1.10 – Holding a workpiece, such as:

- Holding the workpiece for the hand fitting, turning and milling activities:
  - bench vice
  - machine vice
  - chuck
  - collets or clamped directly to the machine table.

1.12 – Mechanical fastening devices, such as:

- nuts
- bolts
- machine screws
- cap screws
- clips
- pins
- locking and retaining devices.

1.13 – *Turning operations, such as:*

- parallel, stepped and tapered external diameters
- drilled, bored and reamed holes
- internal and external screw threads
- special profiles.

1.14 – Milling operations, such as:

- o flat, parallel, square and angled surfaces
- o open ended and enclosed slots
- o special forms
- o drilled and bored holes.

1.15 – Mounting and securing cutting tools, such as:

- o front or rear tool posts
- o mounting cutters on long or stub arbors
- o mounting drills in chucks or by the use of Morse taper sockets
- o tool sharpening and security.

1.17 – Selecting cutting feeds and speeds, such as:

- o type of material
- o size of material
- o operations being performed
- o work holding method/security of workpiece
- o condition of machine
- o finish and tolerance required.
- o 1.19 – Checking workplace and measuring equipment, such as:
- o rules
- o micrometers
- o Verniers
- o gauges and surface finish comparison equipment.

1.20 – Checking calibration, geometric features and surface finishes, such as:

- Calibration:
  - o lengths
  - o diameters
  - o depths
  - o slots
  - o hole positions
  - o angles
  - o profiles.

- Geometric:
  - flatness
  - squareness
  - parallelism
  - concentricity
  - ovality.
- Surface finishes:
  - using comparison blocks or instruments.

1.22 – Leaving work area equipment, such as:

  - isolating machines
  - removing and returning cutting tools
  - cleaning the equipment
  - removing and disposing of waste.

Learning outcome 2: Carry out general machining, fitting and assembly applications

2.1 & 2.2 – Health and safety compliance, such as:

- Complying with legislation, regulations and machining specific guidelines:
  - risk assessments
  - COSHH
  - PPE.
- Checking hand tool safety, for example:
  - cables to hand tools
  - extension leads
  - file handles
  - hammer
  - striking faces
  - positioning of guards
  - calibration of equipment
  - checking and returning equipment to appropriate location.

2.4, 2.5 & 2.6 –- Manufacturing procedures, such as:

- Preparatory activities for manufacturing operations.
- Using appropriate tools to mark out for machining activities, for example:
  - choosing a machine face or filing a flat face as a datum
  - application of an appropriate mark out medium
  - using instruments for direct marking
  - using templates or tracing/transfer methods
  - using rules, squares, scribers, Vernier instruments
  - using datum/centre lines, square/rectangular profiles, circles/radial profiles, hole positions,

2.7 & 2.8 – Different types of material, to include:

- low carbon/mild steel
- high carbon steel
- cast iron
- stainless steel
- aluminium/aluminium alloys
- brass/brass alloys
- plastic/nylon/synthetic
- composite
- other specific material.

2.10 – Work holding devices, to include:

- bench vice
- machine vice
- clamps (such as toolmaker's)
- three-jaw chuck
- four-jaw chuck
- collet chuck
- drive plate and centres.

2.11 – Using hand fitting methods, to include:

- cutting out using hacksaw, band saw
- cutting a screw thread using tapping or dieing
- using different filing techniques to create flat, square and curved profiles
- drilling holes.

2.12 – Methods and techniques, to include:

- interference fits, for example: pressure, expansion or contraction
- threaded fasteners, for example: nuts, bolts, machine screws, cap screws)
- spring clips, for example: external circlips, internal circlips, special clips
- locking and retaining devices, for example: tab washers, locking nuts, wire locks, special purpose types
- rivets, for example: countersunk, roundhead, blind, special purpose types
- applying sealing compounds or adhesives
- electrical bonding of components
- adjusting components, for example: shimming and packing
- torque setting of nuts and bolts.

2.17 – Measuring equipment, to include:

- external micrometers
- a Vernier/digital/dial caliper
- surface finish equipment
- rules
- squares
- protractors
- depth micrometers
- depth Verniers
- feeler gauges
- bore/hole gauges
- slip gauges
- radius/profile gauges
- thread gauges
- dial test indicators (DTI)
- coordinate measuring machine (CMM).

Essential information for tutors and assessors

Essential resources

There are no special resources needed for this unit.

Assessment

This is a Level 2 unit whereas the overarching qualification is Level 3. Therefore, it is important to ensure that the evidence that learners produce for this unit matches the level of demand for Level 2.

This unit is internally assessed. To pass the unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

It is expected that this unit will be assessed in a real or simulated working environment, where evidence is naturally occurring and collected over a period of time.

Centres are responsible for deciding on the assessment activities that will enable learners to produce valid, sufficient, authentic and appropriate evidence to meet the assessment criteria.

The unit is assessed by a portfolio of evidence. Further information on the requirements for portfolios is included in *Section 4: Assessment requirements.*

Wherever possible, centres should adopt a holistic and integrated approach to assessing the skills units in the qualification(s). This gives the assessment process greater rigour, minimises repetition and saves time. The focus should be on assessment activities generated through naturally occurring evidence in the workplace rather than on specific tasks. Taken as a whole, the evidence must show that learners meet all learning outcomes and assessment criteria over a period of time. It should be clear in the assessment records where each learning outcome and assessment criterion has been covered and achieved.

For assessment criteria 2.8, learners must cut and shape **two** different types of material.

For assessment criteria 2.10, learners must show they can use **three** different work holding devices.

For assessment criteria 2.12, learners must use **six** different methods and techniques.

For assessment criteria 2.17, learners must use **all of** external micrometers, a Vernier/digital/dial caliper, and surface finish equipment, as well as **four additional** pieces of measuring equipment.

Unit 2: Health and Safety in the Engineering Workplace

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

The welfare of people working or operating in any manufacturing or engineering environment is of prime importance. All workers should be able to carry out their work in a safe manner that has no negative effect on their health and wellbeing. In fact, many organisations not only reduce risks and make improvements to the working environment but try to make their own working environment superior to others, making it a competitive aspect when recruiting staff.

Health and safety in the workplace are about measures designed to protect the health and safety of employees, visitors and the general public who may be affected by workplace activities. Safety measures are concerned with controlling and reducing risks to anyone who might be affected by these activities.

Health and safety are controlled largely by legislation and regulations, with the law being continually revised and updated. It is important that organisations are aware of these changes and keep up to date with developments.

This unit will give learners an understanding of hazards and risks associated with health, safety and welfare in an engineering workplace, the associated legislation and regulations, and of their roles in complying with the related legal obligations. Learners will be required to undertake full risk assessments and to appreciate the significant risks encountered in the workplace and the measures taken to deal with them. They will study the principles of reporting and recording accidents and incidents, again within a legal context.

This unit could form a key component in many learning programmes since the content is highly applicable to many manufacturing, engineering and industrial situations.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand health and safety legislation and regulations

2 Know about hazards and risks in the workplace

3 Understand the methods used when reporting and recording accidents and incidents.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the key features of relevant regulations on health and safety as applied to a working environment in two selected or given engineering organisations	**M1** Explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in a given health and safety situation	**D1** Assess the extent to which legislation and regulations are satisfied in a given health and safety situation
P2 Describe the roles and responsibilities under current health and safety legislation and regulations of those involved in two selected or given engineering organisations		
P3 Explain the key features of the relevant legislation and EU directives, with regard to environmental management	**M2** Explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities, with regard to environmental management	
P4 Explain the requirements for the safe disposal of waste		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the methods used to identify hazards in a working environment	**M3** Explain how hazards that become risks can be controlled	**D2** Justify the methods used to deal with hazards in accordance with workplace policies and legal requirements
P6 Carry out a risk assessment on a typical item/area of the working environment	**M4** Explain the importance of carrying out all parts of a risk assessment in a suitable manner	
P7 Suggest suitable control measures after a risk assessment has been carried out and state the reasons why they are suitable		
P8 Suggest a suitable process or equipment to assist in moving different loads correctly and safely		
P9 Describe the precautions needed for the safe storage of gases, oil, acids, adhesives and engineering materials		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P10 Explain the principles that underpin reporting and recording accidents and incidents		
P11 Describe the procedures used to record and report accidents, dangerous occurrences or near misses	**M5** Explain how control measures are used to prevent accidents	**D3** Assess the potential costs and implications for the organisation and the individual as a result of an accident in the workplace

Unit content

What needs to be learned
Learning outcome 1: Understand health and safety legislation and regulations
Key features of legislation and regulations: the general content of legislation and regulations or other relevant international equivalents and how they are satisfied by safe systems of work/procedures, including: • Health and Safety at Work etc. Act 1974 – duties of employers, employees, Health and Safety Executive (HSE) and others, The Health and Safety at Work (Northern Ireland) Order 1978 (where applicable to locality), general prohibitions. • Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013 (as amended) – duties of employers, self-employed and people in control of work premises (the Responsible Person) to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences. • Personal Protective Equipment (PPE) at Work Regulations 1992 (as amended) – appropriate if risk cannot be controlled in any other way, types, assessing suitable PPE given the hazard, supply, instructions/training, correct use, maintenance and storage. • Control of Substances Hazardous to Health (COSHH) Regulations 2002 (as amended) – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information. • Manual Handling Operations Regulations (MHOR) 1992 (as amended) – avoid the need for manual handling, types of hazard, assess risk of injury when manual handling is required, control and reduce the risk of injury, training in use of techniques/mechanical aids. • Environmental legislation and EU directives: Environmental Protection Act 1990; Pollution Prevention and Control Act 1999; Clean Air Act 1993; Radioactive Substances Act 1993; Controlled Waste Regulations 2012; Controls on Dangerous Substances and Preparations Regulations 2006. • *Roles and responsibilities of those involved*: employers; employees; HSE, e.g. span of authority, right of inspection, guidance notes and booklets; others, e.g. management, subcontractors, public, suppliers, customers, visitors. • *Application of environmental management systems*: ISO 14000 (family of standards, a management tool); environmental management (what an organisation does to minimise the harmful effects on the environment caused by its activities); ISO 14004 (guidelines on the elements of an environmental management system and its implementation, and examines principal issues involved); ISO 14001 (specifies the requirements for such an environmental management system).

What needs to be learned
Learning outcome 2: Know about hazards and risks in the workplace
• *In the workplace*: methods to identify hazards, e.g. statements, analysis of significant risks, prediction of results or outcomes of those risks, use of accident data, careful consideration of work methods. • *Working environment*: consideration of the workplace and its potential for harm, e.g. confined spaces, working over water or at heights, electrical hazards, chemicals, noise. • *Hazards that become risks*: identification of trivial or significant risk; potential to cause harm; choosing appropriate control measures; electrical safety, e.g. identifying and controlling hazards, cause of injury, effects of electricity on the body, circuit overloading; mechanical safety, e.g. identifying and controlling hazards, cause of injury, rotating equipment, sharp edges; safety devices, e.g. residual current device (RCD), fuses, guards, fail safe, sensors. • *Risk assessments*: items/area to be assessed, e.g. machine operation, work area; five steps (principal hazards, who is likely to be injured/harmed, evaluation of the risks and decisions on adequacy of precautions, recording findings, review assessment). • *Use of control measures*: e.g. removing need (design out), use of recognised procedures, substances control, guarding, lifting assessments and manual handling assessments, regular inspection, use of PPE, training of personnel, other personal procedures for health, safety and welfare. • *Application of aids to lift or move loads*: e.g. pinch bars, rollers, skates, pallet trucks, scissor lifts, forklift trucks, wall and overhead cranes; ancillary equipment, e.g. block and tackle, pull lifts, slings (chain, rope, polyester), shortening clutches, lifting/plate clamps, eye bolts (dynamo, collar), shackles (dee, bow). • *Regulations*: e.g. Provision and Use of Workplace Equipment Regulations (PUWER) 1998, Lifting Operations and Lifting Equipment Regulations (LOLER) 1998. • *Procedures*: safe working load (SWL) capacity of equipment; safe working load limits and angles for slings when lifting; ensuring clearway and not moving loads over others' heads; not transporting people on loads; correct hand signals from floor staff to crane drivers; protection of chains and slings from sharp corners; setting hooks and sling/chain lengths correctly. • *Storage of gases, oil, acids, adhesives and engineering materials*: COSHH Regulations; structure of storage buildings, stillages and shelving; control of ventilation, extraction and temperature; good housekeeping and stock management; storage of flammable liquids/compressed gases, oil, acids and adhesives.

What needs to be learned
Learning outcome 3: Understand the methods used when reporting and recording accidents and incidents
• *Principles*: why employers keep records of serious accidents, incidents and emergencies; responsibilities of competent persons; cost of accidents, e.g. direct, indirect, human consequences; trends, e.g. major causes, fatal and serious injury, methods of classification, statistics. • *Recording and reporting procedures*: regulations on accident recording and reporting, e.g. RIDDOR 1995, accident book, company procedures; procedures to deal with near misses or dangerous occurrences.

Essential information for tutors and assessors

Essential resources

Learners will require access to a wide range of safety literature. Ideally, the centre will be able to provide access to health and safety legislation and learning materials on DVD.

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Level 3 BTEC National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Health and Safety Executive – *Essentials of Health and Safety at Work* (HSE Books, 2006) ISBN 9780717661794

Health and Safety Executive – *Management of Health and Safety at Work* (HSE Books, 2000) ISBN 9780717624881

Health and Safety Executive – *Health and Safety in Engineering Workshops* (HSE Books, 2004) ISBN 9780717617173

Websites

HSE www.hse.gov.uk

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Health and Safety Legislation and Regulations	A written activity requiring learners to explain the key features of relevant legislation and regulations and describe the roles and responsibilities of management and the personnel involved.	A report containing written responses about the key features, responsibilities and management of health and safety legislation and regulations set in a relevant context for learners.
P4, P5, P6, P7, P8, P9, M3, M4, D2	Controlling Hazards and Risks in the Workplace	A practical activity to carry out a risk assessment, plus a written report and oral questioning.	A report, carried out under controlled conditions, describing the methods used to identify hazards and how hazards become risks. A written risk assessment of a typical working environment. A report with written responses that identify control measures and their justification. A record of observation by the tutor of the learner's practical risk assessment.
P10, P11, M5, D3	Reporting and Recording Accidents and Incidents	A written activity requiring learners to explain principles of reporting accidents, incidents and near misses	A report, carried out under controlled conditions, explaining reporting accidents, incidents and near misses

To achieve a pass, learners must demonstrate an understanding of health, safety and welfare issues as applied to engineering processes and companies. They will need to explain the key features of legislation and regulations and describe a range of roles and responsibilities. They will understand the connection between hazard identification, risk assessment and accident prevention. Learners will carry out a risk assessment, suggest suitable controls and show they understand the principles and procedures for reporting and recording accidents and other occurrences relative to health and safety.

This unit could be assessed through three assignments. The first assignment could have a series of written tasks. The first task could ask learners to research and then explain the key features of relevant regulations as applied to two separate working environments (P1). It would be expected that at least four regulations should be considered across the two selected or given engineering organisations.

Another task could require learners to describe the roles and responsibilities of those involved in the environments selected above (P2). The organisations selected could include learners' places of work, or a training workshop or machine shop environment.

A combination of one electrical and one mechanical type would be most appropriate.

The assignment should cover legislation and regulations. It is not expected that all the legislation and regulations listed in the content would be covered, just those applicable to the given context.

The roles and responsibilities of those involved could include employers, employees, the HSE and any one from the list of others in the unit content. A further task could then be used, asking learners to explain the consequences of management not abiding by legislation and regulations when carrying out their roles and responsibilities in one of these situations (M1). For the same situation, learners could carry out research to assess how the legislation and regulations are satisfied (D1). They might consider reviewing workplace incident/accident records/reports.

P3 and M2 could be achieved using a similar approach and applying this to environmental management. All responses could be in a written format, although for the pass criteria a presentation to the class or annotated poster could be used. In these cases, it must be remembered that the presentation skills or poster design skills are not being assessed.

The second assignment could cover P4 to P9, along with the higher criteria M3, M4 and D2. The whole assignment could be based on a practical activity to produce a risk assessment on a typical item or area of a working environment. Again, this working environment could be learners' workplaces or one from the centre's own workshops. Whichever item or area is chosen, it should have a range of hazards that can be identified, for example a machining operation or electrical assembly/wiring type activity could be used.

Written tasks would have to be set to give learners opportunities to achieve the explanations required for P4 to P9, M3 and M4, and the justification required for D2.

P7 could be achieved through an oral question and answer session after carrying out the risk assessment. A standard template can be used to capture the outcomes of the risk assessment as this is what would be found in normal company use. A witness statement/observation record could be used to show learner performance against the requirement of P6.

The final assignment could cover the remaining criteria P10, P11, M5 and D3, with a written task given for each. Learners should be given opportunities to investigate trends in an area they are interested in, which again may be an area similar to their workplace. The assignment should include a range of data given to each learner, some of which may have been researched and collected during the delivery of this part of the unit content.

Unit 3: Communication for Engineering

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

The ability to communicate effectively is an essential skill in all aspects of life. The usual methods of communication – speaking, reading and writing – receive considerable attention and learning time during all stages of education. For engineers, these skills are of no less importance, but there are further complications with the need to also convey technical information such as scale, perspective and standards of working.

The drive towards greater use of information and communication technology (ICT) is very much a part of modern life and this again is certainly the case for engineering. The engineering industry is in the front line of working towards paperless communication methods, for example the electronic transfer of data from the concept designer straight to the point of manufacture.

This unit will give a foundation for employment in a wide range of engineering disciplines (for example manufacturing, maintenance, communications technology), in addition to giving a foundation for further study. It aims to develop learners' ability to communicate using a diverse range of methods. These include visual methods, such as drawing and sketching, and computer-based methods, such as two-dimensional (2D) computer-aided design (CAD) and graphical illustration packages. It will also develop learners' ability to write and speak in a framework of technology-based activities, using relevant and accurate technical language appropriate to the task and the audience.

The unit will introduce learners to a variety of skills and techniques to obtain and use information, for example the presentation of technical reports, business and technical data and the use of visual aids for presentations. Learners will consider how to make best use of ICT in technological settings that are relevant to their programme of study or area of employment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information

2 Be able to use verbal and written communication skills in engineering settings

3 Be able to obtain and use engineering information

4 Be able to use information and communication technology (ICT) to present information in engineering settings.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Interpret an engineering drawing/circuit/network diagram		
P2 Produce an engineering sketch/circuit/network diagram		
P3 Use appropriate standards, symbols and conventions in an engineering sketch/circuit/network diagram		
P4 Communicate information effectively in written work	**M1** Evaluate a written communication method and identify ways in which it could be improved	**D1** Justify choice of a specific communication method and the reasons for not using a possible alternative
P5 Communicate information effectively using verbal methods		
P6 Use appropriate information sources to solve an engineering task	**M2** Review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected	
P7 Use appropriate ICT software packages and hardware devices to present information	**M3** Evaluate the effectiveness of an ICT software package and its tools for the preparation and presentation of information	**D2** Evaluate the use of an ICT presentation method and identify an alternative approach

Unit content

What needs to be learned
Learning outcome 1: Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information
• *Interpret*: obtain information and describe features, e.g., component features, dimensions and tolerances, surface finish; identify manufacturing/assembly/process instructions, e.g., cutting lists, assembly arrangements, plant/process layout or operating procedures, electrical/electronic/communication circuit requirements; graphical information used to aid understanding of written or verbal communication, e.g., illustrations, technical diagrams, sketches. • *Engineering sketches/circuit/network diagrams*: freehand sketches of engineering arrangements using 2D and 3D techniques, e.g. components, engineering plant or equipment layout, designs or installations; electrical/electronic circuit diagrams, system/network diagrams; use of common drawing/circuit/network diagram conventions and standards, e.g. layout and presentation, line types, hatching, dimensions and tolerances, surface finish, symbols, parts lists, circuit/component symbols, use of appropriate standards (British (BSI), International (ISO)).
Learning outcome 2: Be able to use verbal and written communication skills in engineering settings
• *Written work*: note taking, e.g., lists, mind mapping/flow diagrams; writing style, e.g., business letter, memo writing, report styles and format, email, fax; proofreading and amending text; use of diary/logbook for planning and prioritising work schedules; graphical presentation techniques, e.g., use of graphs, charts and diagrams. • *Verbal methods*: speaking, e.g., with peers, supervisors, use of appropriate technical language, tone and manner; listening, e.g., use of paraphrasing and note taking to clarify meaning; impact and use of body language in verbal communication.
Learning outcome 3: Be able to obtain and use engineering information
• *Information sources*: non-computer-based sources, e.g., books, technical reports, institute and trade journals, data sheets and test/experimental results data, manufacturers' catalogues; computer-based sources, e.g., inter/intranet, DVD-based information (manuals, data, analytical software, manufacturers' catalogues), spreadsheets, databases. • *Use of information*: e.g., for the solution of engineering problems, for product/service/topic research, gathering data or material to support own work, checking validity of own work/findings.

What needs to be learned
Learning outcome 4: Be able to use information and communication technology (ICT) to present information in engineering settings
• *Software packages*: word processing; drawing, e.g., 2D CAD, graphics package; data handling and processing, e.g., database, spreadsheet, presentation package, simulation package such as electrical/electronic circuits, plant/process systems; communication, e.g., email, fax, inter/intranet, video conferencing, optical and speech recognition system. • *Hardware devices*: computer system, e.g., personal computer, network, plant/process control system; input/output devices, e.g., keyboard, scanner, optical/speech recognition device, printer, plotter. • *Present information*: report that includes written and technical data, e.g., letters, memos, technical product/service specification, fax/email, tabulated test data, graphical data; visual presentation, e.g., overhead transparencies, charts, computer-based presentations (PowerPoint).

Essential information for tutors and assessors

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be given a variety of sample written materials (letters, memos, technical reports, data sheets, catalogues) and sketches. Centres will need to provide access to appropriate presentation and graphics software (for example Microsoft PowerPoint, Visio), spreadsheet/database software (for example Microsoft Excel/Access) and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and P3	Communicating Technical Information	Explore a product/circuit/network and interpret and prepare appropriate engineering sketches/circuit/ network diagrams	A written report showing the learner's interpretation of the information and features found. Engineering sketches/circuit/ network diagram prepared by the learner
P4, P5, M1 and D1	Writing, Talking and Listening	A series of tasks focused on written work and verbal communication methods	A portfolio of evidence containing examples of note taking, writing styles, use of diary/logbook and use of graphical presentation techniques. Tutor observation of speaking, listening and use of body language
P6, M2	Finding and Using Information	Solving an engineering problem through research and use of information	A written report with suitable reference to the range of sources found and used, including non-computer-based and computer-based resources
P7, M3, D2	The Use of ICT in Engineering	Presenting engineering information using ICT	A written report on the selection and use of computer hardware devices. A portfolio of evidence of the use of word processing, drawing, data handling and communication software packages to present engineering information

To achieve a pass, learners should interpret (P1) and produce (P2) engineering sketches (2D and 3D)/circuit/network diagrams and sketches. This will need to be at a level sufficient for them to understand and communicate technical information. This must include identification and use of appropriate standards, symbols and conventions (P3). The use of sketches/circuit/network diagrams in criteria P1 and P2 is intended to indicate a choice that will depend on the focus of the learning programme in which this unit is being delivered. For example, a learner on a mechanical programme is likely to choose to interpret and produce sketches of components, while a learner studying electrical/electronics is more likely to interpret and produce circuit diagrams.

A single assessment activity could be used to link and capture evidence for the first three pass criteria (P1, P2 and P3). The activity would need to ensure that learners had an opportunity to obtain information, describe features, identify instructions and make use of graphical information (P1). For example, the task could be to work with written operating instructions that include supporting diagrams and sketches (2D and 3D). From the initial investigation, the activity could then require learners to produce their own drawing and sketches (P2). Criterion P3 would need to be applied to both the interpretation (identify) and the production (use) of their working document.

Learners should use written (P4) and verbal (P5) communication methods. The written work must include evidence of note taking, the ability to use a specific writing style, proofreading and amending text, using a diary/logbook and graphical presentation techniques. It might be that all of these will not necessarily occur in a single task/activity. If not, it would be acceptable for a number of pieces of assessment evidence to be brought together to meet this criterion.

The use of verbal methods (P5) will require learners to demonstrate speaking and listening skills and an understanding of the impact and use of appropriate body language. The evidence for this should come from one task/activity so that all three aspects are being dealt with at the same time. This could be a meeting with either peers and/or a supervisor, or could come from a presentation delivered by the learner to a group.

It would be important to ensure that the learner had to take questions from the group to enable the tutor to capture evidence of their ability to listen. The evidence for this criterion is likely to be a tutor observation record or witness statement.

P6 can be assessed using any structured activity that requires learners to identify and use appropriate information sources to solve an engineering task. It is essential that the information comes from both computer-based and non-computer-based sources. The evidence for this criterion could be as simple as suitably referenced work (a bibliography would not be sufficient). However, it would be preferable to have a record of the original source and a hard copy, annotated to show the information identified and used for the task (or at least an example of this process).

The final pass criterion (P7) could be assessed using any relevant tasks that require learners to select and use appropriate ICT software packages and hardware devices to present information. It is essential that the task or tasks chosen for this criterion give learners opportunities to use appropriate software to cover all the ICT applications listed in the content, i.e., there must be evidence of learner selection and use of ICT for word processing, drawing, data handling and communication (such as email). The requirement for hardware devices is limited to the choice and use of a computer system and relevant input/output devices that would be needed for the task carried out.

It is expected that the range of information presented using ICT will include a technical report and visual presentation material, for example overhead transparencies, chart, computer-based presentation (PowerPoint).

To achieve a merit, learners should evaluate a written communication method and identify ways in which it could be improved (M1). This could be learners' own written work or the written work of someone else. The important aspect of this criterion is the learner's ability to use their skills and understanding of communication methods to appraise the work and identify enhancements.

In addition, learners will need to review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected (M2). This criterion is about reflection and the need to carefully consider, measure and express the value (or not) of other people's work as a source of information. Learners need to have identified both non-computer-based and computer-based information sources for P6 and it is this material that they should be reviewing for M2. Achievement might well be implicit if the task undertaken for P6 has reached a satisfactory solution. However, the expected evidence for this criterion would be a copy of the source material used, suitably annotated to explain its value or why it has been rejected.

Finally, merit criterion M3 requires learners to evaluate an ICT software package and its tools for the preparation and presentation of information. This criterion requires learners to have taken time to reflect on their work and consider the use of software tools available (for example good/consistent use of font size/colour, alignment of text, positioning on the page, use of automated labels, legends and titles for graphs).

To achieve a distinction, learners should justify their choice of a specific communication method and the reasons for not using a possible alternative (D1). This could be any communication method that the learner has chosen to use (for example drawings, written, verbal).

It does require learners to have considered at least one possible alternative during the initial selection of the method used. Learners will therefore need to be briefed to collect evidence of this selection process, which might otherwise be lost or ignored (for example initial outlines/drafts, notes of any consultation with others on method to be employed). The key issue for this criterion is the learner's ability to reflect and evaluate. At pass level, learners will have shown their ability to communicate information effectively and, at merit, to be critical of the content of their own or other people's work. At distinction level, they should be critical of the choice of communication method used.

D2 requires learners to evaluate their use of an ICT presentation method and identify an alternative approach. This criterion is about the method of presentation and not the method of communication. It also has a direct link with related pass (P7) and merit (M3) criteria.

At pass, learners need to use ICT to present information and, at merit, to evaluate the effectiveness of the presentation. For D2, learners should consider the overall approach taken. For example, could a word-processed technical report have been presented using a computer-based presentation package, such as PowerPoint, including automated routines and animated graphics or video clips? The evidence for this is likely to be a written evaluation. A rough outline illustrating their identified alternative approach or even a small section of the original reworked using an alternative approach could be used to support the written evaluation.

Unit 4: Mathematics for Engineering Techniques

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

One of the main responsibilities of engineers is to solve problems quickly and effectively. This unit will enable learners to solve mathematical, scientific and associated engineering problems at technician level.

It will enable learners to build on knowledge gained at GCSE and use it in a more practical context for their chosen discipline. Learning outcome 1 will develop learners' knowledge and understanding of algebraic methods, from a look at the use of indices in engineering to the use of the algebraic formula for solving quadratic equations. Learning outcome 2 involves the introduction of the radian as another method of angular measurement, the shape of the trigonometric ratios and the use of standard formulae to solve problems involving surface areas and volumes of regular solids. Learning outcome 3 requires learners to represent statistical data in a variety of ways and calculate the mean, median and mode. Finally, learning outcome 4 is intended as a basic introduction to the arithmetic of elementary calculus.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Be able to use algebraic methods

2 Be able to use trigonometric methods and standard formulae to determine areas and volumes

3 Be able to use statistical methods to display data

4 Be able to use elementary calculus techniques.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Manipulate and simplify three algebraic expressions using the laws of indices and two using the laws of logarithms		
P2 Solve a linear equation by plotting a straight-line graph using experimental data and use it to deduce the gradient, intercept and equation of the line	**M1** Solve a pair of simultaneous linear equations in two unknowns	**D1** Solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P3 Factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	**M2** Solve one quadratic equation by factorisation and one by the formula method	
P4 Solve circular and triangular measurement problems involving the use of radian, sine, cosine and tangent functions		
P5 Sketch each of the three trigonometric functions over a complete cycle		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Produce answers to two practical engineering problems involving the sine and cosine rule		
P7 Use standard formulae to find surface areas and volumes of regular solids for three different examples respectively		
P8 Collect data and produce statistical diagrams, histograms and frequency curves		
P9 Determine the mean, median and mode for two statistical problems		
P10 Apply the basic rules of calculus arithmetic to solve three different types of function by differentiation and two different types of function by integration.	**M3** Apply the rules for definite integration to two engineering problems that involve summation	**D2** Apply graphical methods to the solution of two engineering problems involving exponential growth and decay, analysing the solutions using calculus

Unit content

What needs to be learned
Learning outcome 1: Be able to use algebraic methods
• *Indices and logarithms*: laws of indices $a^m \times a^n = a^{m+n}$, $\frac{a^m}{a^n} = a^{m-n}$, $(a^m)^n = a^{mn}$; laws of logarithms: $\log A + \log B = \log AB$, $\log A^n = n\log A$, $\log A - \log B = \log \frac{A}{B}$; common logarithms (base 10), natural logarithms (base e), exponential growth and decay. • *Equations and graphs*: linear equations, e.g., $y = mx + c$; straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph $y = ax^2 + bx + c$; experimental data, e.g. Ohm's law; pair of simultaneous equations in two unknowns (two linear or one linear and one quadratic). • *Factorisation and quadratics*: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor, e.g. $ax + ay$, $a(x + 2) + b(x + 2)$; by grouping, e.g. $ax - ay + bx - by$; quadratic expressions, e.g. $a^2 + 2ab + b^2$; roots of an equation, e.g. quadratic equations with real roots by factorisation, and by the use of formula.
Learning outcome 2: Be able to use trigonometric methods and standard formulae to determine areas and volumes
• *Circular measure*: radian; conversion of degree measure to radians and vice versa; angular rotations (multiples of π radians); problems involving areas and angles measured in radians; length of arc of a circle $s = r\theta$; area of a sector $A = \frac{1}{2} r^2\theta$ • *Triangular measurement*: functions (sine, cosine and tangent); sine/cosine wave over one complete cycle; graph of $\tan A$ as A varies from 0° and 360° confirming $\tan A = \frac{\sin A}{\cos A}$; values of the trigonometric ratios for angles between 0° and 360°; periodic properties of the trigonometric functions; the sine and cosine rule; practical problems, e.g. calculation of the phasor sum of two alternating currents, resolution of forces for a vector diagram. • *Mensuration*: standard formulae to solve surface areas and volumes of regular solids, e.g. volume of a cylinder $V = \pi r^2 h$, total surface area of a cylinder $TSA = 2\pi rh + 2\pi r^2$, volume of sphere $V = \frac{4}{3}\pi r^3$, surface area of a sphere $SA = 4\pi r^2$, volume of a cone $V = \frac{1}{3}\pi r^2 h$, curved surface area of cone $CSA = \pi rl$

What needs to be learned
Learning outcome 3: Be able to use statistical methods to display data
• *Data handling*: data represented by statistical diagrams, e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table; variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves. • *Statistical measurement*: arithmetic mean; median; mode; discrete and grouped data.
Learning outcome 4: Be able to use elementary calculus techniques
• *Differentiation*: differential coefficient; gradient of a curve $y = f(x)$; rate of change; Leibniz notation $\left(\frac{dy}{dx}\right)$; differentiation of simple polynomial functions, exponential functions and sinusoidal functions; problems involving evaluation, e.g., gradient at a point. • *Integration*: integration as reverse of differentiating basic rules for simple polynomial functions, exponential functions and sinusoidal functions; indefinite integrals; constant of integration; definite integrals; limits; evaluation of simple polynomial functions; area under a curve, e.g. $y = x(x - 3)$, $y = x^2 + x + 4$

Essential information for tutors and assessors

Essential resources

For this unit, learners will need an electronic scientific calculator and have access to software packages that support understanding of the principles and their application to engineering.

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Fuller A, Greer A, Taylor G W – *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Websites

Science, Technology, Engineering and Mathematics Network	www.stemnet.org.uk

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2	Algebraic Methods	A written activity/ test requiring learners to complete five tasks, one for each of the criteria	A report containing written solutions to each of the five tasks carried out under controlled conditions
P4, P5, P6, P7	Trigonometric Methods and Standard Formulae	A written activity requiring learners to use trigonometric methods and standard formula to determine areas and volumes	A report containing the results of calculations and graphic evidence to support the use of trigonometric methods and standard formula for the determination of areas and volumes
P8, P9	Statistical Methods	A written activity requiring learners to collect and display data using different graphical methods, also evaluate the mean, median and mode for a set of discrete and grouped data	A report containing bar charts, pie charts and the results of calculations to determine the mean, median and mode for a set of discrete and grouped data
P10, M3, D1, D2	Calculus Techniques	A written activity requiring learners to produce calculations, graphical solutions and analysis to demonstrate use of calculus techniques	A report containing the solutions to calculations, graphs and analysis of several calculus techniques, carried out under controlled conditions

Criterion P1 could be assessed in the form of a short, written test and could possibly also include criterion P3.

P2 could be assessed through an assignment using data from *Unit 56: Electrical and Electronic Principles*, which ideally would be delivered concurrently with this unit.

If this is not possible, learners should be given a range of data sufficient for them to plot the graph and work out the gradient, intercept and the equation. Data forcing them to draw the line of best fit, as opposed to a set of points directly on the graphical line, might be most appropriate.

For P4, learners could be given a range of different values and assessed by an assignment or a short formal test. The problems given should collectively cover radian, sine, cosine and tangent functions. When considering the content part of this learning outcome, it is important that these problems give learners the opportunity to convert multiples of π radians to degrees and vice versa. The circular measurement problems also need to cover the length of an arc and area of a sector, as well as areas and angles measured in radians. Obviously, the triangular measurement problems are more basic and only expect application of the three functions.

P5 requires learners to sketch each of the three trigonometric ratios, this is probably best done as a classroom exercise. Similarly, P6 could take the form of a written assignment where learners must produce answers to two practical engineering problems involving the sine and cosine rule (for example calculate the phasor sum of two alternating currents and evaluate the resultant and the angle between two forces).

Criterion P7 requires learners to calculate the surface areas and volumes for three different regular solids. This could be achieved through an assignment or perhaps by combining it with other criteria in a short formal test.

An assignment could be used for P8 where learners collect meaningful data (for example classification of workers within their company) and display this information using different graphical methods (for example bar charts). They also need to produce a histogram and plot frequency curves (for example resistance values of 100 resistors or external diameter of pins).

For P9, learners must provide evidence that they are able to determine and then explain the relevance of the mean, median and mode for a set of discrete and grouped data (for example time taken to produce components on a machine rounded to the nearest ten seconds and the 100 resistor values or diameters of pins from P8). This could be done by an assignment. P10 may be assessed through a short formal test, with learners being given a list of the standard differential coefficients and integrals to use.

For M1, learners will need to provide evidence that they can solve a pair of simultaneous linear equations in two unknowns (for example equations formed after the application of Kirchhoff's laws, power transmitted for different belt tensions in a mechanical system). This could be extended to D1 by the introduction of a quadratic equation to be solved simultaneously with a linear equation.

It would be appropriate to use the same assessment method and instrument as P2, possibly combining these two criteria as one assessment activity.

M2 could also be assessed by assignment as it requires learners to evaluate the roots of a quadratic equation by factorisation and by the formula method (for example evaluation of an equation formed after the realisation of a practical situation).

Both the criteria required to achieve D2 could be assessed through a written assignment. Learners need to apply the graphical methods to the solution of two engineering problems involving exponential growth and decay (for example growth of voltage in a capacitor, radioactive decay, application of Taylor's tool life equation C = VTn) and then analyse the results by applying the appropriate method of differential calculus to check the results.

M3 requires learners to demonstrate that they can accurately evaluate two engineering problems involving definite integration (for example area under a velocity-time graph, area under a voltage-current graph).

Unit 5: Properties and Applications for Engineering Materials

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to select or specify them for applications in the engineering industry. This unit will give learners an understanding of the structures, classifications and properties of materials used in engineering and will enable learners to select materials for different applications.

The unit is appropriate for learners engaged in manufacturing and mechanical engineering, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials, some of which learners may not be familiar with initially.

This unit will enable learners to identify and describe the structures of metals, polymers, ceramics and composites and classify them according to their properties. Learners will describe the effects of processing on the behaviour of given materials. Smart materials whose properties can be altered in a controlled fashion through external changes – such as temperature and electric and magnetic fields – are also covered.

Learners will apply their understanding of the physical and mechanical properties of materials, design requirements, cost and availability to specify materials for given applications.

All materials have limits beyond which they will fail to meet the demands placed on them. The common modes of failure will be both demonstrated and explained to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Know the structure and classification of engineering materials

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

3 Be able to use information sources to select materials for engineering uses

4 Understand about the modes of failure of engineering materials.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material		
P2 Classify given engineering materials as either metals or non-metals according to their properties		
P3 Explain mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context		
P4 Explain the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials	**M1** Explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Use information sources to select a different material for two given applications, using the criteria considered in the selection process	**M2** Explain the criteria considered in the selection process	**D1** Justify selection of an engineering material for one given application
P6 Explain the principles of the modes of failure known as ductile/brittle fracture, fatigue and creep	**M3** Explain how two given degradation processes affect the behaviour of engineering materials	
P7 Perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material	**M4** Explain how one destructive and one non-destructive test procedure produces useful results	**D2** Evaluate the results of one test procedure
P8 Explain a different process of degradation associated with each of metals, polymers and ceramics		

Unit content

What needs to be learned
Learning outcome 1: Know the structure of and classification of engineering materials
• *Atomic structure*: element; atom, e.g., nucleus, electron; compound; molecule; mixture; bonding mechanisms, e.g., covalent, ionic, metallic. • *Structure of metals*: lattice structure; grain structure; crystals; crystal growth; alloying, e.g., interstitial, substitutional; phase equilibrium diagrams, e.g., eutectic, solid solution, combination; intermetallic compounds. • *Structure of polymeric materials*: monomer; polymer; polymer chains, e.g., linear, branched, cross-linked; crystallinity; glass transition temperature. • *Structure of ceramics*: amorphous; crystalline; bonded. • *Structure of composites*: particulate; fibrous; laminated. • *Structure of smart materials*: crystalline; amorphous; metallic. • *Classification of metals*: ferrous, e.g., plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous, e.g., aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys, e.g., aluminium-copper heat treatable – wrought and cast, non-heat-treatable – wrought and cast, copper-zinc (brass), copper-tin (bronze), nickel-titanium alloy. • *Classification of non-metals (synthetic)*: thermoplastic polymeric materials, e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials, e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics, e.g. glass, porcelain, cemented carbides; composites, e.g. laminated, fibre reinforced (carbon fibre, glass reinforced plastic (GRP)), concrete, particle reinforced, sintered; smart materials, e.g. electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals. • *Classification of non-metals (natural)*: e.g., wood, rubber, diamond.
Learning outcome 2: Understand material properties and the effects of processing on the structure and behaviour of engineering materials
• *Mechanical properties*: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness. • *Physical properties*: density; melting temperature. • *Thermal properties*: expansivity; conductivity. • *Electrical and magnetic properties*: conductivity; resistivity; permeability; permittivity. • *Effects of processing metals*: recrystallisation temperature; grain structure, e.g., hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

What needs to be learned
• *Effects of processing thermoplastic polymers*: polymer processing temperature; process parameters, e.g., mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time. • *Effects of processing thermosetting polymers*: process parameters, e.g., moulding pressure and time, mould temperature, curing. • *Effects of processing ceramics*: e.g., water content of clay, sintering pressing force, firing temperature. • *Effects of processing composites*: fibres, e.g., alignment to the direction of stress, ply direction; de-lamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets. • *Effects of post-production use*: smart materials, e.g., impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity).
Learning outcome 3: Be able to use information sources to select materials for engineering uses
• *Information sources*: relevant standard specifications, e.g., British Standards (BS), European Standards (EN), International Standards (ISO); material manufacturers' and stockholders' information, e.g. data sheets, catalogues, websites, DVDs. • *Design criteria*: properties, e.g., mechanical, physical, thermal, electrical and magnetic; surface finish; durability, e.g., corrosion resistance, solvent resistance, impact resistance, wear resistance. • *Cost criteria*: initial cost, e.g., raw material, processing, environmental impact, energy requirements; processing, e.g., forming, machining, casting, joining (thermal, adhesive, mechanical); quantity; mode of delivery e.g., bulk, just-in-time (JIT); recycling. • *Availability criteria*: standard forms, e.g., sheet and plate, bar-stock, pipe and tube, sectional, extrusions, ingots, castings, forgings, pressings, granular, powder, liquid.
Learning outcome 4: Understand about the modes of failure of engineering materials
• *Principles of ductile and brittle fracture*: effects of gradual and impact loading, e.g. tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces. • *Principles of fatigue*: cyclic loading; effects of stress concentrations, e.g., internal, external; effects of surface finish; appearance of fracture surfaces. • *Principles of creep*: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress.

What needs to be learned
• *Tests*: destructive, e.g., tensile, hardness, impact, ductility, fatigue, creep; non-destructive, e.g., dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual. • *Degradation processes*: on metals, e.g., oxidation, erosion, stress corrosion; on polymers, e.g., solvent attack, radiation and ageing; on ceramics, e.g. thermal shock, sustained high temperature.

Essential information for tutors and assessors

Essential resources

Learners will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Learners will also require access to equipment to conduct at least one destructive and one non-destructive test and related materials as specified in the unit content.

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Higgins R – *Materials for Engineers and Technicians* (Routledge, 2014) ISBN 9781138778757

Timings R L – *Engineering Materials*, Volume 1 (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials*, Volume 2 (Longman, 2000) ISBN 9780582404663

Tindell H – *Engineering Materials*, *Crowood Metalworking Guides* (The Crowood Press, 2014) ISBN 9781847976796

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Structure and Classification of Engineering Materials	Questions relating to the structure and classification of the range of engineering materials	A written report containing reasoned answers to the set questions
P4, M1	Properties of Engineering Materials	Questions relating to the properties and behaviour of engineering materials.	A written report containing reasoned answers to the set questions
P5, M2, D1	Selection of Engineering Materials	Selection of engineering materials for given applications	A written report listing selection criteria, information sources and justification for selected materials
P6, P8, M3	Failure and Degradation of Engineering Materials	Questions relating to the range of failure modes and degradation processes in engineering materials	A written report containing reasoned answers to the set questions
P7, M4, D2	Testing Engineering Materials	Carry out and report the results of destructive and non-destructive tests on engineering materials	A written report containing an explanation of test procedure and evaluation of test results

The evidence to satisfy the pass criteria P1, P2 and P3 could be achieved by means of a written assignment following a combination of tutor-led practical and theory sessions and individual research. P2 would require the range of materials given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, an elastomer, one ceramic, one composite, one smart material and one natural material.

Achievement of P4 and M1 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with real engineering applications. For smart materials, they need to consider the effects on the properties of the materials' use after production. Examples here may be related to their change in properties from the effects of external stimuli. For example, when a force is applied to a piezoelectric material it produces an electric charge which can be used to trigger a car's airbag in the event of an accident. In many applications the behaviour is reversible, for example a colour change in response to a change in temperature or a variation in the viscosity of a liquid in response to the application of an electric or magnetic field. To satisfy P5, it is likely that learners would apply the knowledge and understanding gained in meeting criteria P1 to P4. Written responses would satisfy these criteria.

P7 could be met using a combination of practical and research activities involving tutor-led demonstrations of available laboratory tests. Learners could then carry out a series of tests and produce a written record of the test results. A witness statement could confirm the learner's involvement. Depending on available resources, it may be best to carry out the destructive test on the non-metallic material and the non-destructive test on the metallic material. This would allow a wider choice of tests for the latter.

To achieve P6 and P8, learners could be given the opportunity to research modes of failure and degradation processes reflected in local conditions, for example a marine environment, or, for employed apprentices, failure and degradation pertinent to their companies' products.

To achieve the merit grade M1, learners will need to explain how the structure and properties of given materials will affect their behaviour in use. This evidence would be best demonstrated by a written task related to the activities carried out to meet P1, P2 and P3. For M2, learners should consider design, cost and availability criteria in their explanation. To satisfy M3, learners could produce a written explanation of the test procedures followed in P7 and the usefulness of the results. In producing evidence for some of this criterion it may be appropriate to include the responses to oral questions. However, centres should ensure that such questions and the responses are recorded for verification and also that they are not the sole source of evidence. M4 could be achieved through an extension of the task given for P8. The processes used in the explanation could be selected to meet local conditions or industrial applications.

To achieve criterion D1, learners need to justify their selection of one of the materials used to satisfy P5, giving reasons why other materials considered for the application were not selected. To satisfy D2, learners are expected to complete a written task to evaluate the results of one of the tests used to meet P7 and M4.

The evidence would depend on the test used but it could include the mathematical results of a tensile test, the values of a hardness test or detailed information gained from a non-destructive test.

Unit 6: Advanced Manual Turning Techniques

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

Engineers use a variety of machinery during the manufacture of finished products. By conducting turning operations that rotate about a centre, engineers can produce complex components to close tolerances. However, the machinery can be dangerous to operate.

In this unit, learners will learn the theory of advanced manual turning techniques using centre lathes whilst complying with relevant legal requirements and current quality standards. They will explore the concepts of different advanced turning techniques and the types of cutting tools and work holding devices that can be used. They will also learn how to determine the correct machining parameters and how to plan the sequence of operations in order to produce components using advanced turning techniques.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit, you will:

1 Understand advanced manual turning techniques

2 Understand how to prepare for advanced manual turning operations

3 Understand the principles of thread cutting using advanced manual turning techniques.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the health and safety requirements applicable to manual turning operations		
P2 Explain advanced manual turning techniques	**M1** Analyse advanced manual turning techniques and tools	**D1** Justify the use of advanced manual turning techniques and tooling in a given situation
P3 Explain the types of tooling available	**M2** Compare cutting tool materials available	
P4 Explain the machining set-up chosen to produce a component from a given drawing	**M3** Assess the effectiveness of machining set-up chosen to produce the required component to the required tolerances	**D2** Justify the machining set-up chosen to produce the required component to the required tolerances
P5 Explain how typical threads are cut on a centre lathe	**M4** Determine the machining parameters required for given thread cutting operations	**D3** Interpret the requirements of given internal and external thread cutting operations to prepare detailed work instructions, using consistently correct technical language
P6 Explain the types of tooling used when cutting internal and external threads.	**M5** Assess the suitability of types of tooling used when cutting internal and external threads	

Unit content

What needs to be learned
Learning outcome 1: Understand advanced manual turning techniques

- Procedures, safety precautions and applicable health and safety requirements relating to the mounting of ancillary equipment and accessories on a centre lathe:
  - specific safety precautions relating to the mounting setting and use of ancillary equipment, work holding devices and accessories on a centre lathe, e.g., faceplates, fixed steadies, travelling steadies, mounting components off centre, taper turning attachment; ensuring that the accessory/ancillary equipment is secure and freedom of movement of cutting tools before starting the machine
  - fitting and adjustment of machine guarding
  - procedures for checking the emergency mechanisms are working correctly, e.g., emergency stop button, guard interlocks
  - use of coolant.
- Typical advanced turning techniques:
  - taper turning:
    - taper specifications including taper per unit length, tangent, gradient and the included angle
    - methods of producing internal tapers including reamers and taper boring and the advantages/disadvantages and limitations of each method
    - equipment used in taper tuning including compound slide, offset tailstock, form tools, taper turning attachment, fixed stead and travelling steady
    - measurement of internal and external tapers including the use of slips and sine bars and taper plug gauges
  - boring:
    - types of boring equipment and their advantages/disadvantages and limitations in use including standard boring bars, adjustable precision boring units, boring bars made from special materials
    - limitations of drills when used to produce bores
    - the types and use of reamers to finish bores and their standard geometry
    - the use of data sources to determine the relationship between drilling and reaming

What needs to be learned
o faceplate/eccentric turning: – methods of mounting an eccentric load on a faceplate – calculation of balance weight position on the faceplate – problems associated with out of balance turning, e.g., poor surface finish, damaged tooling, damaged machinery, personal injury. • Cutting tools and cutting tool materials: o the purpose of rake and clearance angles as applied to lathe tools o types of lathe tool including boring bars, parting tools, thread cutting tools (internal and external), turning tools (left and right hand), finishing tools, corner tools o the purpose of carbide insert chip breakers o cutting tool material types including HSS, coated HSS, plain and multi-coated tungsten carbides, cermets, CBN/diamond, Polycrystalline Diamond, Polycrystalline Cubic Boron Nitride. • Benefits and limitations of each cutting tool material type. • Work holding devices: o typical work holding devices that can be used when thread cutting including, three jaw chuck, four jaw chuck, collet chuck, faceplates o methods used to protect the surface finish of components during thread cutting operations.
Learning outcome 2: Understand how to prepare for advanced manual turning operations
• Planning for advanced manual turning operations: o determine the machining requirements from component drawings, including: – component material type/sizes – surface finish – dimensions/tolerances o type of turning operations required o sequence of machining operations o types of work holding devices and tooling required, e.g., fixed and travelling steadies, faceplates, balance weights, tailstocks, fixed and revolving centres, types of cutting tool required in relation to the material being cut and tolerance/surface finish requirements.

What needs to be learned
• Machine set-up for given advanced manual turning operations: o parameters that need to be considered when setting a centre lathe for advanced turning operations including: – determination of cutting speeds and feed rates by both calculation and the use of charts – depth of cut – selection of work holding devices/ancillary equipment – selection of appropriate cutting tools and setting at centre height – setting of stops – selection of tools for mounting in the tool post for efficiency. • Adjustment of tool height in relation to centreline of the material.
Learning outcome 3: Understand the principles of thread cutting using advanced manual turning techniques
• Thread forms: o geometry of typical metric and imperial single thread forms including UNC, UNF, metric fine, metric coarse, BSW, BSF, square and buttress o typical uses and limitations of thread types o techniques used in multi-pass thread turning using spindle reversal and thread-chasing dials o multi-start threads. • Tooling: o typical tools that can be used to cut screw threads on a centre lathe including taps and dies, internal thread cutting tools, external thread cutting tools o typical materials used to make thread cutting tools including high speed steel, brazed tip, replaceable inserts.

Essential information for tutors and assessors

Essential resources

Access to the internet and relevant engineering data tables is needed for this unit. Learners would also benefit from access to engineering workshops with centre lathes, associated cutting tools, work holding devices and ancillary equipment.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand advanced manual turning techniques	Learners could produce an information leaflet aimed at new apprentices that details the health and safety requirements when conducting advanced manual turning operations. It will also provide details of the types of tooling and associated tooling material types that can be used for taper turning, boring and faceplate/eccentric turning operations that enable operators to make informed choices regarding the suitability of using different types of techniques to conduct advanced manual turning operations.

Learning outcome	Recommended assessment approach
2 Understand how to prepare for advanced manual turning operations	Learners could produce a written report that explains and justifies their selection of tooling, equipment and machining parameters to produce a component to the required tolerances from a given engineering drawing.
3 Understand the principles of thread cutting using advanced manual turning techniques	Learners could produce a portfolio of evidence that includes detailed work instructions for a given threaded component and an information leaflet aimed at apprentice engineers that details the process and parameters for cutting typical internal and external threads on a centre lathe and the types of tooling that can be used.

For distinction standard (D1), learners will go beyond the requirements for the merit criteria to compare their preferred machine set-up to provide a clear justification as to why one taper turning technique, plus the associated tools, one boring technique, plus the associated tools, and one faceplate/eccentric turning technique plus the associated tools are best suited for a given advanced turning operation. Their justification will also detail why alternative techniques can be rejected. For example, drilling and reaming a taper bore may be preferable over other taper boring methods due to the speed of producing the bore and the surface finish requirements.

For merit standard (M1), learners will go beyond the explanations given for the pass criteria by analysing the benefits and limitations of the techniques, and tools they have detailed. For example, they could explain why a taper-turning attachment might be used instead of offsetting the tailstock for certain operations. Learners will also compare four types of cutting tool material giving their relative benefits and limitations of use (M2).

For pass standard (P2), learners explain at least two techniques that can be used for taper turning operations and at least two techniques that can be used for boring operations using suitable component examples. They will also explain how faceplate/eccentric turning operations can be used to turn complex components, with valid reasons.

They will explain the use of at least four tools that are available to conduct taper turning, faceplate/eccentric turning and boring operations with valid examples (P3). Learners will also provide an explanation setting out the main points of the health and safety requirements (P1) pertaining to themselves and their employers in order to conduct turning operations safely.

For distinction standard (D2), learners will go beyond the requirements for the merit criterion and will justify their selected machining set-up to produce the given component to the required tolerances, including the consideration of alternative approaches that could have been used to manufacture the component from a given engineering drawing. For example, travelling steadies may be preferable over fixed steadies when turning a long shaft due to the diameter of the shaft and shaft run out requirements.

For merit standard (M3), learners will go beyond the explanation given for the pass criterion to assess the suitability and effectiveness of the chosen machining set-up in order to produce the component to the required tolerances. For example, learners could detail why fixed steadies are not the most suitable when turning small diameter shafts.

For pass standard (P4), learners will explain the machining parameters, such as the material being cut, dimensions, tolerances, surface finish, tooling requirements, speeds and feed rates and the sequence of operations that must be taken into account when planning machining operations/set-up for the efficient manufacture of a component from a given engineering drawing.

For distinction standard (D3), learners will produce detailed work instructions for the manufacture of the threaded component. The work instructions will justify the use of appropriate tooling, techniques and machining parameters and will be sufficiently detailed to enable a competent third party to set-up a centre lathe and manufacture the given component. Learners will use consistently correct technical language.

For merit standard (M4), learners will go beyond the explanations given for the pass criteria and will accurately calculate the machining parameters required for two thread cutting operations (one internal, one external) such as cutting speeds, feed rates and depths taking into account surface finish, material specification and cutting tool parameters.

Learners are expected to reference and use engineering data tables and manufacturers' specifications where appropriate. They must also assess the suitability of their selected tooling when cutting an internal and an external thread (M5) in order to produce the component to the required tolerances.

For Pass standard (P5), learners will explain how to use a centre lathe to cut thread types and associated thread geometries featured on a given engineering drawing of a single item component. The component will be sufficiently complex to include at least three different thread types and will include both internal and external threads with one thread form being multi-start. They will also need to explain the types of tooling used to cut screw threads on a centre lathe to produce the same component (P6).

Unit 7: Advanced Manual Milling Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Engineers use a large variety of machinery during the manufacture of finished products. By conducting milling operations engineers can produce complex parts with close tolerances, however the machinery can be dangerous to operate.

In this unit you will learn the theory of advanced manual milling techniques that can be used depending on the type of milling machine in use in the workplace, whilst complying with relevant legal requirements and current quality standards. You will explore the concepts of different advanced milling techniques and the types of cutting tools and work holding devices that can be used. You will also learn how to determine the correct machining parameters and how to plan the sequence of operations in order to produce components using advanced manual milling techniques.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand advanced manual milling techniques

2 Understand how to prepare for advanced manual milling operations

3 Understand the principles of cutting gears using advanced manual milling operations.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the health and safety requirements applicable to milling operations		
P2 Explain advanced manual milling techniques	**M1** Analyse advanced manual milling techniques, tools and equipment	**D1** Justify the use of advanced manual milling techniques, tooling and equipment in a given situation
P3 Explain the types of tooling and equipment available	**M2** Compare cutting tool materials available	
P4 Explain the machining set-up chosen to produce a component from a given drawing	**M3** Assess the effectiveness of machining set-up chosen to produce the required component to the required tolerances	**D2** Justify the machining set-up chosen to produce the required component to the required tolerances
P5 Explain how typical gears are cut on a milling machine	**M4** Calculate the machining parameters required for a given gear cutting operation	**D3** Interpret the requirements of given gear cutting operations to prepare detailed work instructions, using consistently correct technical language
P6 Explain work holding and indexing and the tooling used when cutting gears	**M5** Assess the suitability of work holding and indexing and the tooling used to meet the requirements of given gear cutting operations	

Unit content

What needs to be learned
Learning outcome 1: Understand advanced milling techniques
• Procedures, safety precautions and applicable health and safety requirements relating to the mounting of ancillary equipment and accessories on a milling machine: o the specific procedure and safety precautions relating to the mounting, setting and use of ancillary equipment, work holding devices and accessories on a milling machine, e.g. collet chucks, dividing head, tailstock and rotary table; ensuring that the accessory/ancillary equipment is secure and that there is freedom of movement of cutting tools before starting the machine o fitting and adjustment of machine guarding o procedures for checking the emergency mechanisms are working correctly, o e.g. emergency stop button, guard interlocks o o use of coolant. • Typical advanced milling techniques: o straddle milling – equipment used in straddle milling including arbour, types of cutters, spacers o spiral milling: – equipment used in spiral milling including universal dividing head and tailstock – the determination of indexing and angular rotation values using charts and by calculation – types of cutters used in spiral milling o cam milling: – equipment used in cam milling including diving head and associated gears, types of cutters used in cam milling – determining the correct gear ratio when gearing the dividing head to the lead screw of the table – determining the angle of the milling machine spindle from vertical and the dividing head chuck from the horizontal o dovetail milling: – types of dovetail cutters – dovetail specifications including male and female parts, dovetail angle, length of dovetail – measurement of dovetails including parallelism of sides

What needs to be learned
– procedure of clamping the material to the mill prior to carrying operations including clamping of female parts on the sides and milling along the y axis, clamping of male parts and milling along the x-axis. • Cutting tools and cutting tool materials: o types of cutting tool materials including High Speed Steel (HSS), ceramics and carbides o benefits and limitations of each cutting tool material type o types of cutting tool including slot drills, end mills, dovetail, angle cutters, face mills, slide and face, boring heads, drills and reamers o the purpose of rake and clearance angles as applied to milling tools and their influence on cutting efficiency o the benefits and limitations of up-cut milling and climb milling.
Learning outcome 2: Understand how to prepare for advanced manual milling operations
• Planning for advanced milling operations: o determine the machining requirements from component drawings including: – component material type/size – surface finish – dimensions/tolerances o type of milling operations required o sequence of machining operations o types of work holding devices and tooling required such as dividing heads, rotary tables, tailstocks, types of cutters required. • Machine set-up for given advanced manual milling operations: o parameters that need to be considered when setting a milling machine for advanced milling operations including: – determination of cutting speeds and feed rates by both calculation and the use of charts – selection of work holding devices/ancillary equipment – selection of appropriate cutting tools and depth of cut – setting of stops – efficiency of tooling changeover.

What needs to be learned
Learning outcome 3: Understand the principles of cutting gears using advanced manual milling operations
• Gear types: o the types of gear in common use including straight spur gears, bevel gears, helical spur gear, spiral bevel gear, mitre gears, worm gears rack and pinions o typical uses and limitations of the gear types o gear tooth terminology including involute, conformal, base circle, base diameter, pitch circle, pitch diameter, gear tip, tip circle, tip diameter, pressure angle, gear root. • Machining gears using a milling machine: o the machine requirements for cutting gears with the correct number of teeth o setting and checking of the Pitch Circle Diameter (PCD) of a gear before machining o the types of milling cutters that can be used to produce gears including straight toothed spur gears, straight toothed bevel gears, helical spur gears and worm gears o types of material used for milling cutters including high-speed steel, cemented carbide tip, stellites, ceramics o the principles of gear hobbing its application for the mass production of gears o the uses and setting of dividing heads and rotary tables o the determination of indexing and angular rotation values using charts and by calculation o the procedures for aligning dividing heads and rotary tables including use of parallel setting bars, Dial Test Indicators (DTIs) and approximation.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are: access to the internet and relevant engineering data tables. Learners would also benefit from access to engineering workshops containing milling machines, associated cutting tools, work holding devices and ancillary equipment.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand advanced manual milling techniques	Learners could produce an information leaflet aimed at new apprentices that details the health and safety requirements when conducting advanced manual milling operations. It will also provide details of the types of tooling and associated tooling material types that are available that enable operators to make informed choices regarding the suitability of using different types of techniques/equipment to conduct advanced milling operations including straddle/spiral/cam/dovetail milling.

Learning outcome	Recommended assessment approach
2 Understand how to prepare for advanced manual milling operations	Learners could produce a written report that explains and justifies their selection of tooling, equipment and machining parameters to produce a component to the required tolerances from a given engineering drawing.
3 Understand the principles of cutting gears using advanced manual milling techniques	Learners could produce a portfolio of evidence that includes a detailed work instruction for a given gear cutting operation and an information leaflet aimed at apprentice engineers that details the process of cutting a typical gear on a manual milling machine and the types of work holding and indexing and tooling that can be used.

For distinction standard (D1), learners will go beyond the requirements for the merit criteria to provide a clear justification as to why the chosen advanced milling techniques and tooling are best suited for a given advanced milling operation. The justification will also detail why alternative techniques can be rejected. For example, the justification could include consideration of the material to be machined, dimensional tolerances and efficiency of operation.

For merit standard (M1), learners will go beyond the explanation given for the pass criteria by analysing the benefits and limitations of the techniques, tools and equipment they have detailed. Learners will also compare four types of cutting tool material giving their relative benefits and limitations of use (M2).

For pass standard (P2, P3), learners will explain the techniques, tooling and equipment that can be used for four advanced milling operations as detailed in the unit content using suitable component examples. They will explain the use of at least four tools and four pieces of equipment that are available to conduct the advanced milling operations, with valid examples. Learners will also provide an explanation setting out the main points of the health and safety requirements (P1) pertaining to themselves and their employers in order to conduct milling operations safely.

For distinction standard (D2), learners will go beyond the requirements for the merit criterion and will justify their selected machining set-up to produce the given component to the required tolerances, including a consideration of alternative approaches that could have been used to manufacture the component from a given engineering drawing. For example, they could compare the use of horizontal and vertical milling machines when conducting a range of milling operations, drawing valid conclusions.

For merit standard (M3), learners will go beyond the explanations given for the pass criterion to assess the suitability and effectiveness of the chosen machining set-up in order to produce the component to the required tolerances.

For pass standard (P4), learners will explain the machining parameters, such as the material being cut, dimensions, tolerances, surface finish, tooling requirements, speeds and feed rates and the sequence of operations/set-up that must be taken into account when planning machining operations for the efficient manufacture of a component from a given engineering drawing.

For distinction standard (D3), learners will produce a detailed work instruction for the manufacture of the gear component. The work instruction will justify the use of appropriate work holding devices, tooling, techniques and machining parameters and will be sufficiently detailed to enable a competent third party to setup a milling machine and manufacture the given component. Learners will consistently use correct technical language.

For merit standard (M4), learners will go beyond the explanations given for the pass criteria and will accurately calculate the appropriate machine parameters for the gear cutting operations such as cutting speeds, indexing and depths, taking into account surface finish, material specification and cutting tool parameters. Learners are expected to reference and use engineering data tables and manufacturers' specifications where appropriate. They must also assess the suitability of their selected work holding and indexing equipment, and the tooling used, when cutting gears (M5) in order to produce the component to the required specification.

For pass standard (P5), learners will explain how to use a milling machine to cut typical gears featured on a given engineering drawing of a single item component. They will also need to explain the use of work holding devices and tooling and how indexing is used to produce gears on a milling machine (P6).

Unit 8: Advanced Manual Milling and Turning Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Engineers use a large variety of machinery during the manufacture of finished products. By conducting advanced milling and turning operations engineers can produce complex parts with close tolerances, however, the machinery can be dangerous to operate.

In this unit you will learn the theory of how to undertake advanced manual milling and turning operations using milling machines and centre lathes whilst complying with relevant legal requirements and current quality standards. You will explore the concepts of different advanced milling and turning techniques and the types of cutting tools and work holding devices that can be used.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand health and safety relating to advanced manual milling and turning techniques

2 Understand advanced manual milling and turning techniques

3 Understand how to prepare for advanced manual milling and turning operations.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the procedures, safety precautions and health and safety requirements applicable to the mounting of equipment and accessories to milling machines and centre lathes	**M1** Assess the key features of the health and safety requirements applicable to advanced milling operations and advanced turning operations	
P2 Explain advanced manual milling and turning techniques	**M2** Analyse advanced manual milling and turning techniques, tools and equipment	**D1** Justify the use of advanced manual milling and turning techniques, tools and equipment in a given situation
P3 Explain the types of milling and turning tooling and equipment required	**M3** Compare cutting tool materials available	
P4 Explain the machining set-up to produce a milled component from a given drawing	**M4** Assess the effectiveness of machining set-ups chosen to produce the required milled and turned components to the required tolerances	**D2** Justify the machining set-ups chosen to other possible set-ups that could be used to produce the required milled and turned components to the required tolerances
P5 Explain the machining set-up to produce a turned component from given drawing.		

Unit content

What needs to be learned
Learning outcome 1: Understand health and safety relating to advanced manual milling and turning techniques
• Procedures, safety precautions and applicable health and safety requirements relating to the mounting of ancillary equipment and accessories on a milling machine: o the specific procedures, safety precautions and appropriate health and safety requirements relating to the mounting, setting and use of ancillary equipment, work holding devices and accessories on a milling machine, e.g. collet chucks, dividing head, tailstock and rotary table; ensuring that the accessory/ancillary equipment is secure and that there is freedom of movement of cutting tools before starting the machine o fitting and adjustment of machine guarding o procedures for checking the emergency mechanisms are working correctly o e.g. emergency stop button, guard interlocks o use of coolant o environmental considerations such as safe/correct disposal of waste, e.g. swarf, coolant, offcuts of material and recycling, maintaining the work area in a safe and tidy condition, reporting damage and faults o relevant environmental management legislation and regulations, e.g. EU waste legislation, hazardous waste regulations.
Learning outcome 2: Understand advanced manual milling and turning techniques
• Typical advanced milling techniques: o straddle milling – equipment used in straddle milling including arbour, types of cutters, spacers o spiral milling: – equipment used in spiral milling including universal dividing head and tailstock – the determination of indexing and angular rotation values using charts and by calculation – types of cutters used in spiral milling o cam milling: – equipment used in cam milling including diving head and associated gears, types of cutters used in cam milling – determining the correct gear ratio when gearing the dividing head to the lead screw of the table

What needs to be learned
– determining the angle of the milling machine spindle from vertical and the dividing head chuck from the horizontal o dovetail milling: – types of dovetail cutters – dovetail specifications including male and female parts, dovetail angle, length of dovetail – measurement of dovetails including parallelism of sides – procedure of clamping the material to the mill prior to carrying operations including clamping of female parts on the sides and milling along the y-axis, clamping of male parts and milling along the x-axis. • Cutting tools and cutting tool materials used for milling: o types of cutting tool materials including High Speed Steel (HSS), ceramics and carbides o benefits and limitations of each cutting tool material type o types of cutting tool including slot drills, end mills, dovetail, angle cutters, face mills, slide and face, boring heads, drills and reamers o the purpose of rake and clearance angles as applied to milling tools and their influence on cutting efficiency o the benefits and limitations of up-cut milling and climb milling. • Typical advanced turning techniques: o taper turning: – taper specifications including taper per unit length, tangent, gradient and the included angle – methods of producing internal tapers including reamers and taper boring and the advantages/disadvantages and limitations of each method – equipment used in taper tuning including compound slide, offset tailstock, form tools, taper turning attachment, fixed and travelling steadies – measurement of internal and external tapers including the use of slips and sine bars and taper plug gauges o boring: – types of boring equipment and their advantages/disadvantages and limitations in use including standard boring bars, adjustable precision boring units, boring bars made from special materials – limitations of drills when used to produce bores – the types and use of reamers to finish bores and their standard geometry

What needs to be learned
– the use of data sources to determine the relationship between drilling and reaming o faceplate/eccentric turning: – methods of mounting an eccentric load on a face plate – calculation of balance weight position on the face plate – problems associated with out of balance turning, e.g. poor surface finish, damaged tooling, damaged machinery, personal injury. • Cutting tools and cutting tool materials used for turning: o the purpose of rake and clearance angles as applied to lathe tools o types of lathe tool including boring bars, parting tools, turning tools (left and right hand), finishing tools, corner tools o the purpose of carbide insert chip breakers o cutting tool material types including HSS, Coated HSS, plain and multi-coated tungsten carbides, cermets, CBN/Diamond, Polycrystalline Diamond, Polycrystalline Cubic Boron Nitride o benefits and limitations of each cutting tool material type.
Learning outcome 3: Understand how to prepare for advanced manual milling and turning operations
• Planning for advanced manual milling operations: o determine the machining requirements from component drawings including component material type/size, surface finish, dimensions/tolerances, type of milling operations required such as straddle milling/spiral milling/cam milling/dovetail milling and sequence of machining operations o types of tooling required such as dividing heads, rotary tables, tailstocks, types of cutters required, types of cutting tool required in relation to the material being cut and tolerance/surface finish requirements. • Machine set-up for given advanced manual milling operations: o parameters that need to be considered when setting a milling machine for advanced milling operations including determination of cutting speeds and feed rates by both calculation and the use of charts, selection of work holding devices/ancillary equipment, selection of appropriate cutting tools and depth of cut, setting of stops, efficiency of tooling changeover.

What needs to be learned
• Planning for advanced manual turning operations: o determine the machining requirements from component drawings including component material type/sizes, surface finish, dimensions/tolerances, type of turning operations required such as boring/taper turning/faceplate turning, and sequence of machining operations o types of tooling required such as fixed and travelling steadies, faceplates, balance weights, tailstocks, fixed and revolving centres, types of cutting tool required in relation to the material being cut and tolerance/surface finish requirements. • Machine set-up for given advanced manual turning operations: o parameters that need to be considered when setting a centre lathe for advanced turning operations including determination of cutting speeds and feed rates by both calculation and the use of charts, depth of cut, selection of work holding devices/ancillary equipment, selection of appropriate cutting tools and setting at centre height, setting of stops, selection of tools for mounting in the tool post for efficiency, adjustment of tool height in relation to centreline of the material.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are access to the internet and relevant engineering data tables. Learners would also benefit from access to engineering workshops containing centre lathes, milling machines, associated cutting tools, work holding devices and ancillary equipment.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand health and safety relating to advanced milling and turning techniques	Learners could produce an information leaflet aimed at new apprentices that assesses the key features of health and safety requirements relating to advanced manual milling and turning operations. It will also explain the specific procedures and safety precautions applied when mounting equipment and accessories onto milling machines and centre lathes.
2 Understand advanced manual milling and turning techniques	Learners could produce a written report that explains and justifies the techniques, tools and equipment that are available and required to conduct advanced milling and turning operations including the types of materials that cutting tools can be manufactured from.

Learning outcome	Recommended assessment approach
3 Understand how to prepare for advanced milling and turning operations	Learners produce a written report that explains appropriate set-ups when planning the machining operations for one given milled component and one given turned component. They will also consider and justify the effectiveness of the set-ups and what other set-ups could be used for both components to ensure they are made to the required tolerances.

For merit standard (M1), learners will go beyond the explanation given for the pass criterion by assessing the key features of health and safety requirements that are relevant to the safe operation of milling machines and centre lathes during advanced machining operations. Learners will give examples of relevant machining situations that the requirements apply to and consider what may happen if the said requirements were not applied.

For pass standard (P1), learners will explain the procedures and specific safety precautions that must be applied when mounting equipment and accessories to manual milling machines and centre lathes so they can conduct advanced milling and turning operations. Learners will support their work with at least four valid examples − two for milling and two for turning.

For distinction standard (D1), learners will go beyond the requirements of the merit criteria to provide a clear justification as to why the chosen advanced milling and turning techniques, tools and equipment are best suited for given advanced milling and turning operations. Their justification will detail why alternative techniques, tooling and equipment can be rejected for the advanced manual turning operations and the advanced manual milling operations. For example, the justification could include consideration of the material to be machined, dimensional tolerances and efficiency of operation and why a certain work holding device would be used over another type.

For merit standard (M2), learners will go beyond the explanations for the pass criteria by analysing the benefits and limitations of the techniques, tools and equipment they have detailed for each of the milling and turning operations. Learners will also compare four types of cutting tool material giving their relative benefits and limitations of use (M3).

For pass standard (P2), learners will explain the techniques that can be used for two types of advanced manual milling operation and two types of advanced manual turning operation as detailed in the unit content, using suitable component examples. For example, they could explain how a centre lathe is used to conduct taper boring operations and faceplate operations and how a milling machine is used to produce accurate dovetail slots and spiral milling operations with relevant examples. Learners will also need to explain the types of tooling and the other equipment required to conduct the chosen advanced milling and turning operations, with valid examples (P3).

For distinction standard (D2), learners will go beyond the requirements for the merit criterion to justify the machining set-ups chosen to produce the milled and turned components to the required tolerances. Their justification should include a consideration of other possible set-ups that could be used. The other possible set-ups will be detailed in full and learners will provide valid reasons why the original set-ups chosen are more valid, when considering machining efficiency, tolerances, surface finish, safety and costs.

For merit standard (M4), learners will go beyond the explanations given for the pass criteria and will assess the effectiveness of the machining set-ups chosen to produce the milled component and the turned component to the required tolerances. They will show their consideration of appropriate machining parameters for the milling and turning operations, such as cutting speeds and feed rates, taking into account surface finish, material specification and cutting tool parameters. They will include details of why their selected tooling, equipment and work holding devices are suitable in order to produce the components to the required tolerances. Learners are expected to show in their assessment evidence that they have used engineering data tables, manufacturers' specifications and, where appropriate, carried out calculations to determine the appropriate machine set-up parameters.

For pass standard (P4, P5), learners will use given engineering drawings of two components, one milled and one turned, to explain how to set up a centre lathe and a milling machine to produce them both. Learners will explain the machining parameters, such as the material being cut, dimensions, tolerances, surface finish, tooling requirements, speeds and feed rates and the sequence of operations that must be taken into account when planning machining operations/set-up for the efficient manufacture of the components from given engineering drawings.

Unit 9: CNC Programming

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Computer Numerically Controlled (CNC) programming is used as a method of controlling machining tools using computers and digital circuitry. The ability to successfully complete numerical programming facilitates the automation of the production of parts, meaning that products and items can be produced quickly and economically.

The purpose of this unit is to introduce manual programming for CNC applications. You will gain an understanding of the basic concepts of typical CNC program structures. You will learn how to programme repetitive CNC operations using sub-routines, loops and 'canned' cycles. You will know how to write a CNC program to cut a part. Finally, you will determine how to debug your program and set-up and use the program safely to operate a CNC machine.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand the principles of numerical control programming language

2 Know how to write and use numerical control programs to produce a part

3 Know how to programme repetitive numerical control machine operations

4 Understand how to safely communicate with and set up a numerical control machine.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the three-dimensional space parameters controlled in a CNC program		
P2 Describe with the aid of a program flow chart the structure of a given CNC program	**M1** Assess the importance of different parts of a given CNC program	
P3 Describe the key steps that must be programmed in to control a CNC cutting tool	**M2** Compare the features and benefits of different types of CNC program command	**D1** Evaluate the features and benefits of different types of command within a given structure of a CNC program used to cut a given part
P4 Describe different types of CNC program command		
P5 Explain the typical address categorisation used in CNC program code		
P6 Describe the purpose and features of sub-routines and sub programs used in a given CNC program	**M3** Compare the use of sub- routines, sub-programs, loops and 'canned' cycles used in two given CNC programs	
P7 Describe the purpose and features of loops used in a given CNC program		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Describe the purpose and features of 'canned' cycles used in a given CNC program		
P9 Describe the process of debugging a CNC program	**M4** Assess the importance of debugging a CNC program to ensure the safe cutting of a given part using a CNC machine	**D2** Evaluate the benefits and importance of debugging a CNC program to achieve the safe and efficient set-up of a CNC machine to cut a given part
P10 Describe the safe set-up of a CNC machine using a CNC program		

Unit content

What needs to be learned
Learning outcome 1: Understand the principles of numerical control programming language
• Moving in three-dimensional (3D) space: o Axis, e.g., z-axis, x-axis, y-axis, coordinates; directions, e.g., positive cutting too and the direction for different spindles; location, e.g. origin, datum points; positioning, e.g. absolute and incremental positioning of the cutting tool. • Program structure: o program structure: blocks, e.g., End of Block (EOB), flow charts to represent program blocks; statements; 'canned cycle'; characters; register, e.g., Tool Length Offset o program formats and syntax, e.g., fixed sequential, tab sequential and word address.
Learning outcome 2: Know how to write and use numerical control programs to produce a part
• Key steps for programming cutting tools: o data to control the destination of the cutter, the cutting path, e.g., point-to-point or continuous o speed of travel, e.g., rapid or federated; action of the cutter at the destination, o e.g., move to the next destination, drill or stop cutting. • Features and benefits of different types of commands: o modal, non-modal and axis commands o cutting commands for tool motion including linear, radius or circular (arc) motion o miscellaneous commands including those to facilitate automatic or manual tool changing, control and selection of the spindle speed, control of the feed rate. • Preparatory code and function: o Types, e.g. G-Code, M-Code, S-Code, T-Code o code address categorisation, e.g. move the cutter, offset the centre of the cutter, accept measurement data, position, relocate the origin, execute 'canned' cycles, modify operational characteristics.

What needs to be learned
Learning outcome 3: Know how to programme repetitive numerical control machine operations
• Sub-routines or macro: o difference between sub-routines and sub-programs o types and use of sub-routines in code, e.g., milling of repetitive groove, pockets or holes o sub-routine programming rules, e.g., identifying the sub-routine o specifying sub-routine content, means to call up the sub-routine for execution o sub-routine syntax, e.g., branching commands, sub-routine labels, end of sub-routine demarcation, nesting. • Loops: o purpose of loops o typical use of loops, e.g., drilling a linear array of holes; loop programming rules, e.g., identifying the end or beginning of the loop, specifying where to loop back to or from, declaring the number of times the loop repeat; do-loop syntax. • 'Canned 'or fixed cycles: o purpose of 'canned' cycles o types of 'canned' cycles, e.g., fixed, roughing, threading, drilling, tapping; programming a machining activity using 'canned' cycles; customised 'canned' cycles; advantages of the adoption of 'canned' cycles.
Learning outcome 4: Understand how to safely communicate with and set up a numerical control machine
• Program debugging: o simulations and 'dry-runs' of programs o locating and removing bugs, errors and abnormalities o debugging tools o benefits of debugging, e.g. improvement in cycle time or lengthened tool life. • CNC machine set up: o loading the program onto the machine interface, clamping the part, setting tools, locating the origin point, running the program.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are:

- access to a two- or three-axis CNC machine tool
- access to a two- or three-axis machine tool that can be programmed with data from a computer system
- access to a computer with a CNC program language platform
- examples of CNC program code for different machining applications.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand the principles of numerical control programming language	A portfolio requiring learners to demonstrate their knowledge of the underlying principles of CNC programming language. Learners complete tasks in which they need to produce a written description of the CNC three-dimensional space parameter, and a program flow chart describing the key structural elements of a CNC program, with consideration of the importance of each aspect.

Learning outcome	Recommended assessment approach
2 Know how to write and use numerical control programmes to produce a part	A portfolio relating to a CNC program code used to cut a given part. Learners interpret a given CNC code and describe the sequence of key program instruction within the given code. Learners also explain the address categorisation code used in CNC programs. Additionally, learners will consider the features and benefits of different types of CNC program command within the code.
3 Know how to program repetitive numerical control machine operations	An assignment requiring learners to demonstrate their knowledge of how to program repetitive numerical control machine operations. Learners complete written tasks for which they need to produce a description/comparison of the purpose and features of sub-routines and sub-programs, loops and 'canned' cycles.
4 Understand how to safely communicate with and set up a numerical control machine	Learners will prepare a written portfolio illustrated with photographs and diagrams to describe the steps required to safely set up the CNC machine using a program code. Learners will also consider the process of debugging a CNC program to cut a given part and will examine the importance of this to ensure safe and efficient set-up of the CNC machine.

For merit standard (M1), learners go beyond the requirements for the pass criteria to assess the importance of all the parts of a given CNC program code including details of the contribution of each, arriving at a valid conclusion on their importance. The evidence should consider key syntax statements such as the End of Block, as well as the principal elements of code structure.

For pass standard (P1), learners will need to evidence sufficient knowledge of how to position a generic CNC cutter in relation to an origin point in three axes. To achieve this, learners will give a clear account of the x-axis, y-axis and z-axis, directions, location and absolute positioning of a tool.

Learners will also produce a program flow chart interpreting the structure of a given CNC program (P2). Learners should annotate the program flow chart with descriptive comments covering details of the program formats. Learners should demonstrate a clear understanding of the principal structure elements of the code. A detailed understanding of every line of code syntax is not anticipated.

For distinction standard (D1), learners will go beyond the requirements for the merit criterion and will evaluate the features and benefits of different types of command within a given structure of a CNC program used to cut a given part. Learners will bring together all the information about the features and benefits of different types of command. Learners will draw on their evidence including relevant data relating to each command to form a conclusion about the contribution of each. Factors considered might be how robust certain commands are against the likelihood of error and how easy they are to program.

For merit standard (M2), learners will go beyond the requirements for the pass criteria and will compare the features and benefits of different types of command used in CNC programs. Learners will be expected to give clear details of the differences and similarities between the tasks performed by each command within a program used to cut a part.

For pass standard (P3), learners will describe the sequence of key steps/program instruction using a flow chart format. The description must include key commands such as the destination of the cutter, cutting path, speed of travel and action of cutter at the destination.

Learners must also give a clear description of different program commands within the code (P4), including modal, non-modal and axis commands and cutting commands for tool motion, for example linear, radian or circular, and miscellaneous commands, for example to facilitate tool changing, select spindle speed or to control feed rate. Using a written guide, learners should also explain the address categorisation used in the CNC program code, for example S-Code influencing spindle speed or T-Code for tool selection (P5).

For merit standard (M3), learners will go beyond the requirements for the pass criteria and compare the use of sub-routines, sub-programs, loops and 'canned' cycles used in two given CNC programs. Learners will be expected to show they clearly understand the differences and similarities between the tasks performed within each of the programs and will provide a suitable conclusion as to which program is the most efficient and why.

For pass standard (P6, P7, P8), learners will describe the purpose and features of sub-routines and sub-programs, loops and 'canned' cycles used in a given CNC program. Learners will give details of the specific task/s that each performs in a program and how to recognise each of them by specific start and end syntax within the body of the program.

For distinction standard (D2), learners will go beyond the requirements for the merit criterion and will draw together all their information to evaluate the benefits and importance of debugging a CNC program to achieve the safe and efficient set-up of a CNC machine to cut a given part.

Learners will consider, for example, the benefits on the minimisation of cycle time, the length of tool life, the safety of the operator and the importance of debugging in relation to planned maintenance and possible downtime and will reach valid and detailed conclusions.

For merit standard (M4), learners will go beyond the requirements for the pass criteria and will assess the importance of debugging a CNC program to ensure the safe set-up of a CNC machine to cut a given part. The learner's response will be contextualised and will, for example, consider all aspects of program debugging and the verification of a program before its actual use on the machine. The response will draw valid conclusions on the importance of debugging, for example, improved cycle time or lengthened tool life.

For Pass standard (P9), learners will describe the processes involved in debugging a CNC program. Learners will give examples of typical errors and describe the purpose and use of debugging tools and simulations to diagnose potential problems. Learners will also describe the safe set-up of a CNC machine using a CNC program including clamping the part, setting tools, locating the origin point and running the program (P10).

Unit 10: Advanced CNC Turning Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

The demand for high quality machined components with low lead times has led to the automation of traditional engineering machinery such as centre lathes and milling machines. These Computer Numerical Control (CNC) machines are complex to operate and require the machine operator to have skills that are different to those required for manual machining. For example, they may need to generate a part program and will spend more time on set-up and testing.

In this unit you will learn how to operate these machines safely whilst complying with relevant legal requirements. You will explore how CNC lathes undertake advanced turning operations, the types of cutting tools and work holding devices that can be used and how to produce computer programs for the manufacture of components. This unit is a theoretical unit and learners are not expected to manufacture actual components.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand the principles of Computer Numerical Control (CNC) turning operations

2 Understand how to interpret a component specification and produce an operational plan for its manufacture

3 Understand how to produce and test part programs for the manufacture of a turned component using manual programming and CAD/CAM procedures.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain how a CNC lathe differs from a manual centre lathe	**M1** Compare the use of CNC lathe and a manual centre lathe in relation to the manufacture a given component	**D1** Justify the use of CNC lathe over a manual centre lathe in relation to the manufacture of a given component
P2 Explain the CNC turning set-up and the cutting tools needed to produce a component from given detail drawing	**M2** Interpret the requirements from the given detail drawing to form a CNC turning operational plan for a given component	**D2** Justify the order in which CNC turning operations are planned for a given component
P3 Produce and test a part program using manual CNC part programming for a given component drawing	**M3** Assess the part program to ensure it effectively meets the requirements of the given component drawing	**D3** Justify amendments to the manual part program in order to optimise the cycle time
P4 Use a CAD/CAM package to produce a part program from a given component drawing/	**M4** Evaluate the benefits of using CAD/CAM software over manual CNC part programming	

Unit content

What needs to be learned
Learning outcome 1: Understand the principles of Computer Numerical Control (CNC) turning operations
• Health and safety requirements associated with CNC turning operations: o duties of employers and employees under relevant legislation and regulations including HASAWA, PUWER, Control of Noise at Work Regulations, PPE Regulations, Manual Handling Regulations, Display Screen Equipment Regulations. • Hazards associated with CNC operations and their control: o the hazards associated with CNC turning operations including high speed operation, manual handling of work pieces and equipment, automatic operation of tool and work handling devices, lack of operator control or intervention, noise levels o the control of hazards associated with CNC operations including operator training, emergency shutdown procedures, enclosed and interlocked guards, use of PPE. • Main features of CNC turning systems: o the function of the main parts of a CNC system including the machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction, Central Processing Unit (CPU), drive motors, quick change tooling, turret tools, cooling systems, display screens. • CNC machining parameters including datum points, designation of axes, definition of parameters using numerical coding, for example position, movement, spindle speeds, cutting tools, clamping.
Learning outcome 2: Understand how to interpret a component specification and produce an operational plan for its manufacture
• Component specification: o interpretation of a detailed drawing to obtain set-up data including material type, reference points including edge datum and centre line datum, dimensions including external, internal, bore diameters, bore depths, tolerances and surface finish. • Operational plan: o zero datums o work holding equipment such as chucks, faceplates, setting points o sequence of operations including loading, machining, roughing, finishing, measurement, unloading o calculation of tool path coordinates, tool compensation, cutting speeds, feed rates

What needs to be learned
o grouping of similar operations o CNC lathe tooling including external turning tools, parting tools, boring bars, drills, reamers, interior and exterior thread cutting tools o special requirements relating to specific materials o inspection and proving against specification.
Learning outcome 3: Understand how to produce and test part programs for the manufacture of a turned component using manual programming and CAD/CAM procedures
• Features of manual part programming software: o navigation around the user interface including menu bar, identification line, tool display window o system status including work/tool relationships including position, direction, amount of movement o rates of change of parameters including feed rates and spindle speeds o auxiliary functions including metric and imperial units, tool selection, cutting fluids o relevant CNC program codes and their functions, for example G codes, M codes, T codes o dimensional information including axis coordinates, absolute, incremental o block format, for example block number, program code, coordinates o special function program codes, for example measuring system, tool compensation, canned cycles o sub-routines including tool change, work holding, spindle speed, spindle direction. • Features of a CAD/CAM package: o typical hardware configuration including CAD workstation, data storage, hard copy equipment, network system o typical software packages, for example Solidworks, Catia, Autodesk Inventor, Denford VR milling/turning o typical data formats including extensions and proprietary formats, for example DXF, IGS, DWG, CDR, PCX, PLT. • Part program production and testing: o 3D geometric model using CAD software o selection of machining operations o selection of tooling o generation of CNC program using CAM software

What needs to be learned
○ simulation of tool changing and tool paths ○ program correction and editing ○ transfer of data files to CNC machine ○ pre-manufacture run through using graphics display on CNC machine, prove program, dry run.

Essential information for tutors and assessors

Essential resources

For this unit learners need access to the internet and relevant engineering data tables. Learners would also benefit from access to engineering workshops containing CNC lathes, associated cutting tools, work holding devices and ancillary equipment. They will also need access to CNC part programming and CAD/CAM software.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand the principles of computer numerical control (CNC) turning operations	A written report in which learners generate a justification for the use of a CNC lathe over a manual centre lathe to produce a given component. As part of this, they will detail how a CNC lathe differs from a manual centre lathe in terms of the main features of the machines, their safe operation and the different forms of control and will compare how the use of machines differs when producing the given component.
2 Understand how to interpret a component specification and produce an operational plan for its manufacture	Learners are provided with a detailed drawing and information about a component which they need to interpret. Learners will produce an operational plan covering the set-up and cutting tools required to manufacture the product on a CNC lathe and will justify the sequence of operations detailed in their operational plan.

Learning outcome	Recommended assessment approach
3 Understand how to produce and test part programs for the manufacture of a turned component using manual programming and CAD/CAM procedures	A practical task in which learners must use the operational plan developed for Learning outcome 2 to manually produce and test a part program for the manufacture of the given component, and then produce a part program for the same component using CAD/CAM software. In a further sub-task, learners will assess the part program to ensure it effectively meets the requirements of the given component drawing and then justify any amendments made to the program in order to meet the requirements of the component specification. Finally, learners will evaluate the benefits of using CAD/CAM software over CNC manual part-programming.

For distinction standard (D1), learners will go beyond the comparison given for the merit criterion and will justify the use of a CNC lathe over a manual centre lathe to produce the given component, with detailed reasons. Learners should, where possible, support their justification using technical examples from their own workplace.

For merit standard (M1), learners will go beyond the explanation given for the pass criterion and will compare the benefits and limitations of using a CNC lathe over a manual centre lathe in order to manufacture a component from a given detailed drawing. Learners must also include details of how the manufacture of the given component will differ using each. The given component must be sufficiently complex for manufacture using a CNC lathe to be a sensible consideration.

For pass standard (P1), learners will explain how a CNC lathe differs from a manual centre lathe in terms of the main features of the machines, their safe operation and the different forms of control. As part of this, learners will also provide an explanation setting out the main points of the health and safety legislation and regulations pertaining to themselves and their employers in order to conduct CNC turning operations safely.

For distinction standard (D2), learners will go beyond the production of a CNC operational plan produced for the merit criterion by providing details of the decisions they took when generating the said plan, with detailed reasons to support these decisions. As a minimum, the justification will relate to the sequencing of the machining operations and the tooling required.

For merit standard (M2), learners will go beyond the explanation for the pass criterion and will produce a comprehensive CNC operational plan for the manufacture of the given component shown in the detailed engineering drawing. Learners will need to support their operational plan using additional evidence in the form of annotated drawings detailing proposed tooling paths as appropriate, annotated specification sheets and calculations to support machining decisions such as speed and feed rates.

For pass standard (P2), learners will give a clear explanation of how a CNC lathe is to be set-up in order to produce a component using CNC turning techniques from a given detailed engineering drawing (component specification). They will also explain all of the types of cutting tools required to produce the component.

For distinction standard (D3), learners will go beyond the requirements for the merit criteria and will produce a written report that justifies any amendments they have made to their original part program, with detailed reasons to support the changes. For example, they may have amended it in order to reduce the run time and condense the number of steps and tool changes required.

For merit standard (M3), learners will go beyond the requirements for the pass criteria and will produce a written report that reviews their part program and then assesses where improvements to it could be made before reaching a conclusion on how well it enables the given component to be manufactured to the specification detailed in the given component drawing. Learners will also evaluate the benefits and limitations of using CAD/CAM software to produce CNC programs over the use of manual CNC part programming (M4). They will need to draw valid conclusions to their arguments that are appropriately supported with detailed reasons and examples.

For pass standard (P3), learners will produce and test a manual CNC part program from the CNC operational plan developed during the assessment for learning outcome 2. They will generate annotations on their part program that explain the sequence of machining operations for the given component. Learners will also produce a part program for the same component using CAD/CAM software (P4). Their evidence will include a range of annotated screenshots for both the manual programming and the programming using the CAD/CAM software.

Unit 11: Advanced CNC Milling Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

The demand for high quality machined components with low lead times has led to the automation of traditional engineering machinery such as centre lathes and milling machines. These Computer Numerical Control (CNC) machines are complex to operate and require the machine operator to have skills that are different to those required for manual machining. For example, they may need to generate a part program and will spend more time on set-up and testing.

In this unit you will learn how to operate these machines safely whilst complying with relevant legal requirements. You will explore how CNC milling machines undertake advanced milling operations, the types of cutting tools and work holding devices that can be used and how to produce computer programs for the manufacture of components. This unit is a theoretical unit and learners are not expected to manufacture actual components.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1. Understand the principles of Computer Numerical Control (CNC) milling operations
2. Understand how to interpret a component specification and produce an operational plan for its manufacture
3. Understand how to produce and test part programs for the manufacture of a milled component using manual programming and CAD/CAM procedures.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain how a CNC milling machine differs from a manual universal milling machine	**M1** Compare the use of CNC milling machine and a manual universal milling machine in relation to the manufacture of a given component	**D1** Justify the use of a CNC milling machine over a manual universal milling machine in relation to the manufacture of a given component
P2 Explain the CNC milling set-up and the cutting tools needed to produce a component from given detail drawing	**M2** Interpret the requirements from the given detail drawing to form a CNC milling operational plan for a given component	**D2** Justify the order in which CNC milling operations are planned for a given component
P3 Produce and test a part program using manual CNC part programming for a given component drawing	**M3** Assess the part program to ensure it effectively meets the requirements of the given component drawing	**D3** Justify amendments to the part program in order to optimise the cycle time
P4 Use CAD/CAM software to produce a part program from a given component drawing	**M4** Evaluate the benefits of using CAD/CAM software over manual CNC part programming	

Unit content

What needs to be learned
Learning outcome 1: Understand the principles of Computer Numerical Control (CNC) milling operations
• Health and safety requirements associated with CNC milling operations: o duties of employers and employees under relevant legislation and regulations including HASAWA, PUWER, Control of Noise at Work Regulations, PPE Regulations, Manual Handling Regulations, Display Screen Equipment Regulations. • Hazards associated with CNC operations and their control: o the hazards associated with CNC milling operations including high speed operation, manual handling of work pieces and equipment, automatic operation of tool and work handling devices, lack of operator control or intervention, noise levels o the control of hazards associated with CNC operations including operator training, emergency shutdown procedures, enclosed and interlocked guards, use of PPE. • Main features of CNC milling systems: o the function of the main parts of a CNC system including the machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction, Central Processing Unit (CPU), drive motors, quick change tooling, turret tools, cooling systems, display screens. • CNC machining parameters including datum points, designation of axes, definition of parameters using numerical coding, for example position, movement, spindle speeds, cutting tools, clamping.
Learning outcome 2: Understand how to interpret a component specification and produce an operational plan for its manufacture
• Component specification: o interpretation of a detailed drawing to obtain set-up data including material type, reference points including edge datum and centre line datum, dimensions including external, internal, slot length and depths, tolerances, surface finish. • Operational plan: o zero datums o work holding equipment such as vices, direct clamping to the table, setting points o sequence of operations including loading, machining, roughing, finishing, measurement, unloading

What needs to be learned
o calculation of cutter path coordinates, cutter compensation, cutting speeds, feed rates o grouping of similar operations o tooling including milling cutters, milling tool holders, end mills including centre cutting and indexable, flutes, face mills, indexable drills, spot drills, collect chucks, drill chucks o special requirements relating to specific materials o inspection and proving against specification.
Learning outcome 3: Understand how to produce and test part programs for the manufacture of a milled component using manual programming and CAD/CAM procedures
• Features of manual part programming software: o navigation around the user interface including menu bar, identification line, tool display window o system status including work/tool relationships including position, direction, amount of movement o rates of change of parameters including feed rates and spindle speeds o auxiliary functions including metric and imperial units, tool selection, cutting fluids o relevant CNC program codes and their functions, for example G codes, M codes, T codes o dimensional information including axis coordinates, absolute, incremental o block format, for example block number, program code, coordinates o special function program codes, for example measuring system, tool compensation, canned cycles o Sub-routines including tool change, work holding, spindle speed, spindle direction. • Features of a CAD/CAM package: o typical hardware configuration including CAD workstation, data storage, hard copy equipment, network system. typical software packages, for example Solidworks, Catia, Autodesk Inventor, Denford VR milling/turning o typical data formats including extensions and proprietary formats, for example DXF, IGS, DWG, CDR, PCX, PLT. • Part program production and testing: o 3D geometric model using CAD software

What needs to be learned
○ selection of machining operations ○ selection of tooling ○ generation of CNC program using CAM software ○ simulation of tool changing and tool paths ○ program correction and editing ○ transfer of data files to CNC machine ○ pre-manufacture run through using graphics display on CNC machine, prove program, dry run.

Essential information for tutors and assessors

Essential resources

For this unit learners need access to the internet and relevant engineering data tables. Learners would also benefit from access to engineering workshops containing CNC milling machines, associated cutting tools, work holding devices and ancillary equipment. They will also need access to CNC part programming and CAD/CAM software.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand the principles of computer numerical control (CNC) milling operations	A written report in which learners generate a justification for the use of a CNC milling machine over a manual universal milling machine to produce a given component. As part of this, they will detail how a CNC milling machine differs from a manual universal milling machine in terms of the main features of the machines, their safe operation and the different forms of control and will compare how the use of machines differs when producing the given component.

Learning outcome	Recommended assessment approach
2 Understand how to interpret a component specification and produce an operational plan for its manufacture	Learners are provided with a detailed drawing and information about a component which they need to interpret. Learners will produce an operational plan covering the set-up and the milling cutters required to manufacture the product on a CNC milling machine and will justify the sequence of operations detailed in their operational plan.
3 Understand how to produce and test part programs for the manufacture of a milled component using manual programming and CAD/CAM procedures	A practical task in which learners must use the operational plan developed for learning outcome 2 to manually produce and test a part program for the manufacture of the given component and then produce a part program for the same component using CAD/CAM software. In a further sub-task, learners will assess the part program to ensure it effectively meets the requirements of the given component drawing and then justify any amendments made to the program in order to meet the requirements of the component specification. Finally, learners will evaluate the benefits of using CAD/CAM software over manual part-programming.

For distinction standard (D1), learners will go beyond the comparison given for the merit criterion and will justify the use of a CNC milling machine over a manual universal milling to produce the given component, with detailed reasons. Learners should, where possible, support their justification using technical examples from their own workplace.

For merit standard (M1), learners will go beyond the explanation given for the pass criterion and will compare the benefits and limitations of using a CNC milling machine over a manual universal milling machine in order to manufacture a component from a given detailed drawing. Learners must also include details of the how the manufacture of the given component will differ using each. The given component must be sufficiently complex for manufacture using a CNC milling machine to be a sensible consideration.

For pass standard (P1), learners will explain how a CNC milling machine differs from a manual universal milling machine in terms of the main features of the machines, their safe operation and the different forms of control. As part of this, learners will also provide an explanation setting out the main points of the health and safety legislation and regulations pertaining to themselves and their employers in order to conduct CNC milling operations safely.

For distinction standard (D2), learners will go beyond the production of a CNC operational plan produced for the merit criterion by providing details of the decisions they took when generating the said plan, with detailed reasons to support these decisions. As a minimum, the justification will relate to the sequencing of the machining operations and the tooling required.

For merit standard (M2), learners will go beyond the explanation for the pass criterion and will produce a comprehensive CNC operational plan for the manufacture of the given component shown in the detailed engineering drawing. Learners will need to support their operational plan using additional evidence in the form of annotated drawings detailing proposed tooling paths as appropriate, annotated specification sheets and calculations to support machining decisions such as speed and feed rates.

For pass standard (P2), learners will give a clear explanation of how a CNC milling machine is to be set-up in order to produce a component using CNC milling techniques from a given detailed engineering drawing (component specification). They will also explain all of the types of milling cutters required to produce the component.

For distinction standard (D3), learners will go beyond the requirements for the merit criteria and will produce a written report that justifies any amendments they have made to their original part program, with detailed reasons to support the changes to their work. For example, they may have amended it in order to reduce the run time and condense the number of steps and tool changes required.

For merit standard (M3), learners will go beyond the requirements for the pass criteria and will produce a written report that reviews their part program and then assesses where improvements to it could be made before reaching a conclusion on how well it enables the given component to be manufactured to the specification detailed in the given component drawing. Learners will also evaluate the benefits and limitations of using CAD/CAM software to produce CNC programs over the use of using manual CNC part programming (M4). They will need to draw valid conclusions to their arguments which are appropriately supported with detailed reasons and examples.

For pass standard (P3), learners will produce and test a manual CNC part program from the CNC operational plan developed during the assessment for learning outcome 2. They will generate annotations on their part program that explain the sequence of machining operations for the given component.

Learners will also produce a part program for the same component using CAD/CAM software (P4). Their evidence will include a range of annotated screenshots for both the manual programming and the programming using the CAD/CAM software.

Unit 12: Applications of Computer Numerical Control Engineering

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

There are three basic principles to CNC machining. These are: positional control of the cutting tool relative to a workpiece using axes coordinates, the setting of cutting speeds and control of other functions such as the application of cutting fluid. To do this, machine tools need to be loaded with a series of instructions which is acted upon in sequence. These instructions are called program code, and in this unit, learners will be shown how to produce a working program using an industry-standard language.

The unit will consider two aspects of CNC machining. First, learners will investigate machine tools that have an in-built computer system. These are set up by a skilled operator who interprets data taken from an operational plan and converts this into program code.

Learners will then look at machine tools which are downloaded with code generated by a remote computer system running computer-aided design/manufacturing (CAD/CAM) software. The advantage that this type of system has over the stand-alone CNC machine is that a full three-dimensional (3D) simulation of the machining process can be carried out before any cutting of material takes place. This is an important aspect of economic manufacture because incorrect machining of a component will result in lost production and additional costs.

The unit has a high practical content and learners are expected to manufacture actual components. Learners will follow the various steps in the CNC process, starting with interpreting drawings and choosing a suitable machining process, correct cutting tools and work holding devices. They will then write and prove a part program, machine the product and carry out dimensional checking against specification.

The final part of the unit investigates the integration and use of CAD/CAM in the CNC machining process. Learners will be given a drawing file containing details of a component that they will then use to produce a 3D image of the component. Its functionality is confirmed before moving on to the simulation of the machining process using CAM software.

Once the machining operation has been proven and any problems corrected, the data needed to control the movements of cutting tools and other machine operations is downloaded from the computer into the machine's control unit. Machining then takes place, with the program data saved for future use with the earning outcomes and assessment criteria.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand the principles of Computer Numerical Control (CNC) and machine structures

2 Be able to interpret a component specification and produce an operational plan for its manufacture

3 Be able to produce a part program and manufacture a component

4 Be able to use a computer aided design/computer aided manufacture (CAD/CAM) software package to generate a part program and manufacture a component.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the principles on which a machine tool operates when controlled by a CNC system		
P2 Describe, with the aid of suitable diagrams, the structure of a given CNC machine type		
P3 Interpret the specification for a given component and produce an operational plan for its manufacture	**M1** Explain the importance of producing an accurate and detailed operational plan for a component that is to be manufactured using a CNC machine tool	
P4 Produce a part program for a given component	**M2** Explain the importance of correct programming and setting up in order to produce a component to a required specification	
P5 Manufacture a component using a two- or three-axis CNC machine		
P6 Use a CAD/CAM package to produce a part program from a given component detail drawing	**M3** Test the program assessing how it meets the requirements of the drawing	**D1** Compare and contrast the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Manufacture a component on a CNC machine using a post-processed program generated using CAM software	**M4** Explain how the manufactured component meets the requirements of the program	**D2** Evaluate the cost benefits of using CAD/CAM software when programming CNC machines

Unit content

What needs to be learned
Learning outcome 1: Understand the principles of Computer Numerical Control (CNC) and machine structures
• CNC principles: o System, e.g., machine control unit, drive mechanisms, tool/workpiece interface, transducers, feedback, correction o datum points, e.g., machine, component o definition of parameters using numerical coding, e.g., position, movement, spindle speeds, cutting tools, clamping, application of coolant o CNC process, e.g., select machine, select tooling, identify machining sequence, calculate positional coordinates, calculate spindle speeds, programming, post-processing, set-up sheet, verify and edit, store for future use. • Machine structures: o types, e.g., milling, drilling, turning centre, machining centre o designation of axes, e.g., two-axis, three-axis, x, y, z o motor and drive units, e.g., spindles, stepless drives, ball screw, stepper motors o transducers, e.g., positional, linear, rotary, analogue, digital, optical encoders, inductive, capacitive, magnetic o tooling, e.g., modular, quick change, turret o tool transfer, e.g., automatic, chain magazine, circular magazine o work holding, e.g., pallets, sub tables, rotary work changer, grid plate o swarf removal, e.g., chutes, chip controllers, conveyors o cooling, e.g., cutting fluid, cooling systems o computer hardware, e.g. keypad, display, Central Processing Unit (CPU), storage, cabling links, machine control unit (MCU) o computer software, e.g., programming language, CAD/CAM DXF files o safety, e.g., overloading the cutting tool, guards, light barriers, interlocks, operator safety.
Learning outcome 2: Be able to interpret a component specification and produce an operational plan for its manufacture
• Component specification: o detailed drawing o material, e.g., steel, aluminium, polymer, other stable material

What needs to be learned

- reference points, e.g., edge datum, centre line datum
- dimensional, e.g., external, internal, centres distances, bore diameters, tolerances
- surface finish, e.g., Ra, Rz values.

- Operational plan:
  - zero datums
  - work holding, e.g., clamps, fixtures, chucks, vices, setting points
  - changing components, e.g., pallets, sub tables, rotary work changer, grid plate
  - sequence of operations, e.g., loading, machining, roughing and finishing operations, measurement, unloading
  - calculations, e.g., cutter path coordinates for intersections, polar centres, arc centres, cutter compensation, cutting speeds, feed rates; use of trigonometric ratios, e.g. sine, cosine, tangent; cutter speed

    $\left(\frac{\text{surface speed}}{\pi \times \text{cutter diameter}}\right)$; feed rate

    (feed per tooth × number of teeth × spindle speed)
  - grouping of similar operations
  - canned cycles, e.g., irregular pockets, geometric, hole patterns
  - tooling, e.g., cutters, drills, reamers
  - other reference data, e.g., cutting fluids, special requirements relating to specific materials.
- Inspection, e.g., first off proving against specification, on machine measurement; set up sheet and tool list.

Learning outcome 3: Be able to produce a part program and manufacture a component

- Part program:
  - user interface, e.g., menu bar, identification line, tool display window, system status
  - work/tool relationships, e.g., position, direction, amount of movement
  - rates of change, e.g., feed rates, spindle speeds; auxiliary functions, e.g. metric/imperial units, tool selection, cutting fluids, workpiece loading and holding, tool changing
  - CNC codes, e.g., block number, preparatory functions (G codes)
  - miscellaneous functions (M codes)

What needs to be learned
o other letter addresses (arc centres, spindle speed, feed rate) o dimensional information, e.g., axis coordinates (x, y, z), absolute, incremental o words, e.g., modal, non-modal o block format, e.g., block number, G code, coordinates o special function G codes, e.g., movement system, measuring system, tool compensation, canned cycles, sub-routine o M codes, e.g., coolant, tool change, work holding, spindle speed, spindle direction. • Manufacture: o post-processing, e.g., transfer of files/data between systems, download program to machine tool o pre-manufacture, e.g., run through using graphics display on machine tool, prove program, dry run, load workpiece, stepping, adjust feed rates o run program, e.g., machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor o shutdown.
Learning outcome 4: Be able to use a computer aided design/computer aided manufacture (CAD/CAM) software package to generate a part program and manufacture a component.
• CAD/CAM package: o hardware, e.g., CAD workstation, data storage, hard copy equipment, network system to download data to machine tools o software, e.g., Autodesk Inventor, Esprit, Solid Works, Edge CAM, Denford VR milling/turning; universal formats, e.g., extensions (such as DXF, IGS, AI, EPS, PLT, NC), proprietary formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF). • Part program: e.g., 3D geometric model using CAD software, select machining operations, select tooling, generate CNC program using CAM software, simulation of tool changing and tool paths in the machining process, correction and editing. • Manufacture: o post-processing, e.g., transfer of files/data between systems, download program to machine tool o manufacturing, e.g., load and clamp workpiece, set tooling, initiate program cycle, machine workpiece, first off inspect and check against specification, store verified program for future use, quality monitor; shutdown.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are:

- 2D/3D commercial CAD software and CAM software that integrates with the CAD package used for designing
- access to a two- or three-axis CNC machine tool
- access to a two- or three-axis machine tool that can be downloaded with data from a computer system

Textbooks

- Evans K – *Programming of CNC Machines* (Industrial Press, 2007) ISBN 9780831133160
- Smid P – *CNC Programming Handbook* (Industrial Press, 2008) ISBN 9780831133474
- Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	CNC Principles and Machines	An assignment requiring learners to demonstrate their knowledge of the underlying principles of CNC machines and CNC machine structures	Two written tasks for which learners need to produce an explanation of the principles on which machine tools operate and a written description of CNC machine structure
P3, M1	Component Specifications and Operational Plans for Manufacture	A practical assignment requiring learners to interpret a component specification and produce a plan for its manufacture	A practical task for which learners are provided with a detailed drawing and information about a component that they need to interpret. Learners produce an operational plan to manufacture the product on a CNC machine. A further written task gives learners an opportunity to explain the importance of an accurate and detailed plan
P4, P5, M2	Part Programs for Manufacturing Components	A practical assignment requiring learners to produce a part program and use it to manufacture a component	Practical tasks in which learners are given a pre-produced operational plan for which they produce a part program and manufacture a component using three-axis machining

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3, M4, D1, D2	Using CAD/CAM to Manufacture Components	A practical assignment supported by written tasks requiring learners to demonstrate their ability to use CAD/CAM to manufacture a component	Practical and written tasks. Learners are given a detailed drawing for which they write a part program. Learners then need to use their post-processed program to manufacture the component. Written tasks will ask learners to compare CAD/CAM to CNC part-programming and evaluate the cost benefits of CAD/CAM

To achieve a pass grade, learners need to have an understanding of the principles of CNC and be able to manufacture a component. It is not expected that they should be able to program and set up CNC machines at an expert level, and this should be taken into account when designing assignments.

For pass standard, Learners produce a written report. Evidence for P1 should be generic and not specific to a particular type of machine. There is a lot of material that learners will have access to and care should be taken to ensure the validity of the evidence they provide.

P2 relates to a given type of machine, details of which should be specified in the assignment brief. Some learners may be working in a CNC environment and if they have specialised knowledge about a particular machine tool, they could use this towards their evidence
for P2.

Grading criteria P3 and M1 complement each other and are assessed through a second assignment. The assignment brief should provide learners with hard copy information about the component and a detailed drawing presented in printed form to an acceptable industry standard. The brief could also include a pro forma for setting out the operational plan, although learners working in a CNC environment may wish to use their own style of layout. Care should, however, be taken to ensure there are sufficient aspects of an operational plan covered by the content section for learning outcome 2. It must be remembered that a plan for CNC machining is different from one for traditional machining.

For merit standard, learners' evidence should make reference to the operational plan produced for P3 but additional evidence drawn from wider sources should be included. It is expected that learners will consider who will use the plan and the full range of possible implications if there are omissions and/or errors in the plan, with specific examples.

Learners will correctly interpret the requirements of a component spec including materials, reference points, dimensions and surface finish. Their operational plan will describe how the CNC milling machine is to be set up to produce the component from the specification. Learners will support their plan with annotated drawings and specification sheets, calculations to support machining decisions such as speeds and feeds and trigonometric ratios to calculate coordinates and intersections will also be needed to support P3.

The third assignment should be designed around P4, P5 and M2. It will add realism if the same component is used for both pass criteria.

For merit standard, learners consider the impact of correct programming and setting up on producing a required component, with detailed reasons and examples of what could happen if the programming were incorrect, reaching a valid conclusion (M2).

For pass standard, three-axis machining would be the preferred option, using something like a vertical milling machine. As the assignment involves a lot of practical work, evidence presented for assessment should include screenshots, witness statements, observation records and annotated digital images.

Ideally the same component should be used for P4 and P5. Evidence can include screen shots and annotated digital images.

The fourth assignment could cover P6, P7, M3, M4, D1 and D2. Evidence presented for assessment should include screenshots showing tool path simulation, witness statements, observation records and annotated digital images. They will obviously need to identify benefits and limitations of each approach and draw valid supported conclusions.

For distinction standard, Learners who wish to gather evidence for D1 will probably want to use the component specification provided in the third assignment so that they can contrast the effectiveness of the two methods of programming. D1 is very specific and some of the evidence presented could relate to the tasks undertaken to achieve P4, P5, P6 and P7.

When writing about their experiences, learners should include an evaluation of their own effectiveness in using the two systems of manufacture. Factors to be considered might include something on how easy it was to learn the software packages, ease of program editing and the lead times needed to produce the components. Discussions with a manufacturing engineer who works for a company using both systems or that has moved from CNC part programming to an integrated CAD/CAM set-up could be used as further evidence.

A written task will need to be given asking learners to compare the effectiveness of a CAD/CAM method of manufacturing a component to that of using CNC part programming.

A further task can be included to cover D2, in the form of evaluative writing supported by evidence gathered from published case studies. Learners should consider the effectiveness of CAD/CAM programming in the wider context and not just concentrate on the components that they have manufactured.

Because there are well-documented examples of the cost benefits achieved by companies who use CAD/CAM software to program CNC machines, care must be taken to ensure that what the learner presents as evidence is authentic.

For merit standard, M3 and M4 are logical extensions of P6 and P7 respectively requiring explanations of how the entities produced meet the original requirements.

For pass standard, the starting point for P6 and P7 is a detailed drawing and this should be given to learners as a file that can be opened using CAD/CAM software. With the agreement of the tutor, some learners who are taking the CAD unit may wish to use a component that they have previously drawn, but it needs to be in a form that can be easily processed.

Unit 13: Specialist Machining

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Specialist machining techniques can be defined as those where the tool will not necessarily make contact with the workpiece or that do not rely upon mechanical energy. This unit introduces three specialist machining techniques: laser beam, electro-discharge and electro-chemical machining techniques and their applications. You will acquire an understanding of the characteristics of, and principal considerations for the use of these specialist techniques. You will learn how the techniques are set up, safely operated and the parameters that must be managed during machining to prevent common errors and faults. You will study the typical faults and errors arising from the use of each technique.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand the selection and use of specialist machining techniques

2 Know how to carry out specialist machining techniques

3 Understand preventative maintenance for specialist machining techniques.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the characteristics and components of the three specialist machining techniques	**M1** Compare the benefits and limitations of the three specialist machining techniques	**D1** Justify the application of a specific specialist machining technique to a given machined component
P2 Explain safe operation of the three specialist machining techniques		
P3 Explain the use of the three specialist machining techniques		
P4 Explain the machining set-up to produce a component from a given drawing using a specialist machining technique	**M2** Assess the effectiveness of the specialist machining technique set-up to produce the required component	**D2** Evaluate approaches that can be taken to improve the effectiveness of the specialist machining technique set- up for the given component
P5 Explain the specialist machining technique parameters that must be managed to ensure the component meets the requirements of the drawing		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Explain common faults and errors that can occur using the three specialist machining techniques	**M3** Analyse the importance of implementing preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques	**D3** Evaluate the operational advantages of preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques
P7 Explain preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques		

Unit content

What needs to be learned
Learning outcome 1: Understand the selection and use of specialist machining techniques
• Laser beam machining: o characteristics: light amplification by stimulated emission of radiation, high-energy coherent (temporal and spatial) photons, meta-stable energy state, popular inversion, optical lenses, wavelength ranges, result of the application of laser to work piece (e.g. melting and vaporisation of work material and finally material removal) o machining considerations: characteristic length o machine components: lasing medium, solid state (e.g., ruby) or gas (e.g., helium, argon, axial flow, transverse flow, folded axial flow), flash tube (e.g., helical or flat), reflective mirror, lamp, capacitor, switching electrode, high voltage supply o benefits and limitations of laser beam machining: benefits (e.g., technique can be applied at a micro scale, no physical tool therefore no tool wear), limitations (e.g., not suitable for heat sensitive materials like aluminium glass fibre laminates, poor surface finish) o safety precautions: significant heat generated at the cutting face, classification of lasers, hazards associated with operation (e.g., risk to eyes) o application of technique: heat treatment, alloying, cladding, sheet metal bending, rapid prototyping, stereo-lithography, selective laser sintering material removal (e.g., drilling, cutting and trepanning), typically used on metals, plastics and ceramics. • Electro-discharge machining: o characteristics: electro-thermal technique using electrical energy to generate a spark to remove material, potential difference, dielectric medium (e.g., kerosene or deionised water), electrostatic forces, cold emission, ionisation energy, avalanche motion of electrons, heat flux, method of material removal (e.g. shock waves due to collapse of plasma channel following discontinuation of the application of potential difference) o machining considerations: establishing an electric field, connecting the tool to a negative terminal and the workpiece to a positive terminal o machine components: dielectric reservoir, pump and circulation system, power generation and control unit, working tank with work holding device, x-y table accommodating the worktable, tool holder, servo system to feed the tool, power generator (e.g., resistance-capacitance type relaxation generator, rotary impulse type generator, electronic pulse generator)

What needs to be learned
- benefits and limitations electro-discharge machining: benefits (e.g., flexible tool geometry), limitations (e.g. work material must be a conductor of electricity, positive ions impinge on the tool prompting tool wear, local high temperature at the workpiece surface can lead to surface hardening)   - safety precautions: heat is generated at the cutting face   - application of technique: creation of dies for jewellery, badges or coinage; small hole drilling; prototypes and production parts for the aerospace, automobile and electronics industries; typically used on high strength temperature resisting alloys.   - Electro-chemical machining: - characteristics: controlled anodic dissolution at atomic level of an electrically conductive work piece (anode) by a tool (cathode), electrolyte, flow of high current at low potential, ionic dissociation/electrochemical reaction, Faraday's Laws (e.g., first and second), electrochemical equivalence   - machining considerations: selection of electrolyte to suit workpieces to be machined (e.g., neutral salt solution of sodium chloride for steel), sludge, managing potential drop (e.g., the electrode potential, activation over potential, ohmic potential drop, concentration over potential, ohmic resistance of electrolyte)   - machine components: power supply, electrolyte filtration and delivery system, tool feed system, working tank   - benefits and limitations of electrochemical machining: benefits (e.g., tool wear is zero, no direct contact between workpiece and tool so no forces and residual stresses, good surface finish, less heat is generated, can produce complex, concave and curved components), limitations (e.g., cannot be used on soft materials)   - safety precautions: hydrogen gas evolves at the tool (cathode) and has the potential to be explosive, electrolyte poses risk of corrosion to the tool, work piece and equipment   - application of technique: die sinking, profile and contouring, trepanning, grinding, drilling and micro-machining, typically used on hard materials (e.g., titanium, aluminides, Inconel, Wasaploy, metal alloys high in nickel, cobalt and rhenium).

What needs to be learned
Learning outcome 2: Know how to carry out specialist machining techniques
• Laser beam machining: o start-up and shut down of laser beam machine: use of laser safety screen and safety glasses matching laser wavelength and intensity, automatic cut out switch o machining and tooling set up: managing the characteristic length, wavelength ranges, operation on continuous or pulsed mode o adjusting parameters in relation to machining outcomes: setting the power density for different focus lengths, cutting speed, output power, auxiliary gas. • Electro-discharge machining: o start-up/shut down of electro-discharge machine: selecting appropriate electrodes (e.g., graphite, tellurium copper, brass) o machining and tooling set up: material removal rate (e.g., dependant on thermal properties of the work material), geometry of tools, ensuring dielectric fluid provides an oxygen free machining environment o adjusting parameters in relation to machining outcomes: controlling the gap between the tool and the work piece in conjunction with managing the potential difference so an electric field is established, • Electro-chemical machining: o start-up and shut down of electrochemical machines: vertical and horizontal electrochemical machining o machining and tooling setting up: material removal rate (e.g., depends on atomic weight, valency and electricity conductivity of the work piece), feed to the tool, no feed to the tool o adjusting parameters in relation to machining outcomes: controlling the gap between the tool (cathode) and the workpiece (anode), setting the current rate for the desired rate of material removal.
Learning outcome 3: Understand preventative maintenance for specialist machining techniques
• Laser beam machining: o common faults and errors that occur: deformation of small holes when cutting, burring of the workpiece, incomplete cutting state of the laser o specific preventative measures: pulse perforation to achieve better surface finish when cutting small holes, maintaining purity of cutting gas and sufficient output power of the laser to guard against burring, ensure laser nozzle match with the plate thickness

What needs to be learned
- good housekeeping: types of proactive or planned maintenance, not storing flammable materials in the vicinity of laser machining tool.   - Electro-discharge machining: - common faults and errors that occur: incorrect electrical field can lead to arcing and localised material removal, issues with surface finish, overcut and tapercut   - specific preventative measures: maintaining spark at the tool surface to ensure uniform removal of material, dielectric fluid should be dielectric and thermal resistance so it does not break down too quickly   - good housekeeping: types of proactive or planned maintenance, cleaning and alignment of automatic wire threading system and guides, replacing and cleaning power contacts, calibration of brake/clutch roller, emptying wire collection box, replacing door and tank seals.   - Electro-chemical machining: - common faults and errors that occur: potential for short circuiting due to the feed rate exceeding the rate of dissolution   - monitoring performance: managing stray current and variance in electrical conductivity   - good housekeeping: types of proactive or planned maintenance, avoiding direct skin contact with electrolyte, maintaining adequate exhaust ventilation.

Essential information for tutors and assessors

Essential resources

For this unit learners need access to a workshop with specialist machining equipment and appropriate materials.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand the selection and use of specialist machining techniques	Learners produce a report, schematic diagram and an informative presentation, in either slide or video format, related to the characteristics/working principles, components, safe operation and use of the three specialist machining techniques. As part of this, they will also compare the benefits and limitations of the three specialist machining techniques and justify the application of a specific specialist machining technique to produce a given component.

Learning outcome	Recommended assessment approach
2 Know how to carry out specialist machining techniques	Learners complete written tasks in which they need to produce an explanation of the machining set-up required to produce a component from a given drawing using a specialist machining technique, and the parameters that must be managed to maintain the required quality of the component during production. As part of this, learners will also assess the effectiveness of their specialist machining technique set-up to produce the required component and then evaluate approaches that can be taken to improve current set-up.
3 Understand the preventative maintenance of specialist machining techniques	Learners could prepare a guide explaining the different common faults and errors, and the measures and good housekeeping that can be implemented to prevent them for the three different specialist machining techniques. As part of this, learners will analyse/evaluate the importance of implementing and the operational advantages of preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques.

For distinction standard (D1), learners will go beyond the requirements for the merit criterion and will justify the application of a specific specialist machining technique to produce a given component. Learners should clearly provide valid reasons within the justification as to why they consider the technique to be optimal to machine the given component, covering factors such as material, component features, tolerances, surface finish and quantity required.

For merit standard (M1), learners will go beyond the requirements for the pass criteria and will compare the benefits and limitations of the three specialist machining techniques, i.e. laser beam, electro-discharge and electrochemical machining. Learners should comment upon the advantages and disadvantages of the use of the three different machining techniques considering factors such as safety, complexity of set-up, the range of materials that can be machined, the operations that can be carried out, tool life and the quality of outcomes.

For pass standard (P1), learners will explain the characteristics and components of the three specialist machining techniques. Learners should explain the working principles for each specialist machining technique and draw a schematic diagram of the key components of each technique. Learners could also prepare an informative presentation explaining the safe operation and use of the three specialist machining techniques (P2, P3). Learners must cover all three techniques separately and should focus on aspects such as the safety of the operator, controlling the heat generated, the materials that can be machined and the types of operations that can be carried out.

For distinction standard (D2), learners will go beyond the requirements for the merit criterion and will draw together all of their assessment evidence to evaluate approaches that can be taken to improve the effectiveness of the specialist machining technique set-up. For example, how feed rate and material removal rate can be optimised to achieve a fast operation with a high-quality finish.

For merit standard (M2), learners will go beyond the requirements for the pass criteria and will assess the effectiveness of the specialist machining technique as set-up to produce the required component. Learners will be expected to clearly demonstrate that they can accurately assess the current set-up to identify where inefficiencies or problems may occur relating to safety or the quality of the outcome.

For pass standard (P4, P5), learners will explain the machining set-up to produce a component from a given drawing using a specialist machining technique and the parameters that must be managed to ensure the component meets the requirements of the drawing. Learners will give details of the different stages of set-up for the specialist machining equipment, covering machining and tooling set-up and start-up and shut down procedures for the component required, and the parameters that can be adjusted before and during machining to ensure the final outcome is to specification.

For distinction standard (D3), learners will go beyond the requirements for the merit criterion and will evaluate the operational advantages of preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques. They will consider all the different factors, for each technique, and will judge the potential impact of adopting preventative measures and good housekeeping against a more haphazard approach. For example, they will consider some of the issues related to reactive or emergency maintenance rather than proactive or planned maintenance for each specialist machining technique.

For merit standard (M3), learners will go beyond the requirements for the pass criteria and will analyse the importance of implementing preventative measures and good housekeeping to minimise errors and faults during the operation of the three specialist machining techniques. They will arrive at valid conclusions on the importance of adequately completing them for each technique. It is expected that learners will also consider wider issues related to, for example machining lead times and non-value adding activities.

For pass standard (P6, P7), learners will explain common faults and errors that can occur using the three specialist machining techniques, as well as the preventative measures and good housekeeping necessary to minimise errors and faults during the operation of the three specialist machining techniques. For example, learners may refer to the difficulties with using laser beam machining for deep cutting, the production problems that are likely if the dielectric fluid for electro discharge machining is not replaced at regular intervals and keeping the working gap constant during electrochemical machining.

Unit 14: Precision Grinding Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Grinding is an abrasive machining technique that uses hard grits held in a matrix to remove material from a workpiece. It is the oldest of the basic machining processes and long before the advent of modern machinery, stones were used to sharpen scythes and kitchen knives.

In this unit you will learn about the continued importance of precision grinding techniques when shaping hard metal alloys like those used in drill bits or engine components, and how grinding can deliver unparalleled surface finish and dimensional accuracy for precision components. You will gain an understanding of the principles involved in abrasive grinding and how these are applied in a range of precision grinding techniques.

This unit provides the necessary background knowledge required for engineering technicians or apprentices involved in carrying out grinding techniques.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand the principles of grinding

2 Understand the use of different precision grinding techniques

3 Understand how to prepare for and undertake precision grinding techniques.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the characteristics of grinding wheels and their applications	**M1** Compare different grinding wheels in terms of their characteristics and use for different applications and purposes	**D1** Justify the selection of a grinding wheel used in a given industrial application
P2 Explain the key process parameters used in grinding		
P3 Explain the safe use of one-off hand grinding technique	**M2** Compare off-hand and precision cylindrical and surface grinding techniques	**D2** Justify the selection of a precision grinding technique in a given application
P4 Explain one precision cylindrical grinding technique		
P5 Explain one precision surface grinding technique		
P6 Explain how to set up a precision grinding machine to safely to produce a component from a given drawing	**M3** Assess how the set-up and operation of a precision grinding machine can affect component finish and accuracy when using a precision grinding technique	**D3** Justify the set-up and operation of precision grinding machine chosen to produce a component using a precision grinding technique
P7 Explain the safe operation of a precision grinding machine to produce a component.		

Unit content

What needs to be learned
Learning outcome 1: Understand the principles of grinding
• Principles of material removal in abrasive machining including: o abrasive grain properties, e.g., hardness, attrition, friability, geometry o action of abrasive grains on material surfaces, e.g., ploughing, rubbing, cutting, chip formation o waste (mix of dislodged abrasive gains and swarf). • Characteristics of grinding wheels to include: o abrasive type, e.g., silicon carbide, aluminium oxide, synthetic diamond o grain/grit size, e.g., coarse, medium, fine, very fine o bond material, e.g., vitrified, resinoid, epoxy o structure, e.g., dense, open o grade, e.g., soft, medium, hard o rated/maximum operating speed o type, e.g., straight, cylinder, tapered, recessed one side. • Abrasive wheel markings to BS ISO 525. • Importance and effects of grinding process parameters including: o rotational speed o peripheral speed o cross feed rate o infeed rate o grinding fluids o grinding wheel characteristics. • Process capability characteristics, e.g., surface finish, dimensional accuracy, ability to machine extremely hard materials. • Surface finish parameters, e.g., ISO roughness grades, Ra, grit. • Advantages of grinding over conventional milling and turning machining processes. • Typical applications of grinding, e.g., HSG drill bits, tool steel gauge plate, bearing rollers.

What needs to be learned
Learning outcome 2: Understand the use of different precision grinding techniques
• Grinding techniques including safe use of equipment, process characteristics and applications of off-hand grinding, e.g., pedestal mounted or bench grinder. • Precision grinding techniques including safe use of equipment, work holding, process parameters, characteristics and applications of: o cylindrical grinding (centred) o centreless cylindrical grinding, e.g., through-feed, end-feed, in-feed o surface grinding, e.g., horizontal spindle and reciprocating table o creep feed grinding.
Learning outcome 3: Understand how to prepare for and undertake precision grinding techniques
• Interpreting engineering drawings and material specifications for components suitable for precision grinding. • Selection of precision grinding technique, abrasive wheel characteristics and process parameters to suit component requirements. • Use of calculations and reference tables to determine precision grinding process parameters. • Safety and equipment checks, e.g. condition and true of grinding wheel, position of machine guards, personal protective equipment, emergency stop procedure. • Setting machine parameters, e.g., rotational speed, cross feed rate, infeed rate, table travel distance, grinding fluid feed. • Mounting workpiece, e.g., magnetic chuck, between head stock and tail stock centres, chuck. • Machine start-up procedure. • Monitoring and adjustment during grinding. • Safe stopping and workpiece removal. • Machine shut-down procedure and cleaning.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are:

- access to at least one type of precision grinding machine (as defined in the unit content)
- examples of engineering drawings for components suitable for precision grinding.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand the principles of grinding	Learners compile a reference guide to the principles of grinding. This will include a detailed explanation of the characteristics and use of grinding wheels and the key process parameters used in precision grinding. They then read the marks from a range of grinding wheels, compare their characteristics and applications and justify the use of one of these in a given industrial application. Learners produce a portfolio of evidence including: tabulated data, annotated images, notes and text.

Learning outcome	Recommended assessment approach
2 Understand precision grinding techniques	Learners compile an illustrated reference guide to explain in detail a range of grinding processes. They will use this to help explain the differences between an off-hand technique, with which they are likely to be familiar, and precision grinding techniques. In addition, they will provide a fully justified explanation of their selection of a precision grinding technique for use in the manufacture of an engineering component. Learners could produce a portfolio of evidence including: annotated, labelled photographs, sketches, diagrams, notes and text.
3 Understand how to prepare for and carry out precision grinding techniques	Learners provide an illustrated guide to setting up and operating a precision grinding machine safely to make a ground component. This includes the whole process from being provided with a component drawing through to shutting down the machine safely after use. The guide will include an assessment of how decisions made during the set-up and operation of the machine can affect component finish and accuracy. Finally, the settings chosen to produce the component to the required dimensional accuracy and surface finish will be explored and justified. Learners could produce a portfolio of evidence including: annotated, labelled photographs, sketches, diagrams, notes and text.

For distinction standard (D1), learners will go beyond the requirements for the merit criterion and will justify why a specific grinding wheel is used in an industrial precision grinding application. This will be based on a detailed given scenario. Learners will focus on the characteristics of the grinding wheel and the process parameters and how they relate to the specifics of the product being ground. Learners will justify why grinding is necessary and give detailed reasons for why more conventional processes like turning or milling are unsuitable.

Learners will produce written evidence that is easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard (M1), learners will go beyond the requirements for the pass criteria and will interpret the markings on three different examples of abrasive wheels used in precision grinding applications. Learners will compare the different grinding wheels effectively, perhaps using a table to summarise the technical information with additional explanatory notes providing a detailed comparison of characteristics. Learners will link each of the three grinding wheels to a suitable application and the necessary process parameters. For example, two wheels differing only in grit size will be used on similar materials to provide different material removal rates and surface finishes and a wheel with low grit/high feed rate could be used for basic surface finishing on gauge plate whilst a high grit/low feed rate might be used for final finishing on bearing rollers.

The comparisons will use accurate engineering terminology, for example there will be clear definitions of terms such as abrasive type and bond material when comparing different grinding wheels and detailed consideration of how grain/grit size affects surface finish in precision grinding processes. Overall, the evidence will be logically structured and cover the majority of the characteristics and process parameters mentioned in the unit content.

For pass standard, learners will provide evidence that explains the effects of grinding wheel characteristics for grinding applications (P1) and process parameters used in grinding (P2). For example, they will make connections between the abrasive grain type and its effectiveness in material removal to produce a suitable finish in a certain time. The evidence produced will relate to at least three applications, such as the finish grinding of a stainless steel shaft to ISO roughness grade N7.

The explanations may have some omissions, but learners will mostly use engineering terms with accuracy. For example, there may be some lack of clarity in the definitions of terms such as abrasive type and bond material when explaining the characteristics of different grinding wheels or there may be cursory treatment of the importance of grain/grit size.

For distinction standard (D2), learners will go beyond the requirements for the merit criterion and will justify why a specific grinding technique is used in an industrial precision grinding application, based on a detailed given scenario.

Learners will focus on the characteristics of the grinding technique and how they relate to the geometry and finish requirements of the component being machined.

Learners will produce written evidence that is easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e., consistent use of correct grammar and spelling.

For merit standard (M2), learners will go beyond the requirements for the pass criteria and will compare off-hand and precision cylindrical and surface grinding techniques, including similarities and differences and advantages and disadvantages, perhaps by using a table. Learners will provide evidence that indicates a good understanding of an off-hand and both types of precision grinding techniques, for example by providing a detailed explanation of using an off-hand grinder safely to accurately sharpen a drill bit, how through feed centreless cylindrical grinding uses a canted regulating wheel to feed a workpiece between the grinding wheels and work holding using a magnetic chuck in surface grinding, and then explaining how these work and are used in practice.

The comparisons will use accurate engineering terminology, for example there will be clear and correct naming, labelling and annotation of machine parts.

Annotated diagrams or photographs will be used to support the written comparisons of the required techniques.

Overall, the evidence will be logically structured and provide good coverage of the grinding techniques with few technical inaccuracies or omissions.

For pass standard (P3), learners will explain an off-hand grinding technique, including the safe use of equipment, process characteristics and applications. Learners will also explain a cylindrical grinding technique (P4) and a precision surface grinding technique (P5), including the safe use of equipment, work holding, process parameters, characteristics and applications for both.

Learners will provide evidence that may be basic in parts, for example providing an explanation of the process characteristics and parameters of cylindrical grinding without fully explaining their use and impact on the material removal process.

Labelled diagrams or photographs with annotation will be used to support written explanations of the required techniques. The explanations may have some omissions but will mostly use engineering terms with accuracy. For example, there may be some lack of clarity in the definitions of technical terms or in the naming and labelling of machine parts.

For distinction standard (D3), learners will go beyond the requirements for the merit criterion and will justify the set-up and operation chosen to produce a component using a precision grinding technique. Learners will include clear and detailed reasons for the selected set-up and operation. The justification for the set-up and operation of the grinding machine will relate the choice of initial process parameters and ongoing operational adjustments to the requirements of the component being machined, for example justifying the use of grinding fluid to reduce friction, remove heat from the work zone and to increase material removal rate whilst maintaining the required surface finish.

Learners will produce written evidence that is easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e., consistent use of correct grammar and spelling.

For merit standard (M3), learners will go beyond the requirements for the pass criteria and will assess how the set-up and operation of the grinding machine affects the component finish and accuracy. Learners will provide evidence that shows a good understanding of how to set up and carry out a precision grinding technique, for example by providing a detailed explanation of how to mount a cylindrical workpiece between the grinding wheel and support roller when setting up for centreless grinding. The assessment will build on the explanations provided by considering the effects that changing the set-up or operation of the grinding machine will have on component finish and accuracy. For example, the effect on surface finish by reducing the set infeed rate for the final few finishing passes.

Learners use accurate engineering terminology, for example there will be clear and correct naming and labelling of machine parts. Annotated diagrams or photographs could be used to explain how machine parameters are set and how the machine is operated safely when grinding.

Overall, the evidence will be logically structured and provide good coverage of the practicalities of precision grinding with few technical inaccuracies or omissions.

For pass standard, learners will provide evidence relating to one of the precision grinding techniques covered in the unit content. This will be appropriate for the production of a component using a given drawing.

Learners will explain how to set up the precision grinding machine to safely produce the component from the drawing. Learners will include the reasons for safety and equipment tests and for setting the machine parameters (P6).

Learners will also explain how the precision grinding machine is operated safely to produce the component and will provide examples of where and how monitoring and adjustment may take place during grinding (P7).

Evidence may be basic in parts, for example, providing a description of setting the infeed rate on a surface grinding machine without fully explaining its effects.

The set-up and operation may be summarised in a list of steps accompanied by additional explanatory notes. Explanations may have some inaccuracies relating to engineering terminology, for example there may be some lack of clarity in the definitions of technical terms or in the naming and labelling of machine parts. Labelled diagrams or photographs with some annotations could be used to support written explanations of the safe set-up and operation of the grinding machine. Overall, the evidence will be logically structured and provide a good overview of how set-up and operation is carried out but will contain some technical inaccuracies or omissions.

Unit 15: Engineering Inspection and Quality Control

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

Inspection and quality control are essential to all engineering manufacturing operations. The quality control checks and measurements made during and after manufacture ensure that dimensions of the finished component are within acceptable tolerances. Only then will they fit together with other parts, function as intended and comply with all the requirements of their design specifications.

In this unit you will learn about measurement systems and how to interpret dimension and tolerance information found on engineering drawings. You will also look at the tools and equipment used in the accurate and precise measurement of engineering component characteristics and how quality control procedures are planned and carried out.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

In this unit you will:

1 Understand measurement systems and tolerancing

2 Understand the use and calibration of measuring devices

3 Understand how to plan and carry out quality control procedures.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Interpret correctly conventional and geometric tolerances and limits and fits	**M1** Analyse the principles of conventional and geometric tolerancing using examples	**D1** Evaluate the importance of accurate interpretation of tolerancing information using examples
P2 Explain the characteristics and use of measuring devices in engineering	**M2** Compare two measuring devices used in engineering	**D2** Justify the selection of measuring devices for two contrasting applications
P3 Explain the calibration of a given measuring device		
P4 Explain causes of error when using measuring devices, possible consequences of error, and how these are prevented		
P5 Develop a clear inspection plan for a given scenario	**M3** Develop a comprehensive inspection plan for a given scenario, explaining each element	**D3** Justify each element of an inspection plan developed for a given scenario

Unit content

What needs to be learned
Learning outcome 1: Understand measurement systems and tolerancing
• Units of measure commonly encountered in engineering applications including: o Linear, e.g., m, mm, μm o Angular, e.g., decimal degrees, radians o surface finish, e.g., Ra, D, Rmax. • Dimensional tolerancing to include: o standard representation and symbols, e.g., conventional, geometric o use and interpretation of tolerancing on engineering drawings, e.g., linear, angular, straightness, flatness, circularity, cylindricity, concentricity, perpendicularity o standards, e.g., BS 8888. • Limits and fits to include: o standard representation, e.g., alpha numeric code o use and interpretation of limits and fits on engineering drawings, e.g., tolerancing holes and shafts, clearance, transition, interference o standards, e.g., ISO 286.
Learning outcome 2: Understand the use and calibration of measuring devices
• Characteristics, use, calibration and applications of measuring devices including: o linear, e.g., rules, calipers, micrometers, height gauges o angular, e.g., bevel protractor, sine bar o alignment, e.g., straight edge o comparators, e.g., dial test indicators (DTI), lever type, Sigma type o gauges, e.g., angle, radius, ring, plug thread, go/no-go o reference standards, e.g., slip gauges, angle gauges o ancillary equipment, e.g., surface plate, DTI stand o surface roughness tester. • Calibration and record keeping including: o national, reference and working standards o traceability o calibration procedures, e.g., BS870:2008

What needs to be learned
o calibration periods o equipment marking and record keeping. • Causes of measurement error, their effects and precautions used in their prevention, e.g., calibration error, dirt and grease, effects of heat, instrument damage, cosine error, incorrect use, incorrect reading.
Learning outcome 3: Understand how to plan and carry out quality control procedures
• Inspection plans to include: o Sampling, e.g., sample size, sample selection o interpretation of component specifications and engineering drawings, e.g., identification of critical parameters, tolerance limits, inspection criteria o measuring equipment, e.g., selection, suitability, precision, calibration status o sequence of operations. e.g., step by step plan, flow chart, procedure o recording results. e.g., raw data, inspection record sheets o reporting, e.g., data processing, tables, charts, analysis.

Essential information for tutors and assessors

Essential resources

The special resources needed for this unit are:

- access to a range of measuring devices (as defined in the unit content)
- examples of engineering drawings where conventional tolerances, geometric tolerances and limits and fits are shown.

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Learning outcome	Recommended assessment approach
1 Understand measurement systems and tolerancing	Learners compile a reference guide on measurement systems and tolerancing, which includes a detailed explanation of the standard symbols, codes and other indicators found on engineering drawings and examples showing the correct interpretation of given tolerances and limits. A written evaluation of the importance of interpreting this information correctly, and the consequences of not doing so would end the guide. Learners could produce a written report containing annotated diagrams, examples of engineering drawings, notes and text.

Learning outcome	Recommended assessment approach
2 Understand the use and calibration of measuring devices	Learners compile an illustrated reference guide to describe in detail a range of measuring devices and explain their characteristics, uses, calibration and potential sources of error, the possible consequences of error and how error is prevented. They then compare two measuring devices and justify their use in two differing applications. Learners will produce a portfolio of evidence including: annotated, labelled photographs, sketches, diagrams, notes and text.
3 Understand how to plan and carry out quality control procedures	Learners provide a guide on how to develop an inspection plan, which explains the different elements and how they are determined. They will then apply this knowledge by developing a comprehensive inspection plan for a given scenario, justifying the choices made in each step as they do so. Learners produce a portfolio of evidence including: a written guide, an inspection plan, annotated engineering drawings, inspection record sheets.

For distinction standard (D1), learners evaluate why accurate interpretation of tolerancing information is important and focus on the consequences of getting it wrong. They include illustrated examples involving conventional tolerancing, geometric tolerancing and limits and fits.

Learners will produce written evidence that is easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard (M1), learners examine the principles of conventional and geometric tolerancing and limits and fits with clear examples of the use of each. Learners will provide a tabulated summary of symbols, codes and abbreviations that must be accompanied by additional explanatory notes.

Evidence may be basic in parts, for example making general statements about the characteristics described in geometric tolerancing without fully exploring their use and applications. Symbols and codes will be fully expanded upon and explained in plain language using the correct technical terms.

For pass standard (P1), the evidence will show learners have identified and correctly interpreted six examples of conventional tolerances, six examples of geometric tolerances and four examples of limits and fits from a range of engineering drawings.

There may be some omissions, for example there may be some lack of clarity in the definitions of terms such as straightness and flatness.

For distinction standard (D2), learners will produce a written justification for the selection of measuring devices in two contrasting applications. They should include relevant characteristics such as portability, precision, ease of use and suitability for the type of measurement being made in their justification and include reasons why at least one possible alternative was not chosen. The evidence will be easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms.

For merit standard (M2), learners will provide a detailed and illustrated comparison of two measuring devices of a similar type that measure similar characteristics, for example a Vernier height gauge and a micrometer (similar because they both measure linear dimensions). Annotated diagrams or photographs will be used to support a written comparison which will use accurate engineering terminology, for example there will be clear and correct naming, labelling and annotation of their parts.

Overall, the evidence will be logically structured and provide good coverage of the differences in characteristics, use, calibration and applications suited to each device.

For pass standard (P3, P4, P5), learners will explain the characteristics and use of measuring devices in engineering using applied examples. Learners will provide labelled diagrams or photographs with some annotation to support written explanations of the required measuring devices which must include: three linear, two angular, one alignment, two comparators, three gauges and one surface roughness tester along with two examples of related ancillary equipment.

Learners will also explain in detail the calibration of a given measuring device, using two examples from the content. This should make reference to the procedure used for calibration, the standard with which the measuring device is compared, equipment marking and record keeping (P4).

The causes of error when using measuring devices should also be explained with examples of the possible consequences of error. A general treatment of the causes of error encountered when using measuring equipment and how these can be avoided is acceptable for the pass standard.

Explanations may have some omissions, for example there may be some lack of clarity in the definitions of technical terms or in the naming and labelling of the parts of measuring devices.

The coverage requirements must be met but evidence may be basic in parts. For example, explaining the characteristics and use of a Vernier calliper without going on to fully cover calibration or applications.

For distinction standard (D3), learners will produce a written justification that is easy to read and understand by a third party, who may or may not be an engineer. It will be logically structured and will use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

Each decision taken in the development of the inspection plan for a given scenario will be discussed and justified, e.g. evidence might show that a measuring instrument was chosen to match the precision required, but also because it was easy to read and was able to access the feature being measured easily. Some justifications will include clear reasoning why possible alternatives were not chosen.

For merit standard (M3), learners will provide a comprehensive inspection plan for a given scenario that will require at least five separate measurements of critical parameters to be taken on a single component or assembly. learners will provide an explanation of each element of an inspection plan as laid out in the unit content.

The plan will be comprehensive and so cover all the elements of an inspection plan as laid out in the unit content. Overall, the evidence will be logically structured and the plan will be both feasible and effective.

For pass standard (P6), learners will provide a clear inspection plan for a given scenario that will require at least five separate measurements of critical parameters to be taken on a single component or assembly. Examples should be used to help illustrate different elements of the inspection plan.

Overall, the evidence will be logically structured and provide a good overview of how to develop an inspection plan but is likely to contain some technical inaccuracies or omissions.

Unit 16: Engineering Secondary and Finishing Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

For everyday products and components to be manufactured to a required standard, the machines that produce them need to be operated in an efficient and safe manner. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Machine operators will produce better components if they are aware of a range of finishing and secondary processes that can be used. A secondary process is where raw material or a component is taken for further working, usually involving material removal, and is carried out after a primary forming process.

This unit aims to give learners a detailed knowledge of the use of secondary processing machines, including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods).

The unit gives learners an opportunity to examine a range of secondary processing machines, their design and application. To a lesser extent, they will also identify a range of 'non-traditional' techniques, such as electro discharge and broaching.

Learners will investigate heat treatment processes, which are often used to get a product or component into its final state and ready for use. Without these processes parts would fail prematurely or further manipulation would not be possible on certain materials to create a final component. Learners will also understand assembly methods, including automated techniques that can be associated with computer-aided manufacture and other modern approaches, such as flexible manufacturing systems.

Finally, learners will understand how finishing techniques are used in engineering to add either function or aesthetics to a part component or product. Anodising and plating methods will be discussed, as well as hot processes used to obtain a required finish (such as powder coating or hot dipping) and the associated aspects of health and safety.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand how a range of secondary machining techniques are used

2 Know how a range of non-traditional techniques are used

3 Know how heat treatment processes and assembly techniques are used

4 Know how finishing techniques are used.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain how five different secondary machining techniques are used safely on a range of materials	**M1** Compare and contrast why different secondary machining techniques are used when manufacturing products	**D1** Evaluate the effective use of an appropriate secondary machining technique
P2 Explain kinematics in secondary machining techniques		
P3 Identify appropriate non-traditional techniques for six given products		
P4 Describe an appropriate non-traditional technique for a given product		
P5 Explain surface hardening and another heat treatment process for ferrous metals	**M2** Compare and contrast why different heat treatment processes are used when manufacturing products from ferrous metals	
P6 Describe two different manual and an automated assembly technique		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Describe a hot process, anodising and plating method when used for finishing on different components		
P8 Explain the appropriate heat treatment processes, secondary, finishing and assembly techniques needed to manufacture four given components	**M3** From given restrictions and information justify alternative assembly and finishing techniques	**D2** Evaluate a given secondary machining technique and heat treatment process for health and safety risk and impact on the environment

Unit content

What needs to be learned
Learning outcome 1: Understand how a range of secondary machining techniques are used
• Turning: machine, e.g., centre lathe, turret; features of the workpiece, e.g., flat faces, diameters (such as parallel, stepped, tapered), holes (such as drilled, bored, reamed), profile forms, threads (such as internal, external), eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts. • Milling: machine, e.g., horizontal, vertical, universal, planer/gantry; up-cut; down-cut; features of the workpiece, e.g., faces (such as flat, square, parallel, angular), steps/shoulders, slots (such as open ended, enclosed/recesses, tee), holes (such as drilled, bored), profile forms (such as vee, concave, convex, gear), serrations, indexed or rotated forms, special forms. • Boring: machine, e.g., horizontal, vertical; features of the workpiece, e.g., bored holes (such as through workpiece, to a depth, tapered), holes (such as drilled to depth, drilled through workpiece, reamed, threaded), external diameters, grooves/recesses, chamfers/radii, faces (such as flat, square, parallel, angular, milled), slots, forms (such as indexed, rotated), external tapers. • Grinding: machine, e.g. surface (such as horizontal, vertical), cylindrical (such as external, internal), centreless, universal, thread, profile; features of the workpiece, e.g. faces (such as flat, vertical, parallel, square to each other, shoulders and faces), slots, diameters (such as parallel, tapered), bores (such as counterbores, tapered, parallel), profiles forms, thread forms (such as vee, right hand, single start, multi-start, internal, external), angular faces. • Presswork: machines, e.g., single action, multiple action; features of the workpiece e.g., blanking, notching, piercing, joggling, cropping/shearing, bending/forming, coiling/rolling, planishing/flattening, first draw, second draw, compound operations, cupping, embossing, coining. • Health and safety: appropriate legislation and regulations, e.g., Health and Safety at Work etc. Act 1974, Fire Precautions Act 1971, manual handling, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Provision and Use of Work Equipment Regulations (PUWER) 1998, Health and Safety (First Aid) Regulations 1981; use of personal protective equipment (PPE). • Materials: e.g., ferrous, non-ferrous, non-metallic, stainless, special alloys, deep drawing steels. • Kinematics: machine tool design; generation and forming of shapes; six degrees of freedom.

What needs to be learned
Learning outcome 2: Know how a range of non-traditional techniques are used
• Electro discharge: machines, e.g., spark erosion, wire erosion; features of the workpiece e.g. holes, faces (such as flat, square, parallel, angular), forms (such as concave, convex, profile, square/rectangular), other features (such as threads, engraving, cavities, radii/arcs, slots). • Broaching: machines, e.g., horizontal, vertical; features of the workpiece e.g., keyways, holes (such as flat sided, square, hexagonal, octagonal), splines, serrations, other special forms. • Honing and lapping: machines, e.g., honing (such as horizontal, vertical), lapping (such as rotary disc, reciprocating); features of the workpiece, e.g., holes (such as through, blind, tapered), faces (such as flat, parallel, angular).
Learning outcome 3: Know how heat treatment processes and assembly techniques are used
• Heat treatment processes for ferrous metals: surface hardening; other processes, e.g., hardening, tempering, annealing, normalising; appropriate health and safety requirements, e.g., Health and Safety at Work etc. Act 1974, requirements relating to chemicals and materials handling (such as Control of Substances Hazardous to Health (COSHH) Regulations 2002, safe disposal of waste materials and components (fluids, hardening materials), manual handling, safe use of electrical and pressurised equipment, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Provision and Use of Work Equipment Regulations (PUWER) 1998). • Assembly techniques: manual, e.g., screwed fasteners, locking devices, keys, dowels, circlips; automated, e.g., part feeding devices, transfer and indexing, orientation devices.
Learning outcome 4: Know how finishing techniques are used
• Hot processes: e.g., hot dip treatment (such as molten wax, molten tin to steel, molten zinc to steel, organic coatings), powder coating (such as fluidised bed thermoplastic coating powder, fluidised bed thermosetting powder, electrostatic grade thermoplastic powder, electrostatic grade thermosetting powder). • Anodising: e.g., sulphuric acid, chromic acid, hard anodising. • Plating methods: e.g. electroplating (such as copper, gold, silver, cadmium, platinum), electroless nickel, mechanical (such as mechanical zinc, mechanical tin-zinc, mechanical aluminium-zinc), alloy (such as brass, nickel-iron, tin-lead, zinc-nickel, zinc-iron, zinc-cobalt), zinc (such as cyanide zinc, alkaline zinc, acid zinc), nickel and chromium, hard chromium; substrates, e.g. mild steel, stainless steel, brass, copper, zinc based, aluminium.

Essential information for tutors and assessors

Essential resources

Learners should have access to as large a range of the machinery and processes outlined in the unit content as possible.

Textbooks

Health and Safety Executive – *Health and Safety in Engineering Workshops* (Health and Safety Executive, 2004) ISBN 0717617173

Timings R L – *Manufacturing Technology* (Prentice Hall, 1998) ISBN 0582356938

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1 and D1	Secondary and Non-traditional Machining Techniques	An activity requiring learners to carry out research based on actual secondary and non-traditional machining techniques associated with a range of materials	A portfolio containing written responses and diagrams showing the five different secondary machining and non-traditional techniques for a range of material types, possibly supported by a PowerPoint presentation. Alternatively, a case study could be used and presented as a portfolio

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M2	Heat Treatment Processes, Assembly and Finishing Techniques	An activity to investigate the processes associated with the heat treatment of ferrous metals, and the use of hot processes and finishing techniques	A portfolio containing written responses and diagrams showing heat treatment processes for ferrous metals and descriptions of assembly techniques, hot processes, anodising and a plating method. This activity could be supported by a PowerPoint presentation
P8, M3 and D2	Secondary Processes and Finishing Techniques Associated with Manufacturing Products	An activity to investigate the heat treatment processes, secondary, finishing and assembly techniques associated with product manufacture	A portfolio containing written responses to show the processes and techniques used to manufacture four given components, possibly supported by a PowerPoint presentation. Alternatively, a case study could be used and presented as a portfolio

It is important that the assessment strategies used are designed to suit the needs of learners. Good assessment strategies are most likely to be supported by proper presentation of appropriate evidence. A portfolio or file of evidence should not contain course notes, research etc. unless it is to become part of the required evidence and assessment.

Work done through the use of case-study material can be used to generate evidence for the portfolio, particularly if industrial visits are well embedded in delivery. It is likely that a range of products will need to be investigated to ensure learners have opportunities to cover the required range of secondary machining techniques and heat treatment processes, together with finishing and assembly techniques.

To achieve a pass, learners need to demonstrate understanding and knowledge of the different processes and techniques, explain or describe their characteristics and how they are used. While learners need to explain what is meant by kinematics in relation to secondary techniques, they only need to show enough knowledge to describe one non-traditional technique. However, they must select appropriate non-traditional techniques for six different products. Learners also need to describe both surface hardening and one of the other processes, such as annealing, and both types of assembly techniques (manual and automated). They should also describe all three types of finishing techniques as listed in the unit content.

This unit could be assessed through three assignments. The first assignment could be a series of written tasks to cover P1, P2, P3 and P4. The task for P1 should have enough detail for learners to cover turning, milling, boring, grinding and presswork. The types of machine they consider from each of these could be left to the learner, as they may have a preference from their place of work. Alternatively, a specific machine type could be given to different learners across the range. This would help centres authenticate each learner's response.

The tasks should also ensure that learners consider the health and safety requirements and cover at least three of the material types listed in the content.

The six products given for P3 must cover the three non-traditional techniques ranged – electro discharge, broaching and honing/lapping. The products should have sensible characteristics, such as type of material, quantity, size, accuracy (tolerances) and surface texture requirements to clearly direct learners towards the correct non-traditional technique. The written task for P4 could be about one of the machines from these techniques. Again, some learners may have preferences based on their workplace. This assignment could also include further written tasks to cover both M1 and D1.

The second assignment could have tasks to explain heat treatment processes (P5) and assembly techniques (P6). Surface treatment must be covered but freedom can be given as to which other process is described. The task should also ask learners about the health and safety requirements. The task addressing P6 must cover two manual and one automated technique.

A further task could be developed to cover M2, which would give learners an opportunity to cover more of the range of heat treatment processes. A comparison between hardening, tempering and annealing would be sensible. Another task in the assignment could cover P7 ensuring that all finishing techniques are covered.

Another task should be given to allow learners to justify alternative assembly and finishing techniques (M3). In doing so, a range of restrictions and information should be given to ensure learners are able to come up with some sensible alternatives. An example is when the modification of an assembled component allows an automatic feeding device to be used, assuming the batch quantity information indicates it would be viable, or a material amendment needs a change of finishing technique.

The third assignment could have a task requiring learners to explain appropriate processes and techniques as listed in P8 for four different components. These components need to be fairly complex to include a requirement for a heat treatment process, a secondary, a finishing and an assembly technique. These requirements must not be given but be suggested by the component characteristics and specification. This can be done by a set of drawings/specifications or by actual products, with a set of notes that would ensure the learners are able to identify the appropriate process and techniques. A final written task could be included to give an opportunity to cover D2.

To achieve a merit, learners need to compare and explain how different machining techniques are used (M1) and how different heat treatment processes are used in manufacturing (M2). They will need to suggest alternative assembly and finishing techniques when given specific restrictions and information (M3).

To achieve a distinction, learners need to confidently evaluate the effective use of secondary machining techniques (D1) for certain circumstances. Learners should show skills in evaluating a given secondary machining technique and a given heat treatment process for health and safety risk and impact on environmental issues (D2).

Unit 17: Computer Aided Manufacturing

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

An understanding of how computer-aided manufacturing (CAM) systems operate in an engineering business is important for anyone thinking of a career in the design and manufacture of products.

This unit aims to develop an appreciation of the use of computer systems in a world-class manufacturing environment and how they are applied to product design and manufacture. Emphasis is placed on the need for a total approach to product development, in particular the interface between the various functions of the design and make process and the use of simultaneous engineering.

Learners will start by investigating how CAM systems are used to increase the profitability of a business by reducing manufacturing costs, improving quality and being more responsive to customer needs. This is followed by a look at how simultaneous engineering is used to bring together the many functions of a manufacturing business so that there is a team-based, multidisciplinary approach to problem solving. Learners then investigate how simultaneous engineering can be used to meet the demands of a customer-driven economy where people expect an off-the-shelf service for customised products.

The unit covers how newly designed components are modelled using three-dimensional (3D) CAD software so that their functionality can be assessed and any errors corrected before the machining process is simulated using CAM software. Raw materials and the cutting of metal are expensive and getting it right first time is a crucial aspect of economic manufacture.

Learners will investigate how manufacturing processes can be automated by using industrial robots to move materials and components between the machine tools and the workstations that make up a flexible manufacturing system (FMS). Finally, learners will be given the specification for a component, use CAD software to design it and use CAM software to produce a set of instructions for downloading to a machine tool which could be used to make it.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the benefits of CAM and the significance of simultaneous engineering

2 Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process

3 Understand the use of industrial robots and flexible manufacturing systems in engineering

4 Be able to design a simple component and generate a programme for a CNC machine using a CAD/CAM software package.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain how the use of a CAM system can benefit the operation of a manufacturing business	**M1** Describe the criteria used to assess the viability of introducing CAM and simultaneous engineering systems into a business	**D1** Evaluate a current low-technology manual manufacturing system for suitability to move to a CAM environment
P2 Describe the strategies used in simultaneous engineering		
P3 Explain how the interface between design and manufacture can be integrated using suitable CAD/CAM software	**M2** Explain the cost benefits of moving from low-technology manual manufacturing to high-technology automated manufacturing	
P4 Explain the reasons for carrying out modelling of a component and simulation before actually cutting metal		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the applications, advantages and limitations of industrial robots	**M3** Explain the use and operation of robots to move parts between workstations in a flexible machining system	
P6 Explain why a flexible manufacturing system will produce productivity gains for a business deploying a range of processing machines, loading and unloading systems and coordinated work schedules		
P7 Use appropriate software to design a simple component and produce a part program which could be post-processed and used to manufacture it on a CNC machine	**M4** Explain the hardware and software used for this process.	**D2** Discuss post-processing procedures used

Unit content

What needs to be learned
Learning outcome 1: Understand the benefits of CAM and the significance of simultaneous engineering
• Benefits of CAM: increased profitability, e.g., reduced machine set-up times, greater flexibility in terms of batch sizes, reduction in lead times, reduction of labour costs, lower unit costs, optimised use of cutting tools, production of complex shapes; improvements in quality, e.g., elimination of human error, consistent accuracy; greater responsiveness to the requirements of the customer; competing in the world marketplace. • Simultaneous engineering: parallel operation of tasks; multi-discipline team-based working, e.g., marketing, design, modelling, rapid prototyping, manufacturing, development; time-based management, e.g., integration of activities, lean manufacturing, total quality management (TQM), shorter development times, faster time to market, right first time, improved communication.
Learning outcome 2: Understand how the CAD/CAM interface operates and modelling is used to simulate the manufacturing process
• CAD/CAM interface: CAD, e.g., product design using industry-standard CAD software, modification of design ideas, production of working drawings; CAM, e.g. generation of part programmes, scheduling of raw materials; specialised linking software, e.g. edgeCAM, Autodesk Inventor/Esprit, SolidWorks; universal formats, e.g. extensions (such as DXF, IGS, AI, EPS, PLT, NC), propriety formats (such as DWG, CDR, CDL, GE3, NC1, BMP, MSP, PCX, TIF). • Modelling and simulation: use of CAD/CAM software, e.g., 3D modelling of the product, simulation of tool changing and toolpaths in the machining process, simulation of sequential manufacturing processes, rapid prototyping; benefits, e.g. elimination of machining errors, reduction in scrap rates.
Learning outcome 3: Understand the use of industrial robots and flexible manufacturing systems in engineering
• Robots: applications, e.g. pick and place systems, product handling, product assembly, machine loading, safe operation, codes of practice (Health and Safety Executive (HSE) HSG43, Reducing error and influencing behavior HSG 48, Provision and Use of Work Equipment Regulations (PUWER) 1998); advantages, e.g. consistency of performance, 24/7 continuous working, reduced cycle times; limitations, e.g. high standard of maintenance required, precise programming needed, computer systems failure will cause breakdown, new products require complete reprogramming, certain processes still need a skilled operator, complex and expensive equipment.

What needs to be learned
• Flexible manufacturing systems: benefits, e.g. production of different parts without major re-tooling, efficient production of customised products, ease of responding to changes in product mix and production schedules, lean manufacture; processing machines, e.g. CNC machine tool, machining centre, flexible cell, welding station, assembly; loading and unloading systems, e.g. material handling, pick and place, fixed position robot, conveyors; coordination of the working schedule, e.g. process monitoring by computer, optical recognition, inspection, TQM.
Learning outcome 4: Be able to design a simple component and generate a programme for a CNC machine using a CAD/CAM software package
• Using CAD/CAM software: hardware, e.g., CAD workstation, data storage, hard-copy equipment, network system to download data to machine tools; software, e.g., 2D/3D CAD, databases, single-component CAD files, part programming, macros, cutter path simulation; post-processing, e.g. transfer of post-processed files/data between systems, download to machine tools, inspection and quality management.

Essential information for tutors and assessors

Essential resources

Centres will need to give learners access to 2D/3D commercial CAD software and CAM software which integrates with the CAD package used for designing.

Extracts from appropriate standards and legislation and access to industry-standard CNC machining centres and flexible manufacturing systems are also needed.

Textbooks

Amirouche F – *Principles of Computer-Aided Design and Manufacturing* (Prentice Hall, 2004) ISBN 9780130646316

Colestock H – *Industrial Robotics: Selection, Design and Maintenance* (McGraw-Hill, 2005) ISBN 9780071440523

Narayan et al. – *Computer-Aided Design and Manufacturing* (Prentice Hall, 2008) ISBN 9788120333420

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Using CAM and Smart Systems in an Engineering Business	Learners have been asked by their employer to produce a report on the benefits of using CAM and the strategies used in simultaneous engineering.	A written assignment for which learners produce a report detailing the benefits of CAM to a modern manufacturing business and the use of simultaneous engineering.
P3, P4, M2	CAD/CAM Interfacing	Learners need to provide an explanation of how CAD/CAM software is integrated and the reasons for simulation for a local manufacturer considering moving over to CAM systems.	A written assignment for which learners produce a report into the interface between design and manufacture and the purpose of simulation. A further task would require learners to explain the cost benefits of modern manufacturing systems.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M3	Industrial Robots and Flexible Manufacturing Systems	Learners have been asked by their employer to produce a report on the benefits and limitations of using industrial robots and the use of flexible manufacturing systems.	A written assignment consisting of tasks requiring learners to discuss the applications of industrial robots and explain why a flexible manufacturing system can produce gains for a business.
P7, M4, D2	Using CAD/CAM Software	Learners need to design a component for a client and produce a part program for its manufacture.	A practical assignment for which learners will need to design a component and produce the part program necessary for its manufacture. Evidence is likely to be supported by screen prints and tutor observation records.
D1	Evaluating the Suitability of a CAM Environment	Learners have been asked by senior management to investigate the implications and suitability of moving from low-technology manufacturing to a CAM environment.	A written assignment for which learners produce a report detailing the suitability of moving to a CAM system for a low-technology manual system.

Assessment of this unit could be through five assignments.

It is suggested that the first assignment covers P1 and P2, with learners being asked to support their thoughts with evidence taken from published case studies relating to well-known companies (for example Toyota and Airbus Industries). It is important that learners demonstrate a good understanding of the reasons why, in a customer-driven, global market environment, a manufacturing company can survive only if it uses smart systems in the operation of its business. There is scope to expand this first assignment to include M1. A visit to an engineering company which has moved to using world class manufacturing systems would be a good way of gathering research information.

Grading criteria P3 and P4 complement each other and can be assessed through a second assignment. Learners should not be expected to demonstrate proficiency in the use of CAD/CAM software. A visit to a company to look in detail at the way a component is designed and manufactured would be a useful way to gather evidence. This could involve talking to a CAD designer and being shown the processes of design, modelling and manufacturing. There is scope to include M2 in this assignment.

A third assignment could cover grading criteria P5 and P6. Thought needs to be given to structuring the tasks so that learners restrict themselves to just the applications of robots and do not get sidetracked into explaining in great detail their operating principles. As recommended earlier, restricting learners to three applications will be enough to produce valid evidence to meet P5. As criterion M3 builds on P5 and P6 it can be a part of the third assignment.

The fourth assignment could be a practical activity covering P7. The component to be designed should be kept very simple as learners are not required to prove competence in using high-level design skills. As suggested earlier, a simple embossed key fob design which uses the line, arc, diameter and text commands in its design will produce a profile sufficiently complex for a part program and its post-processing. Screen prints could be used as evidence of tool path simulation, supported by witness statement or observation records of learner performance.

M1 builds on P1 and P2. To achieve it there should be evidence of thought having been given to the pressure on design and manufacturing engineers to optimise resources and use business improvement techniques.

M2 links into P3 and P4 but also draws on knowledge from P1 and P2. Explanations should be supported by examples taken from real companies which have successfully moved from low-technology to high-technology manufacturing systems and might include figures for the amounts of cost savings achieved.

M3 requires a greater understanding of how a robot operates and will build on knowledge gained when achieving P5 and P6. Evidence presented should be at a systems (black box) level and the assignment tasks should not be asking for detailed knowledge about, for example, the internal workings of a specific drive or sensor unit within the robot.

Tasks based on a scenario which relates to a specific machining system could be used to generate evidence. Learners are not expected to explain how the actual machining functions operate because the criterion relates only to the handling and moving of parts. M4 requires an explanation of the hardware and software used for component design.

Grading criterion D1 builds on content covered in learning outcomes 1, 2 and 3 and could be a very detailed piece of writing based around a scenario. For this reason, it might be best covered by a fifth assignment. Learners could assume the role of a manufacturing engineer who has been tasked with presenting proposals to senior management on the implications and suitability of moving from low-technology manufacturing to a CAM environment. There are a lot of well-documented examples of how this has been achieved successfully by well-known companies and care must be taken to ensure that what learners present as evidence is authentic. Where appropriate, employed learners should be given the option of analysing their own company. D2 requires a discussion of the post-processing utilised in the component designed in P7.

Unit 18: Setting and Proving Secondary Processing Machines

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

For components to be manufactured to a required standard, the machines that produce them need to be set up by technicians correctly, ready for an operator to use. During this process, trial components are made to check accuracy and ensure a minimum amount of waste during production. Once satisfied that a machine's parameters are correctly set, the technician would then brief the machine operator and the mass production of accurate components can begin.

The aim of this unit is to give learners a detailed understanding of the setting of secondary processing machines, including traditional machines (for example lathes and drilling machines) and others found in a more specialist workshop (for example spark or wire erosion methods). Learners' ability to set a machine and brief an operator will stem from their knowledge of the machine itself and their ability to select and use the most appropriate work-holding devices and tooling.

The unit provides an opportunity for learners to examine a range of secondary processing machines, their set-up and the best use of work-holding devices and tools. Learners will need to gain an understanding of the features of the component to be made to enable them to effectively set up the machine and hand over to an operator.

Safety is an important issue to be considered when setting and using secondary processing machines. In this unit, learners will gain knowledge about, and demonstrate safe working practices when carrying out activities. They will also carry out checks for component accuracy and demonstrate this accuracy after setting a machine and when handing over to an operator.

With the knowledge and understanding gained from this unit, there are other opportunities for investigation of a wider range of secondary processing machines, their work-holding devices, tools and machine parameters.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Know how traditional and specialist secondary processing machines function

2 Understand how work holding devices, tools and machine parameters are set up to produce a range of components

3 Be able to safely set up a secondary processing machine to accurately make a component

4 Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe how four different secondary processing machines function when machining a given component for each	**M1** Explain the effects of using an inappropriate work holding device when setting up a secondary processing machine	**D1** Justify the choice of a work holding device for a given component when setting up a secondary processing machine
P2 Explain how work holding devices and tools are used on four different secondary processing machines to manufacture a different given component for each machine		
P3 Explain how a range of machine parameters are set up to produce required features on components machined on four different secondary processing machines	**M2** Explain the importance of setting machine parameters correctly to produce accurate features on a component produced by a secondary processing machine	
P4 Set up a secondary processing machine to safely produce a given component		
P5 Carry out checks for accuracy of a given component during the set-up of a secondary processing machine		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Explain how to produce trial components on a secondary processing machine	**M3** Explain the impact of producing trial components and correct handover procedures on the operator being able to continuously produce accurate components	**D2** Evaluate the impact that aspects of working safely have on the effectiveness and accuracy of setting up a secondary processing machine
P7 Explain how to hand over a secondary processing machine to an operator, including a description of the handover procedures used		

Unit content

What needs to be learned
Learning outcome 1: Know how traditional and specialist secondary processing machines function
• Secondary processing machines: basic principles of operation; machine's suitability to manufacture given components; relevant safe working practices for each machine; machine terminology, e.g. cross slide, spindle, head stock, generation of shapes, forming of shapes; traditional secondary machining techniques, e.g. turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), milling (horizontal, vertical, universal), grinding (surface, cylindrical, centreless, universal, thread grinding, tool and cutter grinding, universal or purpose-built machines), drilling (single spindle, multi-spindle); specialist secondary machining techniques, e.g. boring (horizontal, vertical), electro discharge (spark erosion, wire erosion), honing and lapping (horizontal and vertical honing, rotary disc lapping, reciprocating machines).
Learning outcome 2: Understand how work-holding devices, tools and machine parameters are set up to produce a range of components
• Work holding: devices for traditional secondary machining techniques, e.g. chucks (hard or soft jaws, three or four jaw, collet, power, magnetic), fixtures and other machine specific devices for: o turning (drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies) o milling (clamping direct to machine table, pneumatic or magnetic table, machine vice, angle plate, vee block and clamps, indexing head/device, rotary table) o grinding (centres, faceplate, machine vices, clamps, angle plates, vee blocks, works rests, control stops, injector mechanisms, magnetic blocks, pots, arbors) o drilling (clamping direct to machine table, machine vice, angle bracket, vee block and clamps, drill jigs, indexing device). • Devices for specialist secondary machining techniques, e.g. angle plate, vee block and clamps, other machine specific devices for: o boring (clamping direct to machine table, machine vice, pneumatic or magnetic table, indexing/rotary device) o electrical discharge machining (clamping direct to machine table, machine vice, pneumatic or magnetic table, ancillary indexing device) o honing and lapping (pots, magnetic blocks, faceplate).

- Tools: materials and form, e.g., solid high-speed steel, brazed tungsten carbide, indexable tips, electrode material, abrasive stone, composite wheels; tools for traditional secondary machining techniques, e.g. for:
    - turning (turning tools, facing tools, form tools, parting-off tools, thread chaser, single-point threading, boring bars, recessing tools, centre drills, twist/core drills, solid reamers, expanding reamers, taps, dies, knurling tool)
    - milling (face mills, slab mills/cylindrical cutters, side and face cutters, slotting cutters, slitting saws, profile cutters, twist drills, boring tools, end mills, slot drills)
    - grinding (soft wheel, hard wheel, cup, flaring cup, straight sided wheel, recessed wheel, double recessed wheel, dish, saucer, disc, segmented)
    - drilling (drill bit, flat-bottomed drill, counterboring tool, countersinking tool, centre drill, spot facing tool, reamer, tap).
- Tools for specialist secondary machining techniques, e.g., for:
    - boring (boring tool, facing, turning, recessing, chamfering or radii, forming, twist drill, tap, reamer, milling cutter)
    - electrical discharge machining (plain electrode, profile electrode, hollow electrode, wire)
    - honing and lapping (mandrel, wedge, honing stone, lapping disc/pad).
- Machine parameters: position of workpiece; position of tools in relationship to workpiece; cutting fluid/dielectric flow rate; position and operation of machine guards/safety mechanisms; parameters for different traditional secondary processing techniques, e.g., for:
    - turning (threading/profile/taper mechanisms, workpiece revolutions per minute, linear feed rate, depth of cut for roughing and finishing)
    - milling (linear/table feed rate, milling cutter revolutions per minute, depth of cut for roughing and finishing)
    - grinding (linear/table feed rate, depth of cut for roughing and finishing, cross feed, dressing of wheels)
    - drilling (tooling revolutions per minute, linear feed rate, swarf clearance).
- Parameters for different specialist secondary processing techniques, e.g., for:
    - boring (set up and tooling relative to datum, feed rate, cutter/tool revolutions per minute, depth of cut for roughing and finishing)
    - electrical discharge machining (electrical conditions, wire tension, wire speed, alignment of electrodes and wire, ventilation and fume extraction, filtration)
    - honing and lapping (revolutions per minute or reciprocating speed, stroke length, stroke overrun length, stroke speed, stone or disc pressure).

What needs to be learned
• Features of the component: materials, e.g., ferrous, non-ferrous, non-metallic; holes, e.g., drilled, bored (parallel or tapered), reamed, threaded, blind, through, counterbored, flat bottomed; relevant component features produced using traditional secondary processing techniques, e.g., for: o turning operations (flat faces, parallel diameters, stepped diameters, tapered diameters, profile forms, external threads, eccentric features, parting off, chamfers, knurls or special finishes, grooves, undercuts) o milling operations (flat faces, square faces, parallel faces, angular faces, steps/shoulders, open ended slots, enclosed slots, recesses, tee slots, profile forms, serrations, indexed or rotated forms, special forms) o grinding operations (flat faces, vertical faces, parallel faces, faces square to each other, shoulders and faces, slots, parallel diameters, tapered diameters, profiles forms, other thread forms, vee-form threads, right-hand threads, single start threads, multi-start threads, external threads, angular faces) o drilling operations (countersinking, spot facing, holes). • Relevant component features produced using specialist secondary processing techniques, e.g., for: o boring operations (internal profiles; external profiles, e.g., external diameters, grooves/recesses, chamfers/radii, flat faces, square faces, parallel faces, angular faces, slots, index or rotated forms) o electrical discharge machining operations (holes; faces – flat, square, parallel, angular; forms – concave, convex, profile, square/rectangular; other features – threads, engraving, cavities, radii/arcs, slots) o honing and lapping operations (honing holes; lapping faces, e.g., flat, parallel, angular),

What needs to be learned
Learning outcome 3: Be able to safely set up a secondary processing machine to accurately make a component
• Set up: machine guards in place; select and set tooling; checking tool/wheel condition; holding components securely without distortion; selection and use of suitable work-holding device(s); set machine parameters to manufacture given component. • Safe working: safe set-up of moving parts, e.g., setting stops, preventing tooling clashes; use of machine guards to protect operator and others; choice and handling of cutting fluids/dielectric flow rate; checks for insecure components; facilities for emergency stop and machine isolation; identification of appropriate protective clothing and equipment; housekeeping arrangements (work area clean and tidy); safe working practices relevant to specific secondary processing technique, e.g. for: o turning (handling turning tools, airborne particles, tool breakage, swarf disposal) o milling (handling milling cutters, cutter breakage, swarf disposal, backlash in machine slides) o boring (handling tools and cutters, airborne particles, tool breakage) o electrical discharge machining (electrical components, handling dielectrics, fumes, handling and storing electrodes and wires) o grinding (handling grinding wheels, sparks/airborne particles, bursting wheels) o drilling (handling drills, taps and reamers, tool breakage, swarf disposal) o honing and lapping (handling and storing stones, airborne particles). • Checks for accuracy: components to be free from burrs and sharp edges; use of appropriate tools and instruments; checks for dimensional accuracy and surface texture; checks relevant to specific secondary machining technique e.g., for: o turning (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO, surface finish 63 μin or 1.6 μm, reamed or bored holes within H8, screw threads BS medium fit, angles within +/− 0.5 degree) o milling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 μin or 1.6 μm, flatness and squareness within 0.001 inch per inch or 0.125 mm per 25 mm, angles within +/− 0.5 degree) o boring (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO surface finish 63 μin or 1.6 μm, flatness and squareness within 0.005 inch per inch or 0.025 mm per 25 mm, angles within +/− 0.5 degree, bored holes within H8) o electrical discharge machining (components to be free from false starts; dimensional tolerance to BS/ISO, surface texture 32 μin or 0.8 μm or 18 VDI; checks, e.g., for parallelism, angle/taper, squareness, profile)

What needs to be learned
◦ grinding (tolerance to BS/ISO surface texture 8 µin or 0.2 µm, free from false grind cuts) ◦ drilling (components to be free from false tool cuts, dimensional tolerance equivalent to BS/ISO, surface texture 63 µin or 1.6 µm, reamed holes within H8, screw threads BS medium fit) ◦ honing and lapping (components to be free from stone/disc marks; dimensional tolerance equivalent to BS/ISO; surface finish 8 µin or 0.2 µm; honed components checked for parallelism and ovality/lobbing; lapped components checked for parallelism and flatness).
Learning outcome 4: Know how to produce trial components relevant to the use of a secondary processing machine before handing over to an operator
• Trial components: to meet the features and accuracy required by the specification. • Use of machine: correct use of work holding devices; tools; machine parameters and safety. • Handing over: correct set-up; supplies of components and consumables; machine functions correctly; quality requirements; consideration of safe working. • Handover procedures: demonstrating operation; explaining the key stages; highlighting critical areas, e.g., safety, specific tolerances, finishes; observing operator and correcting any errors; ensuring operator is working safely and competently before leaving; periodic checks of machine and operator performance.

Essential information for tutors and assessors

Essential resources

To meet the needs of this unit it is essential that the centre has or has access to some if not all of the range of machines specified in the unit content. This should include at least one specialist secondary processing machine. All auxiliary equipment such as that required for measuring accuracy should also be made available.

Textbooks

Edwards J – *Lathe Operation and Maintenance* (Hanser, 2003) ISBN 9781569903407

Kalpakjian, Serope – *Studyguide for Manufacturing Engineering &* Technology (Cram101 Textbook Reviews) ISBN 9789810694067

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Producing Components Using Secondary Processing Techniques	Learners are required to produce a component using a secondary processing machine and check it for accuracy.	A practical assignment evidenced through photographs, tutor observation records and learner notes.
P1, P2, P3, M1, M2, D1	Investigating Secondary Processing Machines	Learners need to prepare an information leaflet giving details of four different secondary processing machines.	A written report detailing how each secondary processing machine functions, and the work holding devices, tools and machine parameters associated with each.
P6, P7, M3, D2	Producing Trial Components and Handing Over Secondary Processing Machines	Learners explain to a new member of staff how to produce a trial component and correctly hand over a secondary processing machine.	A written report detailing how to produce trial components and the correct handover procedures for a secondary processing machine.

Assessment evidence for this unit is likely to be gained from a mixture of written tasks and practical process evidence (witness statements/observation records).

To achieve a pass grade, learners must demonstrate knowledge of a range of different secondary processing machines and their techniques when carrying out set-up procedures. Both traditional and specialist techniques need to be covered. This means that learners need to know set up procedures for at least one technique from each range and an overall total of four.

Assessment of the procedure of actually setting up a machine, the knowledge required to prove the process by making trial components and handing over to an operator is restricted to one secondary processing machine, which can be either traditional or specialist. Centres and learners should pick the one most suitable for individual needs, considering any work-based learning expectations.

To achieve a merit grade, learners will need to demonstrate that they can explain some of the effects of using an inappropriate work-holding device when setting up a secondary processing machine. This could be achieved through the selection of appropriate work holding devices for P2, together with learners demonstrating an appreciation of the possible effects of an inappropriate device. In addition, learners are required to explain the importance of producing accurate features on components, M2, that have been produced by a secondary processing machine. They also have to explain the importance of setting machine parameters correctly. For example, if the depth of cut and/or feed rate in a turning operation is not set correctly, then the component is likely to have an out of tolerance surface finish and not be free from false tool cuts.

Finally, learners need to explain the impact of producing trial components and correct handover procedures on the operator being able to continuously produce accurate components.

For example, if trial components are meeting the correct accuracy checks then the 'setter' will be confident when demonstrating to the operator the procedures to follow and the correct tolerance and finish requirements explained more easily to the operator. The required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

To achieve a distinction grade, learners will need to justify their choice of a work holding device for a given component when setting up a secondary processing machine. This machine is likely to be one from their chosen skill route. Judgement needs to be made as to whether the device used would succeed and whether it is likely to meet the needs and features of the component, alignment and use of the tooling and tool-component interface.

They also need to evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine. They need to consider whether the use of the safety equipment hampers the set-up process. Again, the required evidence for these criteria is likely to be in the form of a written response to tasks set for the learner.

Wherever possible, it is important to maximise the opportunities for assessment through practical tasks. A possible scenario would be to use a total of three assignments. It may be best to set a practical assignment as the first of these. This could be to set up a secondary processing machine (P4) and carry out checks for accuracy (P5). Evidence for these criteria could be in the form of annotated photographs, observation record/witness statement(s), notes and sketches produced by learners that capture the processes carried out.

Learners will also need to maintain a record of all measurements taken and the action taken to correct any errors in the set up to complete the requirements of P5.

Following the practical, learners could then prepare a written report on how this secondary machining process functions and is set up. This could then be used to cover one of the four different machines required for P1, P2 and P3. It may also be the best opportunity to work towards the merit and distinction criteria M1, M2 and D1.

The second assignment could follow on from the practical activities and involve learners preparing a report on the machining process used in assignment 1. They would also need to research and report on three more machines to generate the evidence required for P1, P2 and P3. The tasks undertaken should make it clear what secondary processing machines are to be covered (this could be set by the tutor or could be decided through learner choice).

To meet the requirements of the unit content for outcomes 1 and 2, both traditional and specialist techniques need to be covered. However, as long as at least one of each type is covered then the other two can be either traditional or specialist machines. When choosing from the examples listed in the unit content, for example turning (centre lathe, capstan, turret, single-spindle automatic, multi-spindle automatic), it would be sufficient to select from any one of the machines listed, for example for a turning machine – use of a single-spindle automatic. This applies equally to the other aspects of unit content where examples are given.

The choice from these lists will be solely determined by the component being machined. For example, work holding devices for turning lists drive plate and centres, faceplates, magnetic or pneumatic devices, fixed steadies or travelling steadies. If the component only requires mounting on a faceplate, then this would be sufficient. However, when choosing components centres need to take care to ensure the use of a reasonable range of techniques. For example, if all the components, for all four machines selected could be simply held in a three-jaw chuck to complete all operations, then this would be considered insufficient.

The last assignment could ask learners to explain how trial components are produced (P6) and how to handover a secondary processing machine to an operator (P7). The assignment could also provide an opportunity to explain the impact of producing trial components and the impact of correct handover procedures on the operator being able to continuously produce accurate components (M3). It could also evaluate the impact of working safely on the effectiveness and accuracy of setting up a secondary processing machine (D2). See earlier examples of what is expected for criteria M3 and D2; remember that the explanation and evaluation are likely to be a consideration of the experience of the practical work carried out in the first assignment.

Although simulated or practical activities would be the preferred means of capturing evidence for P6 and P7, it is accepted that this might not always be possible or realistic for a number of reasons. If a simulation is possible then for P7 it may be best if the tutor takes the role of the operator.

For both P6 and P7 process evidence (records of observation and oral questioning) could be used. This process evidence could then be supplemented/supported by the product evidence that will be available from the activities, for example the trial components, learners’ own preparation notes before handover and their own records of the actual handover process.

Unit 19: Computer Aided Drafting in Engineering

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Computer-aided drafting is fast becoming the primary means of communicating design information in many industry sectors, particularly in engineering and manufacturing. Two-dimensional (2D) CAD drawings and three-dimensional (3D) CAD data can be shared with Computer Numerical Control (CNC) machines using computer-aided manufacturing (CAM) software. 3D models can be rendered to produce photo-realistic representations, or can be animated to produce moving views of products and components as they would appear in service. Additionally, models can be used to analyse features such as mass, volume and mechanical properties.

This unit will enable learners to produce a variety of CAD drawings, from single-part 2D components to complex 3D models. Advanced techniques, such as using pre-prepared symbols to construct circuit diagrams and assembly drawings, will provide opportunities for learners to develop their skills. Learners will investigate the use of CAD in industry, the hardware and software required and the links with other software packages. In doing this, learners will appreciate the advantages of CAD over more conventional methods of drawing production.

Finally, learners will generate 3D models, make comparison with 2D CAD drawings and evaluate the impact of this technology on manufacturing companies and their customers.

The unit as a whole provides an opportunity to carry out practical CAD activities using a full range of commands and drawing environments. In addition, learners will gain an understanding of the use and impact of CAD on the manufacturing industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Know the national and international standards and conventions that CAD drawings and design need to comply with

2 Understand the advantages of using CAD in comparison with other methods

3 Know about the software and hardware required to produce CAD drawings

4 Be able to produce and interpret CAD drawings

5 Be able to use CAD software to produce 3D drawings and views.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the requirements of national and international standards and conventions relating to engineering drawing practice		
P2 Explain which features of CAD drawings need to comply with national and international standards		
P3 Explain the advantages, compared to other methods, of producing drawings electronically using a CAD package	**M1** Explain the relationship between CAD and other software/ hardware used in manufacturing	**D1** Justify the use of CAD in a manufacturing company
P4 Describe the software and hardware that are required to produce CAD drawings		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Produce 2D CAD detail drawings of five components that make up an assembly or sub-assembly to given standards, using appropriate commands	**M2** Explain how the range of commands used to produce CAD drawings can impact drawing production	
P6 Produce a circuit diagram containing at least five components to appropriate standards, using appropriate commands		
P7 Produce an assembly drawing and exploded view of an assembly or sub-assembly containing at least five parts, using appropriate commands		
P8 Interpret the properties of an engineering component or circuit from a given CAD drawing		
P9 Construct a 3D CAD drawing as a surface and solid model	**M3** Explain how 3D CAD models can be used in the design process	**D2** Evaluate the impact of the use of 2D and 3D CAD models on final design requirements

Unit content

What needs to be learned
Learning outcome 1: Know the national and international standards and conventions that CAD drawings and design need to comply with
• Requirements of current national and international standards and conventions: engineering drawing practice: BS 8888:2013, BS 5070-3 1988, BS EN 13622:2002, ISO standards. • Features of CAD drawings that need to comply with national and international standards: drawing sheet sizes and layouts, projection – first and third angle types of line, lettering and numbering, dimensioning, section cross hatching. • Standard representations: welding symbols, electrical symbols, pneumatic/hydraulic symbols, mechanical symbols.
Learning outcome 2: Understand the advantages of using CAD in comparison with other methods
• Advantages of CAD: quality; accuracy; time; cost; electronic transfer of information; links with other software, e.g., CAD/CAM, rendering software, animation software, finite element analysis (FEA). • Other methods: manual drafting; model making.
Learning outcome 3: Know about the software and hardware required to produce CAD drawings
• Software: operating systems; CAD software packages, e.g. AutoCAD, AutoCAD/ Inventor, Microstation, Catia, Pro/ENGINEER, Solidworks; minimum system requirements, e.g. hard disk space, memory required, processor, video card. • Hardware: keyboard; mouse; other input devices, e.g., light pen, digitiser, joystick, thumbwheel; monitor; printer; other output devices, e.g., plotter, rapid prototyping; storage, e.g. floppy disk, hard disk, memory stick, CD, network.
Learning outcome 4: Be able to produce and interpret CAD drawings
• CAD drawings: orthographic projections; circuit diagrams, e.g., hydraulic, pneumatic, electronic; exploded/assembly drawing; standards, e.g., BS 8888, BS 3939, BS 2917. • Commands: absolute/relative/polar coordinates; features, e.g., line types, grids, snaps, circle, text, hatching, dimensioning, layers/levels, colour; viewing, e.g., zoom, pan; inserting other drawings, e.g., symbols, blocks; modifying, e.g., copy, rotate, move, erase, scale, chamfer, fillet. • Interpret: determine properties of drawn objects, e.g., list, distance, area, volume.

What needs to be learned
Learning outcome 5: Be able to use CAD software to produce 3D drawings and views
• 3D environment: 3D views, e.g. top, front, side, isometric. • 3D models: 3D techniques, e.g. addition and subtraction of material, extrude, revolve, sweep, 3D coordinate entry (x, y, z), wire frame drawing, 2D to 3D (thickness, extrusion); surface models; solid models.

Essential information for tutors and assessors

Essential resources

Learners will need to have access to a suitably equipped IT facility with access to a printer/plotter. Access to software with 2D and 3D capabilities, such as AutoCAD and Inventor, is also required. While general graphics packages would not be suitable, any CAD software capable of generating the evidence required for this unit would be acceptable.

Textbooks

Ambrosius L – *AutoCAD 2009 and AutoCAD LT 2009: All-in-one Desk Reference for Dummies* (John Wiley and Sons, 2008) ISBN 9780470243787

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Yarwood A – *Introduction to AutoCAD 2012* (Routledge, 2011) ISBN 9780080969473

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and P2	National and International Standards Report	Learners to research national and international standards and relate to engineering CAD drawing practice.	A report describing national and international standards and an explanation of CAD features that need to comply with these standards.
P3, P4, M1 and D1	CAD Report	Learners to research and compare the use of CAD with other methods and determine the software and hardware required to produce CAD drawings; in addition, an investigation of how CAD links to other software and hardware and a justification of the use of CAD in manufacturing.	A report containing written responses about the use of CAD and alternative methods; in addition, the software and hardware requirements of a CAD system should be listed and explained. An explanation of how CAD links with other software and hardware should support a justification of the use of CAD in a manufacturing context.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P7 and M2	CAD Portfolio	Learners to create an assembly drawing of at least five parts and detail CAD drawings of the five components; in completing the task learners should be able to explain how they used a range of commands in the CAD software to produce drawings efficiently.	A portfolio of five component drawings and an assembly drawing containing the five individual parts; in addition, a short report containing written responses and/or screen dumps explaining how a range of CAD commands were used to produce the completed drawings efficiently.
P6 and P8	CAD Circuit Diagrams	Learners to produce a CAD circuit diagram containing at least five components to appropriate standards and using appropriate commands. Learners also to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram.	A circuit diagram containing at least five components. In addition, a given detail drawing or circuit diagram, annotated or with a brief summary explaining the information included.

Criteria covered	Assignment title	Scenario	Assessment method
P9, M3 and D2	CAD 3D Models	Learners to produce a single CAD 3D model using both surface and solid modelling techniques, possibly based on one of the part drawings used as evidence for P7. Learners also to research the use of 3D CAD models in the design process and evaluate the impact of the use of 2D and 3D CAD models on final design requirements.	A 3D model produced using both surface and solid modelling techniques; in addition, a report explaining how 3D CAD models are used in the design process and evaluating the use of 3D CAD models in final design requirements, including comparing and contrasting impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

An assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to the national and international standards and conventions. While much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of which features of CAD drawings comply with national and international conventions could be generated by giving learners drawings which highlight the details required for meeting national and international conventions.

The assessment evidence for P3 and P4 could be produced through a case study or through studying the company in which learners may be employed. Typically, it would take the form of a written report or presentation.

To achieve P3, learners must demonstrate an understanding of how CAD is used in comparison with more traditional drawing methods, stating its advantages and explaining how CAD systems can be linked with other software. A description of basic hardware and software requirements to operate a CAD system will be required to achieve P4.

The remaining pass criteria could be evidenced through a series of competence-based practical activities. Evidence could be in the form of witness statements, tutor observation records or a portfolio, although it is likely that electronic files will be used for the majority of the assessment. Screen dumps can often be a good source of evidence to show the range of commands used during the development of the drawings. The process evidence for these remaining pass criteria (P5 to P9) could be obtained from further assignments. In the first of these, learners would be required to produce five separate CAD drawings of the components which make up an assembly or sub-assembly. The full range of commands must be used, and the drawings should be dimensioned to an appropriate standard, enabling P5 to be achieved. These drawings could then be used to produce an assembly and exploded view drawing (P7).

A further assignment would require production of a circuit diagram to achieve P6. This might reflect the learner's occupation or area of interest and should be assembled from symbols previously introduced by the tutor and/or externally sourced. This assignment could also ask learners to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram (P8).

The final assignment would require production of a single 3D model using both surface and solid modelling techniques to enable achievement of P9. This might be a 3D version of one of the part drawings used as evidence for the assembly and exploded view drawing.

To achieve a merit grade, learners will need to look beyond how drawings are produced and evaluate their use and application. This will typically be through looking more closely at the relationship between CAD and other software. Learners should explain how linking CAD to other software/hardware impacts on an organisation (for example improving production, reducing waste, reducing lead times). This will build on the evidence generated for P3 and enable criterion M1 to be achieved.

An explanation of the range of commands for criterion M2 and how they impact on drawing production in terms of efficiency (for example speed, accuracy, repeatability) links with P5, P6 and P7. Similarly, knowledge for criterion M3 of how 3D models can be used in the design process links with the 3D activity in P9.

To achieve distinction criterion D1, learners should justify the use of CAD and will need to analyse other factors (for example disadvantages, costs, training requirements). This links with P3 and P4 as well as M1 and M2. Learners should evaluate the relative merits of using CAD software. This could be as part of the case study outlined as possible evidence for the P3 criterion.

To achieve D2, learners will need to evaluate 2D and 3D drawings from a customer perspective. This links directly with P9 and M3. Learners will need to compare and contrast the impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

Unit 20: Further Engineering Mathematics

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

Mathematics can be used to evaluate the intended and actual performance of a product or system at every stage of its life cycle. For example, mathematics may be used during the design of a product to determine whether it performs to specification. Statistics may be used during manufacturing processes as part of the quality control (QC) system and to determine the in-service reliability of a product. Statistics can also be used to evaluate the vast amounts of data that can be gathered about products and customers using mobile communications and the Internet of Things (IoT).

In this unit, you will use algebraic techniques to solve engineering problems involving sequences, series, complex numbers and matrices. You will investigate the use of statistics as a data-processing and analysis tool, for example applying techniques used by a quality assurance engineer to monitor the output from a manufacturing process.

As a future engineer, you will need to understand and develop skills to solve problems using algebraic and statistical procedures. These are transferable skills. and you will use them to support your study of other units in this course. This unit will help to prepare you for an apprenticeship or for employment in a range of engineering disciplines as a technician. You could also progress to a higher-level course, such as a Higher National Diploma (HND) or a degree in an engineering discipline.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Examine how sequences and series can be used to solve engineering problems

2 Examine how matrices and determinants can be used to solve engineering problems

3 Examine how complex numbers can be used to solve engineering problems

4 Investigate how statistical and probability techniques can be used to solve engineering problems.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Solve given problems using routine arithmetic and geometric progression operations	**M1** Solve given problems accurately, using routine and non-routine arithmetic and geometric progression operations	**D1** Evaluate, using technically correct language and a logical structure, engineering problems using non-routine sequence and series operations, while solving accurately all the given problems using routine and non-routine operations
P2 Solve given problems using routine power series operations	**M2** Solve given problems accurately, using routine and non-routine power series operations	
P3 Solve given problems using routine matrices and determinant operations	**M3** Solve given problems accurately, using routine and non-routine matrices and determinant operations	**D2** Evaluate, using technically correct language and a logical structure, engineering problems using non-routine matrices, determinant and complex operations, while solving accurately all the given problems using routine and non-routine operations
P4 Solve given problems using routine complex number operations	**M4** Solve given problems accurately, using routine and non-routine complex number operations	

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Solve an engineering problem using routine central tendency, dispersion and probability distribution operations	**M5** Solve an engineering problem accurately, using routine and non-routine central tendency, dispersion and probability distribution operations, providing an explanation of the process	**D3** Evaluate the correct synthesis and application of statistics and probability to solve engineering problems involving accurate routine and non-routine operations
P6 Solve an engineering problem using routine linear regression operations	**M6** Solve engineering problems accurately, using routine and non-routine regression operations, providing an explanation of the process	

Unit content

What needs to be learned
Learning outcome 1: Examine how sequences and series can be used to solve engineering problems

Arithmetic and geometric progressions

- Definitions:
  - sequence as an ordered collection of numbers a, b, c, d
  - progression as a sequence that increases in a particular pattern, i.e. there is a constant relationship between a number and its successor
  - series as the sum of the values in a sequence $a + b + c + d$ ...
  - terminology – first term a, last term l, connection by law.
- Routine operations involve:
  - arithmetic progression (AP):
    - common difference d
  - general expression for a sequence in AP:

    $a, (a + d), (a + 2d), (a + 3d), \ldots , (a + nd)$

    nth term (last term) $l = a + (n - 1)d$
  - sum of an AP to nth term (arithmetic series):

    $$s = a + (a + d) + (a + 2d) + \ldots + (l - d) + l = \frac{1}{2}n(a + l)$$
  - geometric progression (GP):
    - common ratio r
    - general expression for a sequence in GP $a, ar, ar^2, ar^3, \ldots, ar^n$
  - sum of a GP to nth term (geometric series):
    $s = a + ar + ar^2 + ar^3 + \ldots + ar^n = \frac{a(1 - r^n)}{(1 - r)}$
    - convergence
    - sum to infinity.
- Non-routine operations involve:
  - engineering applications, e.g., lathe spindle speeds, cost of deep drilling, depreciation costs of capital equipment, gear box ratios, manufacturing estimation.

Binomial expansion

- Definitions:
  - binomial expression that takes the form $(a + b)^n$
  - binomial theorem: $(a+b)^n = \sum_{k=0}^{n} {}_nC_k\, a^{n-k} b^k$ when n is a positive integer

    $(a+b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \frac{n(n-1)(n-2)}{3!}a^{n-3}b^3 + ... + b^n$ (a finite series)

    which can be written as $(a+b)^n = \sum_{k=0}^{k=n} {}_nC_k\, a^{n-k}b^k$ where ${}_nC_k = \frac{n!}{(n-k)!k!}$

    alternative form $(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + ... + x^n$

  - binomial theorem when n is not a positive integer:

    $(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + ... + x^n$ for $-1 < x < 1$ only

    (an infinite series)

- Routine operations involve:
  - construction of Pascal's triangle
  - expansion of $(a + b)^n$ for positive values of n using Pascal's triangle.
- Non-routine operations involve:
  - expansion of $(1 + x)^n$ for non-positive integer values of n using the binomial theorem
  - calculation of the nth term using the binomial theorem
  - engineering applications, e.g., small errors, small changes, percentage changes, approximation of errors.

Power series

- Definitions:
  - a power series as $f(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + ... + a_nx^n$
  - a Taylor series as $f(x) = f(a) + f'(a)(x-a) + \frac{f^2(a)}{2!}(x-a)^2 + ... + \frac{f^{(n)}(a)}{n!}(x-a)^n$
- Routine operations involve:
  - a Maclaurin series as a Taylor series with $a = 0$
  - convergence and divergence

What needs to be learned
o conditions for convergence and divergence. • Non-routine operations involve: o numerical value for e using a power series o proof that $\frac{dy}{dx}(e^x) = e^x$ using series o engineering applications, e.g. error in area or volume for small error in measurement of length, oscillator frequency for an electrical circuit if components have small errors in their values.
Learning outcome 2: Examine how matrices and determinants can be used to solve engineering problems
• Matrices • Definitions: o matrix type – element and order (row × column) o matrix terminology – element, row, column, order (row × column), equality, zero (null matrix), identity (unit) matrix, transpose, square, leading diagonal, triangular. • Routine operations involve: o addition, subtraction, multiplication by a real number o inverse of a (2 × 2) matrix o solution of sets of simultaneous equations with two variables using inverse matrix methods. • Non-routine operations involve: o multiplication of matrices o solution of sets of simultaneous equations with two variables using Gaussian elimination. **Determinants** • Definitions: o the determinant of a matrix as a useful value that can be computed from the elements of a square matrix, denoted by $\det(A)$ or $\lvert A \rvert$ o a singular matrix is one with the determinant $\lvert A \rvert = 0$ • Routine operations involve: o the determinant of a (2 × 2) matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $\lvert A \rvert = ad - bc$ o the inverse of a two-dimensional matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $A^{-1} = \frac{1}{\lvert A \rvert}\begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$

What needs to be learned
• Non-routine operations involve: o the determinant of a (3 × 3) matrix $A = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$ using $\lvert A \rvert = a\begin{pmatrix} e & f \\ h & i \end{pmatrix} - b\begin{pmatrix} d & f \\ g & i \end{pmatrix} + c\begin{pmatrix} d & e \\ g & h \end{pmatrix}$ o use of Cramer's rule to solve for sets of simultaneous equations with two variables o engineering applications, e.g., simultaneous linear equations with more than two variables (electrical circuits, vector arrays, machine cutter paths).
Learning outcome 3: Examine how complex numbers can be used to solve engineering problems
Complex numbers • Definitions: o algebraic form (Cartesian, rectangular notation): $(a + jb)$ o real part, imaginary part, j notation, j-operator, powers of j o modulus: $\lvert a + jb \rvert = \sqrt{a^2 + b^2}$ o argument: $\arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$ o polar form $r\angle\theta$; θ is usually expressed in radians but may be in another angular measure o complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$ • Routine operations involve: o placement of complex numbers on an Argand diagram o addition and subtraction in rectangular form o multiplication by a constant coefficient o conversion between rectangular and polar forms ($r \rightarrow p$ and $p \rightarrow r$) using trigonometry and a scientific calculator o multiplication and division of complex numbers in polar form.

What needs to be learned

Learning outcome 4: Investigate how statistical and probability techniques can be used to solve engineering problems

Statistical techniques

- Routine operations involve:
  - discrete data, continuous data, ungrouped data, grouped data, rogue values
  - presentation of data: bar charts, pie charts, histograms, cumulative frequency curves
  - measures of central tendency (location): arithmetic mean, median, mode
  - measures of dispersion: variance, standard deviation, range and inter-percentile ranges
  - linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ represented graphically.
- Non-routine operations involve:
  - equation of linear regression line $y = mx + c$ where

$$m = \frac{N\sum_{1}^{N}(x_i y_i) - \sum_{1}^{N}(x_i)\sum_{1}^{N}(y_i)}{N\sum_{1}^{N}x_i^{2} - \left(\sum_{1}^{N}x_i\right)^{2}} \text{ and } c = \overline{y} - m\overline{x}$$

$$\overline{x} = \frac{\sum_{1}^{N}x_i}{N} \text{ and } \overline{y} = \frac{\sum_{1}^{N}y_i}{N}$$

  - correlation coefficient using Pearson's correlation

$$r_{x,y} = \frac{N\sum_{1}^{N}x_i y_i - \sum_{1}^{N}x_i \sum_{1}^{N}y_i}{\sqrt{N\sum_{1}^{N}x_i^{2} - \left(\sum_{1}^{N}x_i\right)^{2}} - \sqrt{N\sum_{1}^{N}y_i^{2} - \left(\sum_{1}^{N}y_i\right)^{2}}}$$

- Use of spreadsheets and/or scientific calculators to calculate the equation of the line of regression and correlation coefficient, e.g. tabulating calculations, using trendline and CORREL() functions in a spreadsheet, or a standard scientific calculator.
- Use of spreadsheets and/or scientific calculators to identify the most appropriate type of regression line, e.g., linear, logarithmic, exponential or variable power.

What needs to be learned
Probability distributions • Routine operations involve: o normal distribution – shape and symmetry, skew, tables of the cumulative distribution function, mean, variance o normal distribution curve – areas under it relating to integer values of standard deviation. • Non-routine operations involve: o confidence intervals for normal distribution and probability calculations. **Statistical investigation** • The use of appropriate mathematical methods to solve the given engineering problem. • Engineering applications, e.g., inspection and quality assurance, calculation of central tendencies and dispersion, forecasting, reliability estimates for components and systems, customer behaviour, condition monitoring and product performance. • Reflection on the problem-solving process and the solution obtained, making refinements if necessary. • Presentation of the solution to the given engineering problem.

Essential information for tutors and assessors

Essential resources

For this unit, learners must have access to:

- maths support websites, e.g., www.mathcentre.ac.uk/students/topics
- spreadsheet software and/or a scientific calculator such as Casio FX-85GT.

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A and Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Sequences and Series to Solve Engineering Problems	An activity requiring learners to solve problems based on sequences and series.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P3, P4, M3, M4, D2	Matrices, Determinants and Complex Numbers to Solve Engineering Problems	An activity requiring learners to solve problems based on matrices, determinants and complex numbers.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P5, P6, M5, M6, D3	Statistical and Probability Techniques to Solve Engineering Problems	An activity requiring learners to solve engineering problems based on statistical data.	An informal report containing the results of learners' analysis and calculation of measured and supplied data; carried out under controlled conditions. Where appropriate, processing of statistical data can be done by spreadsheet.

For P1 and P2, learners must demonstrate the correct use of routine operations (skills and methods) when working with given problems based on sequences and series.

Overall, minor arithmetic and scaling errors are acceptable, as are 'carry through' errors, provided that the basic method is sound. For example, a term in a sequence may be incorrectly calculated but the value used correctly in subsequent calculation of the series, affecting the final value. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For P3 and P4, learners must demonstrate the correct use of routine operations (skills and methods) when working on given problems based on matrices, determinants and complex numbers.

Overall, minor arithmetic errors are acceptable, as are ‘carry through’ errors, provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. Learners will include evidence of simple checks to determine if numerical answers are ‘reasonable’.

For P5 and P6, learners will present the solutions of engineering problems involving measures of central tendency, dispersion and probability distribution. Ideally, they will research their own problems but if this is not possible then they can be given to learners. The solutions may not be complete and there may be some inaccuracies or omissions but there should be evidence of some proficiency of method. Learners will apply the appropriate routine operations (skills and methods) needed to process statistical data.

For example, when evaluating sampled dimensional data from a machining operation, learners will present data appropriately and determine routine values such as the mean and standard deviation for a sample but may not compare the values with historical data. They will tabulate measurements and present data in a scatter graph, and they may estimate the line of regression graphically.

Overall, the report should be logically structured. It may contain some arithmetic errors that ‘carry through’, for example the value of the mean of a set of sampled dimensional data from a machining operation may be incorrect, but that value used correctly to find the standard deviation. The methods chosen may not be optimal, but the chosen statistical methods should be applied correctly. Minor errors and omissions are acceptable. For example, the axis titles on a scatter graph may be missing units. There will be an appreciation of the correct use of units but there may be errors or inconsistency in their application. Learners will include evidence of simple checks to determine if numerical answers are ‘reasonable’.

For M1 and M2, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on sequences and series.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor, for example appropriate significant figures and decimal places. Solutions must be structured logically, and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M3 and M4, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on matrices, determinants and complex numbers.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor, for example appropriate significant figures and decimal places. Solutions must be structured logically, and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M5 and M6, learners will present accurate solutions for engineering problems related to measures of central tendency, dispersion and probability distribution, breaking them down into planned stages to obtain solutions. They will apply appropriate routine and non-routine operations (skills and methods) needed to process statistical data accurately. For example, tabulation of data, graphical presentation, accurate calculations of mean and standard deviation comparing measured values with historical data, accurately produced annotated scatter graph (with chart title, axis titles including units and gridlines) and calculation of line of regression and correlation coefficient for a linear relationship and regression line for a non-linear relationship.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor or appropriate for the chosen problems being solved. Solutions will contain an explanation of the process that will be logically structured, and the correct mathematical terminology and relevant units will be used.

There may be limited number of minor errors or omissions in non-routine operations. For example, when evaluating sampled dimensional data from a machining operation, learners may determine the mean and standard deviation for a sample and find a degree of correlation between samples, but not draw conclusions from, the values.

To achieve D1, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving sequences and series. Where appropriate to the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be presented correctly in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to specified numerical precision, as specified by the assessor, through the use of appropriate significant figures.

For D2, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving matrices, determinants and complex numbers. Where appropriate with the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate they are able to work to specified numerical accuracy through the use of appropriate significant figures, as specified by the assessor.

In order to achieve D3, learners will demonstrate mastery in the application of the processing and evaluation of statistical data generated from engineering sources. The identified problems must be sufficiently complex to allow learners to apply both routine and non-routine operations (skills and methods) to their solution. For example, in terms of measures of central tendency and dispersion learners may evaluate one set of measured and four sets of equivalent historical data such as dimensional data from a machining operation or reliability data sourced from products in service. Before starting to process any data, learners will establish that the data sets are large enough to enable reliable analysis to be carried out.

For regression, they will propose a theoretical relationship between two variables, collect data, calculate a mathematical relationship between dependent and independent variables using appropriate analytical and graphical methods, and reflect on the accuracy of the initial proposal for a linear and a non-linear relationship.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. There will be correct use of mathematical terminology and the application of relevant units. Learners will work to specified numerical precision, as determined by the assessor or that are appropriate for their chosen problems being solved, through the use of appropriate significant figures or decimal places. Small and large numerical values will be correctly presented in an appropriate format, i.e., engineering notation or standard form.

Unit 21: Organisational Efficiency and Improvement

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

In this unit, learners will gain an understanding of continuous improvement in their sector and identify areas in production where lean working could be used to aid the company. They will learn about quality control methods used in industry and understand the key factors required to remain competitive in the market.

Learners will understand the importance of human resource management in terms of building successful teams and the effect this can have on recruitment and retention of employees.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand production activities

2 Understand application of quality control and quality assurance

3 Understand organisational improvement techniques and competitiveness

4 Understand personal rights and responsibilities in an organisation.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the different types of production	**M1** Compare the advantages and disadvantages of different types of production	**D1** Justify the selection of a production type for a given process
P2 Describe the requirements that need to be considered when selecting a type of production		
P3 Describe the different stages of production planning		
P4 Explain how to apply typical process charts to production planning		
P5 Explain the meaning of the terms 'quality control' and 'quality assurance'	**M2** Explain the importance of using a structured approach for quality control and quality assurance	**D2** Evaluate a quality management process and make suggestions for improvement
P6 Describe the role and stages of inspection activities		
P7 Explain the application and content of the BS EN ISO 9000 series of standards		
P8 Explain the role and responsibilities of the quality manager		
P9 Describe the requirements of quality planning		
P10 Describe the principles of total quality management (TQM)		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P11 Explain the meaning of the terms Lean Manufacture, Kaizen, just-in-time and Kanban and their overall advantages	**M3** Explain the consequences for an organisation of not maintaining continuous improvement standards	**D3** Evaluate a production process and identify where improvements can be made to increase productivity and organisational competitiveness
P12 Explain the importance of improving organisational productivity		
P13 Describe the need for continuous improvement to ensure organisational competitiveness		
P14 Describe the key requirements for managing the production process		
P15 Explain the importance of teamwork and the individual's contribution to effective teamwork		
P16 Explain the key features of employment legislation in relation to personnel rights and responsibilities	**M4** Explain the effects of not adhering to employment legislation in relation to personal rights and responsibilities	
P17 Describe the personnel opportunities for development and progression that are available in the workplace		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P18 Describe the role of the representative bodies in the engineering sector that support personnel and organisations		
P19 Explain the implications that 'Investors in People' has on an organisation and its personnel.		

Unit content

What needs to be learned
Learning outcome 1: Understand production activities
• Types of production: e.g., mass; flow; automated; batch; one-off. • Considerations: market requirements; design of product; plant and equipment availability; plant and equipment layout; personnel; production control; quality control; cost. • Methods and application of cellular and just-in-time (JIT) production: relation to modern production requirements; application of push and pull types of production to meet company and customer needs and expectations. • Stages of production planning: scheduling, loading, dispatching (coordination of pre-production activities); requirements, e.g., engineering drawings, technical data, personnel, machinery/tools, components, materials, consumables. • Process charts: e.g., flow charts/diagrams, Gantt charts; symbols used in process charts.
Learning outcome 2: Understand application of quality control and quality assurance
• Quality control and assurance: meaning of 'quality control' and 'quality assurance'; fitness for purpose, e.g. meeting customer expectations; purchasing; production planning and procedures for quality assurance; manufacture (process control); final inspection and dispatch; Statistical Process Control (SPC), e.g. measuring quality/performance, document control as an integral part of quality assurance, records of the correct operation; types and the purpose of sampling, e.g. spot check, random sampling, process sampling, batch sampling; mean time between failures (MTBF) in the context of sample size and frequency. • Inspection: checking every stage for deviation from design specification; adjustments that need to be made; stages of inspection, e.g., goods inward, during production (process control), final inspection; role of the inspector in checking compliance with quality standard and procedures; quarantine area to store defective work. • BS EN ISO 9001: internationally recognised quality assurance standard; role of the quality manual and process/procedures manual; internal/external audits. • Quality manager: relationship with other managers/departments in the company; considerations to be made when developing a quality plan, e.g., quality requirements (customer expectations), allocation of responsibilities (at all levels), the setting up of systems to measure quality and report progress, identification and calibration of quality equipment, ability to take corrective actions where necessary.

What needs to be learned
• Total quality management (TQM): main principles and goals; advantages of adopting TQM, e.g., competitiveness in the market, enabling growth and longevity, reducing stress, building teams, partnerships and cooperation.
Learning outcome 3: Understand organisational improvement techniques and competitiveness
• Business Improvement Techniques (BIT): principles of lean manufacture, e.g., removal of waste of all kinds (time, motion, inventory, poor cost of quality etc.), stimulating productivity and quality; use of value-added processes, Kaizen as a philosophy that encompasses continuous improvement; just in time (stockless production or lean production), e.g., manufacturing to order not to stock; Kanban inventory control. • Productivity: meaning of the term 'production'; benefits to the company of increasing productivity; company, e.g., multinationals, nationals and regional, Small and Medium Enterprises (SMEs) and sole traders; managing the production process, e.g., layout of the production area, batch production, synchronisation, lead-time. • Continuous improvement: meaning of 'continuous improvement'; continuous improvement cycle (plan, do, check, and action); benefits gained; flexible working and multi-skilling; importance in the national and global marketplaces, e.g., multinationals, nationals, SMEs and sole traders. • Teamwork: roles in a team, e.g., leaders, doers, thinkers, carers; balance in a team; what individuals bring to a team; team building; communication in the team.
Learning outcome 4: Understand personal rights and responsibilities in an organisation
• Organisational documentation and employment legislation: documentation, e.g., contracts of employment, staff handbook; personnel records, grievance procedures; appraisals; disciplinary procedures; legislation, e.g. Employment Rights Act 1996, Working Time Regulations 1998, Health and Safety at Work etc. Act 1974, Data Protection Act 1998, Equal Opportunities Act 2010, Human Rights Act 1998, Equality Act 2010. • Development and progression opportunities: company training programmes; apprenticeships; organisational training opportunities; promotion; transfer; higher education; professional qualifications. • Roles of representative bodies: e.g., trade unions, professional bodies, employers' organisations (EEF, the manufacturers' organisation); industry training support. • Investors in People (IiP) national standard: four key principles – commitment, planning, action and evaluation; how organisations acquire IiP status.

Essential information for tutors and assessors

Essential resources

Case study into quality management of a sample company for learners with unsuitable employers to study their own company.

Evidence from previous employment law cases to allow learners to identify the importance of a company abiding by the law.

Textbooks

Waldock B – *Being Agile in Business: Discover Faster, Smarter, Leaner Ways to Work* (Pearson Education, 2015) ISBN 9781292083704

Hutchinson S – *Performance Management: Theory and Practice* (CIPD, 2013) ISBN 9781843983057

Mullins L J – *Management and Organisational Behaviour*, 10th Edition (FT Publishing International, 2013) ISBN 9780273792642

Journals

Business Review Magazine (Phillip Allan Publishers – see www.phillipallan.co.uk)

The Economist (The Economist Newspaper Group Inc)

Websites

BBC News	www.bbc.co.uk/business
National Learning Network	www.nln.ac.uk

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4 M1, D1	Production Processes and Planning	A company decides to manufacture a product. Learners should analyse the possible types to produce it and identify the most suitable, justifying their selection	A written task encompassing production and production planning
P5, P6, P7, P8, P9, P10 M2, D2	Investigation into Quality Management	Learners will analyse existing quality management procedures in a company (or their own company if suitable) and use the data found to suggest improvements	Case study of the company they are working at or a different one if appropriate
P11, P12, P13, P14, P15 M3, D3	Continuously Improving Productivity	Learners identify the most common production methods used by companies (and their own company if appropriate) and analyse the impact that these processes have had on productivity	A written task, case study

Criteria covered	Assignment title	Scenario	Assessment method
P16, P18, M4	Employers' Rights and Employment Law	Learners analyse their workplace employment contracts and processes, alongside existing cases brought against companies to analyse the importance and effect of the law and union's role in defending workers' rights.	A written task, case study.
P17, P19	Investment in People	Learners will identify the importance of investment in the workforce, how companies obtain IiP and what effect that has on employment.	A written task.

To achieve a pass grade, all the pass criteria must be met. Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2, P3 and P4 could be achieved by means of a written task based on a given product that needs to be manufactured. For P1, learners need to identify a range of production processes that could be used to manufacture a product and explain the underlying principles behind them. For P2, learners should identify the customer requirements for a given type of product and describe how these requirements will impact on the selection of a specific production method. For P3, learners would identify the key stages in production planning to produce their production plan for the given product. For P4, learners can add in the need for and importance of process charts in the plan to identify key stages in the production. This task can also allow learners to achieve M1 through a thorough analysis of the company. Alternatively, a case study into quality management of a sample company could be used. At least two possible production types should be compared. D1 can be achieved through learners justifying their choice of production type in detail.

Achievement of P5, P7, P9 and P10 could use a written task asking learners to identify the terms and roles suitable for accurate quality control procedures and how this can be built into TQM. This could be linked to a case study, based around a company visit if possible. Learners would have to identify the areas where standards such as ISO 9001 are vital in industry and how the companies involved identify the relevant roles for P6 and P8 respectively. As part of this written task, learners can also draw evidence of explaining the importance of structure in the quality procedures to gain M2.

This case study or visit should then allow learners to identify and evaluate the QA procedures in operation and allow them to suggest improvements for D2.

P11 and P12 can be achieved through a written analysis of the different types of production process and their advantages in improving productivity. This would then lead to a description of the importance of continuous improvement for P13 and also allow learners the opportunity for detailed discussion to achieve M3 at the same time. Learners should describe a given production process and the importance of the management structures present for P14 and then explain the impact effective team building and teamwork has on productivity for P15. Learners can then suggest improvements to this in detail, which would give the opportunity to achieve D3.

The achievement of P16 should be tied to an analysis of learners' own workplace human resources departments to explain the key features, and also allow the opportunity to discuss why it is important for companies to follow the law, with some examples of the effects for M4. This could be linked to the importance of representation from bodies such as workers' unions for P18.

P17 and P19 can be achieved through research into why companies should continually develop their staff and the effect that Investors in People has on encouraging employment and development.

Unit 22: Manufacturing Planning

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

There are many new technologies involved in planning the manufacturing of products, parts and components but many smaller companies still operate and work with traditional approaches.

This unit will give learners a good understanding of the basic techniques of manufacturing planning and an awareness of scheduling requirements. It introduces learners to different types of production and will give them an understanding of the stock holding policies that still exist in many engineering companies. Knowledge of the costs associated with holding stock can aid future manufacturing strategies and any related business improvement considerations.

Before learners develop a production plan, they are expected to have an understanding of the general aspects of planning and control and the techniques used to measure efficiency in a product manufacturing system. Some of these techniques could be explored in detail should learners show an added interest in this area.

Learners are required to produce a production plan from a given range of information in a product specification and prepare a production schedule to support the delivery of the production plan. This unit provides underpinning knowledge for a range of other units, particularly those associated with business improvement.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the techniques and policies used to improve product manufacturing efficiency

2 Understand general aspects of planning and control

3 Be able to use a product specification to produce a production plan

4 Be able to produce a production schedule.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the six different types of production	**M1** Explain the circumstances in which cellular production would be better than batch production	**D1** Discuss the relationship between economic order quantities and stock holding costs
P2 Explain a stock holding policy for a given type of inventory	**M2** Explain how you determined the economic order quantity	
P3 Determine an economic order quantity from given data		
P4 Explain an appropriate technique used to improve product manufacturing efficiency		
P5 Explain the aspects of planning in manufacturing		
P6 Explain functions of control used in manufacturing planning		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Use a product specification to produce a production plan	**M3** Compare the importance of different types of information in a product specification when producing a production plan and schedule	**D2** Evaluate the use of a production plan when preparing a production schedule and the dangers of the schedule not meeting stock holding requirements
P8 Explain the use of a production schedule		
P9 Produce a production schedule from a production plan and given data	**M4** Analyse how the use of presentation techniques can be used to overcome capacity and production planning problems	

Unit content

What needs to be learned
Learning outcome 1: Understand the techniques and policies used to improve product manufacturing efficiency
• Types of production: jobbing; batch; cellular; flow; mass; automatic. • Stock holding policy: types of inventories, e.g., materials, parts, components, tools, consumables, finished goods; stock holding costs, e.g. ordering/replenishment, holding, obsolescence; buffer stock; reorder levels; storage areas; economic order quantity, e.g. data $Q = \frac{\sqrt{2C_s r}}{C_C}$ or $Q = \left(\frac{2C_s r}{C_C}\right)^{\frac{1}{2}}$ • Appropriate techniques: e.g., method study, value analysis, job design (ergonomics, layout, safety); work measurement.
Learning outcome 2: Understand general aspects of planning and control
• Aspects of planning: capacity measurement, e.g., machine hours, man hours, throughput, department hours; production planning; pre-production planning; other aspects, e.g., information technology, documentation, health and safety, environmental issues. • Control: functions, e.g., production control, quality control.
Learning outcome 3: Be able to use a product specification to produce a production plan
• Product specification: aspects relative to manufacturing and not the customer; type of information required for manufacture, e.g., engineering drawings, process description, make and assembly techniques and requirements, materials required, measurements, tolerances and other quality specifications. • Production plan: consideration of a product specification and types of production; requirements (processes, materials required, quantities required, tools and equipment, labour required, estimated process times, quality checks.
Learning outcome 4: Be able to produce a production schedule
• Production schedule: based on the requirements identified within a production plan; presentation techniques, e.g., use of a Gantt chart, critical path network, line of balance technique; data, e.g., completion deadline, customer requirements, capacity available.

Essential information for tutors and assessors

Essential resources

For this unit, centres need a range of production data and information as described in the unit content for learning and assessment. Ideally, examples and data from industry will be provided for learners and access to manufactured products will be required.

Textbooks

Slack N, Chambers S and Johnston R – *Operations Management* (Prentice Hall, 2009) ISBN 9780273730460

Timings R L – *Basic Manufacturing* (Routledge, 2004) ISBN 9780750659901

Waters D – *Inventory Control and Management* (John Wiley and Sons, 2003) ISBN 9780470858769

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1	Types of Production in Manufacturing Industries	A written activity requiring learners to look at a case study of real-life production and stock control.	Written responses to case study-based questions about the key features of different production types and describing a stock holding policy and the techniques used to improve efficiency.
P5, P6	Product Specifications	A written assignment and oral questioning on developing a product specification for an existing product and designing a common specification template that accounts for control functions in production.	A whole group activity with learners creating a product specification for a real-world product they have access to and explaining a product template for use in further assignments that explain planning and control aspects of production.
P7, P8, P9, M2, M3, D1	Product Planning and Scheduling	Presenting a production plan and schedule based on a product specification. Write up report on the presentation and production schedule.	Presentation and accompanying documents that explain the use of a production schedule and other data. Written report on presentation evaluating the use made of the production schedule and the presentation techniques used.

It is important that the assessment strategies used are designed to suit the needs of learners and any local industry requirements. Good assessment strategies need to be supported by the proper presentation of appropriate evidence. The portfolio should not contain course notes, research etc. unless this is part of the required evidence and assessment.

Work done through the use of case study material can be used to generate evidence for learners' portfolios. An integrated approach to this unit would be a suitable way for learners to gather evidence, particularly for learning outcomes 3 and 4.

To achieve a pass grade, learners should demonstrate knowledge of types of production, stocking policies and understanding techniques used to improve manufacturing efficiency. Learners are also expected to explain general aspects of planning and control and the use of a production schedule. They should then demonstrate the correct development of a production plan when using a product specification, a schedule and other data.

This unit could be assessed using three assignments. The first assignment could cover learning outcome 1 and its associated criteria (P1, P2, P3, P4, M1, M2 and D1), with a task set for each criterion. For P3, a range of data – such as ordering or replenishment costs per order (C_S), holding costs (C_C) and usage rate (r) – should be given to allow an economic order quantity (Q) to be determined. This could then be extended to include an explanation for M2 and a discussion of the relationship between economic order quantities against the costs involved in holding stock (D1).

Criteria P5 and P6 could be set in a second assignment as separate written tasks. A final assignment could be developed to cover P7, P8, P9, M3, M4 and D2. A product specification should be made available to each learner for them to use to develop a production plan. They could then be asked to produce a production schedule when given further data, such as completion time and capacity available. Standard templates for both the plan and schedule can be used as this would be similar to industrial practice.

Another task would then need to be given, asking learners to provide a written response when explaining the use of a production schedule. Further written tasks should also be included to cover M3, M4 and D1.

To achieve a merit grade, learners should explain what parts of the product specification are most important when developing a plan and schedule. A task for M1 could be given to build on the response given to P1 in the first assignment. A task for M3 should be left until all pass criteria have been attempted and therefore be in the third and final assignment about planning and scheduling. Learners should also be able to analyse how information found in Gantt charts and critical path network documents could be used to identify and help overcome any over-capacity problems and how improvements can be made to the production plan (M4). This criterion requires a written task set in the final assignment.

To achieve a distinction grade, learners should demonstrate a comprehensive knowledge understanding and of manufacturing planning. Learners will confidently evaluate the development of a production schedule when using a production plan and other data in terms of whether that schedule will have an effect on stock holding requirements (D2).

Unit 23: Mechanical Measurement and Inspection Techniques

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

In order to produce components that meet the design criteria, manufacturing companies have to know whether the components they make are to the required dimensional and accuracy standards. Companies carrying out maintenance activities also need to know that the components they are working with, repairing or servicing are to the required size and accuracy.

Measurement and inspection play an important role in establishing these needs and support other areas of assuring quality in the products produced. The process of finding out whether a product is accurate and to dimensional standards also needs to be done in an efficient and effective way.

The aim of this unit is to provide a broad understanding of mechanical measurement and inspection techniques that apply to a range of engineering activities in different companies. The unit will give learners an understanding of a range of techniques and equipment commonly used in mechanical measurement and inspection.

Learners will be introduced to principles of measurement and the use of comparators and gauges, along with sampling and Statistical Process Control (SPC). Learners will develop the skills needed to select and use standards, measuring equipment, comparators and gauges. They will appreciate the fundamental requirements of measurement and inspection techniques and apply standards to them.

Learners will have an opportunity to carry out practical measurements using linear measuring equipment and techniques and comparators and gauges. They will also prepare a process control chart for a given process.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand principles and applications of mechanical measurement

2 Be able to use measurement equipment and techniques

3 Be able to use comparators and design a gauging system for inspection

4 Be able to apply sampling and Statistical Process Control (SPC) during inspection.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the different types of limits and fits	**M1** Analyse the use of the concept of limits and fits	
P2 Use tolerancing principles to calculate hole and shaft tolerances for a range of required component fits		
P3 Explain the principles of measurement		
P4 Use linear measurement equipment to carry out practical measurements for given products	**M2** Explain the use of linear measuring equipment when used on given products	**D1** Evaluate the use and accuracy of linear measuring equipment when used on given products
P5 Use further measurement techniques on given products to establish surface texture, alignment and angular measurements		
P6 Use comparators to measure dimensions and angles for a simple given product	**M3** Compare different uses of comparators when used to measure dimensional accuracy	**D2** Analyse the calibration requirements of comparators and measurement equipment.
P7 Design a gauging system for a simple given application		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Explain the technique of acceptance sampling and state when 100% inspection is applicable	**M4** Explain process capability in relationship to Statistical Process Control (SPC) for a given relevant process	
P9 Produce control charts for a given process		

Unit content

What needs to be learned
Learning outcome 1: Understand principles and applications of mechanical measurement
• Limits and fits: e.g., concepts of limits and fits, definitions of the types of fits (clearance, transition, interference). • Tolerances: principles, e.g., standard symbols and interpretation, maximum material condition, maximum variation of form, grades of tolerance; hole tolerances, shaft tolerances. • Principles of measurement: units; standards, e.g., BS 969, BS 1134, BS 2634, BS 4500; calibration, e.g. national standards, traceability; errors and instruments; kinematics of equipment.
Learning outcome 2: Be able to use measurement equipment and techniques
• Linear measurement equipment: range (Verniers, callipers, micrometers); principles involved; scales; types; use in dimensional measurement; specific calibration issues. • Further measurement techniques: determining surface texture, e.g. significance to component function, surface texture symbols, roughness average, waviness, finish, amplitude parameters, spacing parameters, instrumentation used for surface texture measurement; determining alignment, e.g. principles of straight edges, measurement of straightness, squareness, flatness and parallelism; determining angular measurements, e.g. concepts of geometry, divided circles, principles of angular measurement, angular scales, methods for angular measurement, taper measurement.
Learning outcome 3: Be able to use comparators and design a gauging system for inspection
• Comparators: types of comparator, magnification, cosine errors, use of angle dekkor, specific calibration issues. • Gauge design: principles of gauge design (gauge types, gauge materials, Taylor's principle, principle of go/no-go gauging); slip gauges as references for length standards (classification of slip gauges, multiple slip gauge use, ancillary equipment, care and maintenance required, wringing); slip gauges for instrument calibration (use with dial gauges in dimensional measurement, specific calibration issues). • Simple application: measuring a component containing round (external or internal), linear and angled features, following the use of a high precision manufacturing method such as grinding, e.g., the jaw of a toolmaker's clamp.

What needs to be learned
Learning outcome 4: Be able to apply sampling and Statistical Process Control (SPC) during inspection
• Sampling: acceptance sampling, 100% inspection. • Statistical process control: charts (mean, range); process capability, conformance, cost, process variability; process, e.g., grinding machine, high-volume lathe.

Essential information for tutors and assessors

Essential resources

For this unit, centres need a range of measuring and inspection equipment as defined by the content, plus a range of products for learners to measure. Centres will need to provide access to engineering data handbooks, manufacturers' specifications and suitable current British Standards (e.g. BS 969: Limits and Tolerances on Plain Limit Gauges, BS 1134: Method for the Assessment of Surface Texture).

Textbooks

Drake P – *Dimensioning and Tolerancing Handbook* (McGraw-Hill, 1999) ISBN 9780070181311

Griffith G – *Geometric Dimensioning and Tolerancing: Applications and Inspection* (Prentice Hall, 2001) ISBN 9780130604637

Timings R L – *Fundamentals of Engineering* (Routledge, 2002) ISBN 9780750656092

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3 and M1	Tolerances and Fits	A time-constrained assignment requiring learners to demonstrate their knowledge of tolerances and fits	A practical assignment requiring learners to calculate tolerances for component fits, supported by written tasks
P4, P5, M2 and D1	Using Measurement Equipment and Techniques	An assignment requiring learners to use linear measuring equipment and further measuring techniques	A practical task in which learners use Verniers, callipers and micrometers and determine surface texture, alignment and angular measurements on at least two products. A further written task can be used to give learners an opportunity to evaluate the use of linear measuring equipment

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3 and D2	Comparators and Gauges	A practical assignment requiring learners to use comparators and design a gauging system.	Two practical tasks in which learners measure dimensions and angles using comparators. Learners then design a gauging system. A further written task could build on the practical work so that learners can carry out a comparison and analysis for M3 and D2.
P8, P9 and M4	Sampling and Statistical Process Control	An assignment requiring learners to investigate sampling and inspection techniques.	A series of three written tasks in which learners provide an explanation of sampling and inspection techniques. Learners will need to produce control charts from given data.

Four assignments could be developed for the assessment of this unit.

The first assignment could be a time-constrained assignment addressing criteria P1, P2, P3 and M1. A range of data for all three types of fit should be given, allowing learners to apply their knowledge of tolerancing to develop suitable tolerances for each fit. Tasks need to be included that ensure the range of unit content – such as maximum material condition and tolerance grades – are covered (P2). Written tasks should be given for the other criteria, P3 and M1, targeted in this assignment.

For the second assignment, addressing criteria P4, P5, M2 and D1, a range of products need to be made available so that each learner is able to use a Vernier, a calliper and a micrometer.

It would be useful if the products had both internal and external features to be measured. Obviously, the products need to be machined to allow the accuracy that demands the use of this equipment. The instructions should ensure that surface texture, alignment and angular measurements are taken.

Particular care needs to be taken with the choice of product to ensure it is large enough to allow alignment measurements to be taken as ranged in the content. At least two products are required to ensure the range of features and accuracy can be measured and the use of the equipment evaluated. A written task needs to follow the practical activity to address M2. A witness statement/observation record would support the evidence for the use of this equipment, along with a table of measurements taken.
D1 will form an extension to the practical work and will require an evaluation of the range of instruments – Vernier, a calliper and a micrometer.

The third assignment, addressing criteria P6, P7, M3 and D2, could also be based around a practical exercise. The choice of product for the use of comparators (P6) needs to ensure that there are both dimensions and angles to be measured. No more than two angles are required otherwise the product will be too complex.

Care will need to be taken when planning an assessment activity for the designing of a gauging system (P7). Data or a particular specification should be made available that ensures the principles of gauge design are applied and slip gauges are used. The unit content suggests as an example the jaw of a toolmaker’s clamp, so in this case as long as there are external and internal features, linear and angled features the product is suitable. An overly complex product would not be suitable. A written task should be given to provide opportunities for criteria M3 and D2 and could be an extension of the practical work. Again, a witness statement/observation record would support evidence of the use of comparators, along with a table of measurements taken.

The last and fourth assignment could address criteria P8, P9 and M4. Data needs to be given for a process that allows learners to present control charts (P9) for both mean and range and link this to M4. A further written task needs to be set for P8.

Unit 24: Engineering Design

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

An understanding of how the design process operates within an engineering business is important for anyone considering a career in the design and manufacture of products. This unit provides learners with the opportunity to consider design in a holistic way. It combines study of the technical aspects of engineering design with wider issues such as the environment, sustainability and legislation.

The unit introduces and develops the concept of design for manufacture. It is crucial that the design process be effective. Success in the marketplace can be achieved only if products are fit for purpose, marketable and meet customer requirements. The importance of market research, generation of new ideas and the consequences of poor design are investigated.

Learners will also investigate the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture. These issues include the impact of legislation and standards, the need to conform to environmental and sustainability requirements, materials selection and the types of manufacturing process available. On completion of the unit learners will understand the wider implications of engineering design and the reasons why it cannot be carried out in isolation from the rest of the manufacturing/production process.

The unit content is linked together through a practical task which starts with learners interpreting the requirements of a customer and producing a product design specification (PDS). This is followed by an investigation into the legislation, standards and reference sources that are used by designers who work in manufacturing engineering. This knowledge is then used to influence the production of their own design proposals. These proposals are refined and developed into a final design solution which meets the requirements of the customer. Design ideas will have been communicated using a number of techniques including sketching and formal engineering drawing, design calculations and written commentary.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Know how the design process operates when dealing with customers

2 Know the impact of legislation, standards and environmental and manufacturing constraints can have on the design function

3 Be able to prepare design proposals that meet the requirements of a product design specification

4 Be able to produce and present a final design solution.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the operation of the design process in an engineering company	**M1** Explain the possible impact of a poor design process on customer relationships and requirements	**D1** Evaluate the impact of legislation and standards on the design process in relation to the profitability of the business
P2 Interpret the requirements of a given customer and produce a product design specification	**M2** Explain the importance of using a range of accurate design reference materials when developing design proposals	**D2** Evaluate a final design solution against customer requirements and a PDS and suggest improvements.
P3 Describe the appropriate legislation and standards which apply to the design of two different products	**M3** Explain the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture	
P4 Describe the environmental, sustainability and manufacturing constraints which influence the design of a given product		
P5 Produce design proposals which meet the requirements of a given PDS		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Extract reference information from component manufacturers' catalogues and materials and design databases		
P7 Use a range of techniques to present a final design solution which meets the requirements of a given PDS and relevant legislation and design standards.		

Unit content

What needs to be learned
Learning outcome 1: Know how the design process operates when dealing with customers
• The design process: triggers, e.g., market pull, demand, profitability, technology push, innovation, market research; process of design for manufacture; decision making; use of new technologies, e.g., computer aided design (CAD), simulation, rapid prototyping, computer integrated manufacture (CIM); lines of communication. • Customer: customer/client relationship; types of customers, e.g., external, internal; requirements of customer, e.g., performance specifications (physical dimensions, mass), compliance to operating standards, reliability and product support, end of life disposal, production quantities (custom built, modification to an existing product, small batch, large volume). • Product design specification (PDS): analysis of customer requirements; production of an agreed PDS; documentation, e.g., physical dimensions, materials, mass, operation and performance.
Learning outcome 2: Know the impact of legislation, standards and environmental and manufacturing constraints on the design function
• Legislation and standards: relevant and current legislation, standards and codes of practice, e.g., British Standards (BS), International Standards (ISO), electromagnetic compatibility (EMC) directive, European legislation (European Conformity (CE marking)). • Environmental and sustainable constraints: energy efficiency; environmental impact; constraints, e.g., Environmental Protection Act, Waste Electronic and Electrical Equipment Directive; end-of-life disposal, e.g., refurbishment, recycling, disassembly, material recovery, non-recyclable components. • Manufacturing constraints: availability of resources, e.g., labour, material, equipment; influence of physical and mechanical properties of a material in relation to manufacturing methods; cost effective manufacture, e.g., set up cost (jigs, tools), production quantities; health and safety in the workplace, e.g., Health and Safety at Work Act, Control of Substances Hazardous to Health (COSHH) Regulations.

What needs to be learned
Learning outcome 3: Be able to prepare design proposals that meet the requirements of a product design specification
• Requirements of a PDS: interpretation of technical requirements, e.g., operating performance, physical dimensions; interpret economic requirements, e.g., production quantities, product life, marketplace positioning. • Prepare design proposals: ideas generation, e.g., research into existing products, freehand sketching, simulation, flow charts; realistic design proposals, e.g., fitness for purpose, manufacturability, aesthetics, ergonomics. • Design reference material: manufacturers' catalogues, e.g., screw fixings, bearings, seals, electrical connectors, drive belts, gear drives; materials databases, e.g., mechanical properties, physical properties; design databases, e.g., structural beam sections, corrosion protection, anthropometric data.
Learning outcome 4: Be able to produce and present a final design solution
• Final design solution: evaluation of proposals and selection of most appropriate for further development, e.g., suitability for available manufacturing processes, cost effectiveness, contribution to profits, visual appearance; development of design proposal into a feasible solution suitable for prototype manufacture, e.g., specify materials, appropriate manufacturing processes, estimation of manufacturing cost, quality; conformity to relevant legislation and design standards. • Presentation techniques: 2D engineering drawings, e.g., general arrangement drawing, assembly drawing, detail drawings, circuit diagrams, flow diagrams, schematic diagrams; drawing conventions and relevant British Standards, e.g., BS308, BS8888, BS7307, BS3939, BS2197; documentation, e.g., design diary, logbook, product specification; design calculations, e.g., sizes of materials to meet strength requirements, electric motor power, electronic circuit performance, battery life.

Essential information for tutors and assessors

Essential resources

To meet the needs of this unit it is essential that learners have, or have access to, some if not all of the following:

- a range of customer design requirements
- a range of products to investigate design requirement features
- manual drawing equipment
- 2D commercial CAD software
- extracts and illustrations from appropriate drawing standards and conventions
- reference material which provides information about the physical and mechanical properties of materials
- legislation and design standards
- component and material suppliers' catalogues.

Textbooks

Dieter G and Schmidt L – *Engineering Design* (McGraw-Hill, 2013, 5th Edition)
ISBN 9780073398143

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing*
(Butterworth-Heinemann, 2012) ISBN 9780080966526

Tooley M and Dingle L – *BTEC National Engineering 3rd Edition* (Newnes, 2010)
ISBN 9780123822024

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and M1	Design Report	An activity requiring learners to research and/or visit a design department and investigate the relationship between designer and customer	A report containing written responses about the design process and its impact on customer relationships. In addition, a PDS should be generated from a given customer specification
P3, P4 and D1	Product Evaluation	An activity requiring learners to research legislation and standards that apply to two different products as well as the manufacturing, environmental a nd sustainability constraints for one of them	A report containing written responses outlining legislation and standards that apply to two different products and an evaluation of the manufacturing, environmental and sustainability constraints for one of them in terms of profitability for the business

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M2, M3 and D2	Design Proposals	An activity requiring learners to interpret a given PDS and, by using appropriate research techniques, present a final design solution from a selection of design proposals.	A portfolio of design solutions and a written report explaining how a final design solution has been selected. In addition, explanations of the importance of accurate design reference materials and an evaluation of the chosen design solution with reference to the given PDS.

Assessment of this unit could be covered through three assignments. To achieve a pass grade learners are expected to describe how the design process operates in an engineering company and its links to other aspects of the business. It is suggested that during the first assignment the evidence for P1 could be gained by learners visiting the design department of an engineering company, carrying out an interview with an engineering designer and preparing a short report. It is important that learners understand that design cannot be carried out in isolation and that it is an income-generating function with the customer having the final say.

After the visit or similar activity, a written task for P2 should be given that asks learners to produce a PDS from the requirements of a given customer.

A second assignment could involve a research activity. Two different products need to be given to each learner and research carried out to allow them to describe the legislation and standards that apply to each product (P3) and the environmental, sustainability and manufacturing constraints that influenced the design of one of these products (P4).

Learners will need to demonstrate a basic mastery of design and drawing skills and they should be producing sketches and drawings which are broadly in line with British Standards and which use simple drawing conventions. There should be some evidence of design calculations when presenting evidence for P5, P6 and P7.

For assessment of these criteria a third assignment could be set where a PDS should be given, and learners asked to produce a range of design proposals (P5). Three proposals would generally be sufficient although, if the solutions are complex, two would be enough.

In doing this, it is important that learners use design reference material (P6) and a range of techniques to present the final solution (P7). The techniques used are dependent on the solution (for example if it involves an electronic system then circuit diagrams will be needed as well as perhaps general arrangement drawings).

Learners will demonstrate a basic understanding of the use of information sources such as books, technical reports, data sheets, catalogues, CD ROM and online databases. They should be selecting, interpreting and applying data extracted from a limited range of sources and will have been given guidance on what to look for.

Design work must show good evidence of knowledge gained from the linked units so that learners can be critical about their evolving designs and adapt them, rather than pursue a single idea. Grading criteria P5 and P6 link the extraction of reference information about materials and components to the design proposals being put forward by the learner. This will give more focus when gathering resource material. It is intended that the assessment evidence for P6 is based on development ideas generated in P5.

To achieve a merit grade learners will need to apply evaluative skills and explain the impact of poor design. To achieve M1 the manufacturer/client relationship should be explored in some depth with evidence supported by examples taken from case studies based on real products. These could be discussed during the visit in the first assignment.

M1 builds on knowledge used to achieve P1 and P2 and may be best attempted in the first assignment.

To achieve M2 learners should support their reasons for having accurate reference material by using examples taken from documented sources of products which are mission critical (for example correct specification of dimensions and material for a load bearing structure such as a roof beam). As such, a further written task could be set in assignment three to facilitate M2.

M3 builds on P5 and P7 and a further written could be set task in assignment 3. There should be evidence of thought being given to economic issues and the pressure on a designer to design to a price in order to be competitive. Explanations should be supported by examples relating to real products that learners are familiar with.

To achieve a distinction grade learners should be able to focus on specific legislation and standards when working towards D1. Learners should support their evaluation of the impact of legislation and standards on the design process with examples drawn from documented sources (for example businesses that have either lost market share by being caught out by changes in legislation or others that have benefited through anticipating changes and beating competitors in the market). As such, a task targeting D1 could be set as part of assignment 2.

To achieve D2, evaluation could relate to a design solution provided by the tutor, but it may be better to link with P7 so that learners evaluate their own work. A written task in assignment 3 may be appropriate for this.

Unit 25: Engineering Drawing for Technicians

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

It is important that when a product has been designed it is manufactured correctly and to specification. To achieve this, it is crucial that the people making the product in a workshop are provided with well-presented engineering drawings, produced to international standards and conventions. This avoids errors of interpretation that can lead to the scrapping of expensive parts.

An understanding of how graphical methods can be used to communicate information about engineering products is an important step for anyone thinking of taking up a career in engineering. This unit gives learners an introduction to the principles of technical drawings and their applications using hand drawing and computer-aided design (CAD) techniques.

Learners will start by carrying out freehand sketching of simple engineering products using pictorial methods that generate three-dimensional (3D) images. A range of standard components, such as fixing devices, will be sketched together with other solid and hollow items. Learners are then introduced to a more formalised drawing technique that conforms to British Standards and will put this into practice through a number of drawing exercises. A consistent presentation style will be used as learners draw single part components and simple engineering assemblies.

These drawings will contain all the information needed to manufacture or assemble the product, including information such as dimensions, manufacturing notes and parts lists. The use of conventions to represent standard items will be investigated, such as screw threads and springs in mechanical type drawings or circuit symbols such as solenoids and resistors in electrical/electronic type drawings.

Having learned the principles of engineering drawing, learners will then move on to using a two-dimensional (2D) CAD system for the production of drawings using basic set-up, drawing and editing commands. The first task is to produce a drawing template which can be saved to file, as this reinforces the concept of standardisation and consistency of presentation. This is followed by drawing exercises of single-part components, a simple multi-part assembly and circuit diagrams.

Overall, the unit will develop learners' ability to create technical drawings and allow them to compare the use of manual and computer aided methods of producing engineering drawings.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Be able to sketch engineering components

2 Be able to interpret engineering drawings that comply with drawing standards

3 Be able to produce engineering drawings

4 Be able to produce engineering drawings using a computer-aided design (CAD) system.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Create sketches of engineering components using a range of techniques	**M1** Assess the suitability of the different techniques for the sketches	
P2 Describe the benefits and limitations of using pictorial techniques to represent a given engineering component		
P3 Interpret the main features of a given engineering drawing which complies with drawing standards	**M2** Explain in the importance of working to recognised standards when producing engineering drawings	
P4 Produce detailed drawings of three given single-piece components that comply with drawing standards	**M3** Explain how the sketches comply with drawing standards	
P5 Produce an assembly drawing of a product containing three parts that complies with drawing standards		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Produce a circuit diagram that complies with drawing standards, with at least five different components which use standard symbols	**M4** Explain in how a given engineering drawing would be used and the reasons it is suitable for its intended audience **M5** Explain the hardware components of a typical industry standard CAD system	**D1** Evaluate the use of different methods of producing engineering drawings including manual and computer aided methods **D2** Evaluate the functionality of a CAD software package
P7 Prepare a template drawing of a standardised A3 sheet using a CAD system and save to file		
P8 Produce, store and present 2D CAD drawings of a given single-piece component and an assembly drawing of a product containing three parts		

Unit content

What needs to be learned
Learning outcome 1: Be able to sketch engineering components
• Sketches: regular solids, e.g., cube, rectangular block, 900 angle bracket; hollow objects, e.g., circular tube, square section tube; standard components, e.g., nuts, bolts, screws, pulleys; engineering components, e.g., pulley support bracket, machine vice. • Sketching techniques: sketching equipment, e.g., paper (plain, squared, isometric), pencil, eraser; pictorial, e.g., oblique drawing (cavalier and cabinet), isometric; orthographic, e.g., single and linked views; sketching in good proportion; dimensions, e.g., overall sizes, detail. • Benefits and limitations of using pictorial techniques: benefits, e.g., speed of production, visual impact; limitations, e.g., lengths and shapes not true, not produced to a recognised standard, dimensions difficult to read; consequences of interpretation errors, e.g., incorrect manufacture, incorrect assembly, cost to scrap.
Learning outcome 2: Be able to interpret engineering drawings that comply with drawing standards
• Interpret: obtaining information from engineering drawings, e.g., component features, dimensions and tolerances, surface finish, manufacturing detail, assembly instructions, parts list, circuit operation. • Drawing standards: British Standards, e.g. BS 8888, BS 3939, BS 2917, PP 7307; company-standardised layouts, e.g. drawing number, title and issue number, projection symbols (first angle, third angle), scale, units, general tolerances, name of person responsible for producing drawing; line types, e.g. centre, construction, outline, hidden, leader, dimension; lettering, e.g. titles, notes; orthographic projection, e.g. first angle, third angle; views, e.g. elevation, plan, end, section, auxiliary; representation of common features, e.g. screw threads, springs, splines, repeated items; section views, e.g. hatching style, webs, nuts, bolts and pins, solid shafts; symbols and abbreviations, e.g. A/F, CHAM, Φ, R, PCD, M; circuit symbols, e.g., electrical, electronic, hydraulic, pneumatic.
Learning outcome 3: Be able to produce engineering drawings
• Detail drawings of single-piece engineering components: projection method; scale; title block; line work; views; sections; dimensions; tolerances; surface finish; notes. • Assembly drawings: line work, e.g., centre lines, construction, outline, cutting plane, sectional view, hatching; representation of standard components, e.g. nuts, bolts, screws, keys; parts referencing, e.g. number referencing, parts list; notes, e.g. assembly instructions, installation features, operating instructions.

What needs to be learned
• Circuit diagrams: circuits, e.g., electrical, electronic, hydraulic, pneumatic; components, e.g. transformers, rectifiers, solenoids, resistors, capacitors, diodes, valves, pumps, actuators, cylinders, receivers, compressors.
Learning outcome 4: Be able to produce engineering drawings using a computer aided design (CAD) system
• Prepare a template: standardised drawing sheet, e.g., border, title block, company logo; save to file. • CAD systems: computer systems, e.g., personal computer, networks; output devices, e.g., printer, plotter; storage, e.g., server, hard disc, CD, pen drive; 2D CAD software packages, e.g., AutoCAD, Microstation, Cattia, Pro/Engineer, Pro/Desktop. • Produce engineering drawings: set-up commands, e.g., extents, grid, snap, layer; drawing commands, e.g., coordinate entry, line, arc, circle, snap, polygon, hatch, text, dimension; editing commands e.g., copy, move, erase, rotate, mirror, trim, extend, chamfer, fillet. • Store and present engineering drawings: save work as an electronic file, e.g., hard drive, server, pen drive, DVD; produce paper copies, e.g., print, plot, scale to fit.

Essential information for tutors and assessors

Essential resources

For this unit, learners need to have, or have access to, manual drawing equipment and a CAD system that uses a 2D commercial engineering software package. Learners will also need extracts and illustrations from appropriate drawing standards and conventions.

Textbooks

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Fane B – *AutoCAD 2014 for Dummies* (John Wiley and Sons, 2013) ISBN 9781118603970

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Producing Engineering Sketches	Learners have been asked to produce sketches of a range of different objects.	A practical assignment requiring learners to produce a portfolio of engineering sketches with accompanying written descriptions.
P3, M2	Interpreting and Using Drawing Standards	Learners have to read and interpret an engineering drawing in order to report the key features of the component, circuit or assembly to a colleague.	A written assignment for which learners need to produce a short report detailing the main features of a given engineering drawing that complies with drawing standards. A further task would require them to explain the importance engineering standards.
P4, P5, M3	Producing Engineering Drawings	Learners need to produce an engineering drawing of three components and an assembly drawing for use by the manufacturing department of their company.	A practical assignment in which learners produce component and assembly drawings.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M4, D1	Producing Circuit Drawings	Learners need to produce a circuit diagram for use by the manufacturing department of their company	A practical assignment in which learners produce a circuit diagram
P7, P8, M5, D2	Producing Engineering Drawings Using CAD	Learners need to prepare and produce 2D CAD drawings for use by the manufacturing department of their company	A practical assignment in which learners produce 2D CAD drawings of a component and an assembly

Assessment of this unit could be through the use of five assignments. To achieve a pass, learners are expected to show competence in a number of graphical techniques and to be able to apply these to the production of engineering drawings which meet recognised standards.

The first assignment, to cover P1, P2 and M1, could consist of a small portfolio of sketches and written descriptions. Items drawn must include regular solids and hollow objects, standard and engineering components. The techniques used must be valid and involve sketching equipment, pictorial and orthographic representation and sketching in good proportion with the addition of some dimensions (as specified in the unit content). An assessment of these techniques will meet the requirement for M1.

The second assignment, to cover P3 and M2, will need to be carefully structured and should be based on a drawing of a component or assembly rather than a circuit diagram so that the unit content can be properly covered. M2 builds on the evidence presented for P3 and these two criteria could be assessed using a single assignment. The wider issues of standardisation and manufacturing for the global marketplace should be addressed with learners supporting their explanations with case study evidence.

The third assignment could cover P4, P5 and M3 with the three single-piece components in P4 being used for the assembly drawing in P5. This would then make the assignment more realistic in terms of what happens in industry. M3 would require an explanation of how the sketches in P4 comply with drawing standards.

The fourth assignment could cover P6, M4 and D1, with learners being given a choice of the type of circuit they produce depending on their interest (i.e. from electrical, electronic, hydraulic and pneumatic).

The circuit can be drawn by hand but using CAD may be the preferred method if a library of components is available. M4 requires an explanation of the use of engineering drawings to communicate information effectively. D1 could be carried out as a separate task, requiring an evaluation of the various drawing techniques used by learners and link directly with the criteria P1, P5, P6 and P8. To add depth to their evidence, learners could be asked to look more widely at what is used in industry – particularly the use of 3D CAD systems which generate solid models. This would then bring them full circle back to the start of the unit, where they were producing pictorial sketches.

P7, P8, M5 and D2 can be covered by a fifth assignment, which could ask for increased competence in the application of standards when producing drawings. To help authenticate learners' work, additional evidence could be in the form of witness statements, tutor observation records and 'screen dumps' which show the range of commands used during the development of the drawings. M5 and D2 could form a separate task as part of this assignment, requiring an explanation of CAD hardware and an evaluation of CAD software functionality.

Unit 26: Mechanical Principles of Engineering Systems

Level: 3

Unit type: Optional

Guided learning hours: 60

Unit introduction

The use and application of mechanical systems is an essential part of modern life. The design, manufacture and maintenance of these systems are the concern of engineers and technicians who must be able to apply a blend of practical and theoretical knowledge to ensure that systems work safely and efficiently. Science underpins all aspects of engineering and a sound understanding of its principles is essential for anyone seeking to become an engineer.

Learners are introduced to the behaviour of loaded engineering materials and the analysis of a range of static engineering systems. They will gain an understanding of dynamic systems through the application of Newtonian mechanics. Finally, they will deal with the effects of heat transfer, the expansion and compression of gases and the characteristic behaviour of liquids at rest and in motion.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Be able to determine the effects of loading in static engineering systems

2 Be able to determine work, power and energy transfer in dynamic engineering systems

3 Be able to determine the parameters of fluid systems

4 Be able to determine the effects of energy transfer in thermodynamic systems.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Calculate the magnitude, direction and position of the line of action of the resultant and equilibrant of a non-concurrent coplanar force system containing a minimum of four forces acting in different directions	**M1** Calculate the factor of safety in operation for a component subjected to combined direct and shear loading against given failure criteria	
P2 Calculate the support reactions of a simply supported beam carrying at least two concentrated loads and a uniformly distributed load		
P3 Calculate the induced direct stress, strain and dimensional change in a component subjected to direct uniaxial loading and the shear stress and strain in a component subjected to shear loading		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Solve three or more problems that require the application of kinetic and dynamic principles to determine unknown system parameters	**M2** Determine the retarding force on a freely falling body when it impacts on a stationary object and is brought to rest without rebound, in a given distance	**D1** Compare and contrast the use of D'Alembert's principle with the principle of conservation of energy to solve an engineering problem
P5 Calculate the resultant thrust and overturning moment on a vertical rectangular retaining surface with one edge in the free surface of a liquid		**D2** Evaluate the methods that might be used to determine the density of an irregular shaped solid material
P6 Explain Archimedes' principle	**M3** Determine the upthrust on an immersed body	
P7 Use the continuity of volume and mass flow for an incompressible fluid to determine the design characteristics of a gradually tapering pipe		
P8 Calculate the dimensional change when a solid material undergoes a change in temperature and the heat transfer that accompanies a change of temperature and phase	**M4** Determine the thermal efficiency of a heat transfer process from given values of flow rate, temperature change and input power	

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P9 Solve two or more problems that require application of thermodynamic process equations for a perfect gas to determine the unknown parameters of the problems	**M5** Determine the force induced in a rigidly held component that undergoes a change in temperature	

Unit content

What needs to be learned
Learning outcome 1: Be able to determine the effects of loading in static engineering systems
• Non-concurrent coplanar force systems: graphical representation, e.g. space and free body diagrams; resolution of forces in perpendicular directions, e.g. $F_x = F\cos\theta$, $F_y = F\sin\theta$; vector addition of forces, resultant, equilibrant, line of action; conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$) • Simply supported beams: conditions for static equilibrium; loading (concentrated loads, uniformly distributed loads, support reactions). • Loaded components: elastic constants (modulus of elasticity, shear modulus); loading (uniaxial loading, shear loading); effects, e.g. direct stress and strain including dimensional change, shear stress and strain, factor of safety.
Learning outcome 2: Be able to determine work, power and energy transfer in dynamic engineering systems
• *Kinetic parameters*: e.g., displacement (s), initial velocity (u), final velocity (v), uniform linear acceleration (a). • *Kinetic principles*: equations for linear motion with uniform acceleration $v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$ • *Dynamics parameters*: e.g., tractive effort, braking force, inertia, frictional resistance, gravitational force, momentum, mechanical work ($W = Fs$), power dissipation (average power = $\frac{W}{t}$, instantaneous power = Fv), gravitational potential energy ($PE = mgh$), kinetic energy ($KE = \frac{1}{2}mv^2$) • *Dynamic principles*: Newton's laws of motion, D'Alembert's principle, principle of conservation of momentum, principle of conservation of energy.
Learning outcome 3: Be able to determine the parameters of fluid systems
• *Thrust on a submerged surface*: hydrostatic pressure, hydrostatic thrust on an immersed plane surface ($F = \rho gAx$); centre of pressure of a rectangular retaining surface with one edge in the free surface of a liquid • *Immersed bodies*: Archimedes' principle; fluid, e.g., liquid, gas; immersion of a body, e.g. fully immersed, partly immersed; determination of density, e.g. using floatation, specific gravity bottle. • *Flow characteristics of a gradually tapering pipe*: e.g., volume flow rate, mass flow rate, input and output flow velocities, input and output diameters, continuity of volume and mass for incompressible fluid flow.

What needs to be learned
Learning outcome 4: Be able to determine the effects of energy transfer in thermodynamic systems
• *Heat transfer*: heat transfer parameters, e.g., temperature, pressure, mass, linear dimensions, time, specific heat capacity, specific latent heat of fusion, specific latent heat of vaporisation, linear expansivity; phase, e.g., solid, liquid, gas; heat transfer principles, e.g. sensible and latent heat transfer, thermal efficiency and power rating of heat exchangers; linear expansion. • *Thermodynamic process equations:* process parameters, e.g., absolute temperature, absolute pressure, volume, mass, density; Boyle's law (pV = constant), Charles' law ($\frac{V}{T}$ = constant), general gas equation ($\frac{pV}{T}$ = constant), characteristic gas equation ($pV = mRT$)

Essential information for tutors and assessors

Essential resources

For this unit, centres need to provide access to laboratory facilities with a sufficient range of investigation and demonstration equipment wherever possible. In particular, tensile testing equipment, dynamics trolleys, linear expansivity apparatus, apparatus to determine density and apparatus for verification of Boyle's and Charles' laws would be of significant value.

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Static Systems	Problems involving engineering components subjected to static force systems.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P4, M2, D1	Dynamic Systems	Problems involving force, work and power in dynamic engineering system.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P5, P6, P7, M3, D2	Fluid Systems	Problems involving hydrostatic thrust and fluid dynamics. Experimental methods used to determine density.	A written report containing an introductory explanation to each step in the sequence of calculations and findings, and an evaluation of the methods used to determine density.
P8, P9, M4, M5	Thermodynamic Systems	Problems involving heat transfer and dimensional change in thermodynamic systems and involving the expansion and compression of gases.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.

Criterion P1 requires the solution of a single non-concurrent force system that contains a minimum of four active forces. It will be expected that two of these forces will be set to act in directions other than the horizontal and vertical. This will necessitate the resolution of forces in perpendicular directions, for example the use of $F_x = F\cos\theta$ and $F_y = F\sin\theta$, as the first step in the solution to the problem.

A typical problem might be an engineering component under the action of at least four non-concurrent forces whose magnitudes and directions are given. One of the forces might be its own weight but at least two of them should act in directions other than the horizontal and vertical. Learners would be expected to produce space and free body diagrams, resolve forces horizontally and vertically and take moments of the forces about some suitable reference point. The magnitude and direction of the resultant force and the position of its line of action could then be found through vector addition, application of Pythagoras' theorem and consideration of the resultant turning moment.

P2 will use similar skills to those required for P1 but in this case they will be applied to a simply supported beam carrying two-point loads, as a minimum, and a uniformly distributed load. These specifications will provide centres with a variety of loading possibilities that can be used for assessment purposes. During the delivery phase for this part of the unit a greater range of loading may be considered but centres need only work with the minimum for assessment purposes.
Neither the content nor criteria stipulate that the point loads should be anything other than perpendicular to the beam. During delivery however, it may be useful to demonstrate the resolution of forces applied at an angle to the beam and calculation of the magnitude and directions of the support reactions.

The assessment for criterion P3 will require a task to calculate the direct stress, direct strain and the accompanying dimensional change in a directly loaded component. It will also require a task to calculate the shear stress and shear strain in a component or material subjected to shear loading. Centres should consider how the tasks set for P3 could be extended to incorporate an opportunity to achieve M1. This might involve consideration of the factor of safety in operation for an angled joint that is bolted or riveted such that the fastenings are subjected to both tensile and shearing forces.

It will require the setting of at least three dynamic system tasks to ensure that the range of kinetic and dynamic principles is applied to achieve P4. Centres should not fragment the application of kinetic and dynamic principles to the extent that they oversimplify the problems. It is the interrelationships between the kinetic and dynamics principles that are as important as the use of any single equation. The principles applied in P4 can be directly linked to M2, although achievement of M2 will require a further task to be set to consider the impact of a freely falling body. Suitable examples of this type of problem are listed in the delivery section of these guidance notes. A final task to achieve the distinction criterion D1 will be required to enable learners to consider and solve an engineering problem using the two alternative approaches (i.e. D'Alembert's principle and the principle of conservation of energy), and compare the two methods.

P5 may be achieved by calculating resultant thrust and overturning moment on a rectangular retaining surface, examples of which are listed in the delivery section. P6 requires an explanation of Archimedes' principle.

M3 may be achieved by calculating the upthrust on a totally immersed body using Archimedes' principle. An understanding of fluid principles is needed to achieve D2, which requires learners to evaluate the methods used to determine the density of an irregular shaped solid object.

Criterion P7 examines learners' basic understanding of fluid flow. It may be achieved by considering the design of a gradually tapering pipe to suit given dimensional and flow constraints.

Criteria P8 and P9 have been designed to assess the thermodynamics aspects of the unit. P8 will require tasks to determine the dimensional change in an engineering component that accompanying a change in temperature, and the sensible and latent heat transfer that accompanies a change of temperature and phase in a substance. P9 will require tasks involving the range of thermodynamic process equations applicable to the expansion and compression of an ideal gas. The area of work covered by P8 – the effects of heat transfer – is extended in the merit criteria M4 and M5.

Unit 27: Electrical and Electronic Principles in Engineering

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

The modern world relies on electrical and electronic devices – from mobile telephones to jet aeroplanes, these devices have had an enormous impact on the way we live today. Without early engineers such as Faraday and Lenz, who studied the then new concept of electricity, many of the inventions we now take for granted would not have been developed.

The unit starts by developing and extending learners' understanding of fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners are then taken through the various properties and parameters associated with capacitance and inductance, before finally considering the application of single-phase alternating current (AC) theory. The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

For learners wishing to follow an electrical/electronic programme, this unit is an essential building block that will provide the underpinning knowledge required for further study of electrical and electronic applications.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

2 Be able to apply the concepts of capacitance in DC circuits

3 Know the principles and properties of magnetism

4 Be able to use single-phase alternating current (AC) theory.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Use DC circuit theory to calculate current, voltage and resistance in DC networks	**M1** Use Kirchhoff's laws to determine the current in various parts of a network having four nodes and the power dissipated in a load resistor containing two voltage sources	
P2 Use a multimeter to carry out circuit measurements in a DC network		
P3 Describe the forward and reverse characteristics of two different types of semiconductor diode		
P4 Describe the types and function of capacitors	**M2** Explain capacitance, charge, voltage and energy in a network containing a series-parallel combination of three capacitors	
P5 Carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor		
P6 Calculate the charge, voltage and energy values in a DC network for both three capacitors in series and three capacitors in parallel		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Describe the characteristics of a magnetic field		**D1** Evaluate the performance of a motor and a generator by reference to electrical theory
P8 Describe the relationship between flux density (B) and field strength (H)		
P9 Describe the principles and applications of electromagnetic induction	**M3** Explain the application of electromagnetic induction in motors and generators	
P10 Use single-phase AC circuit theory to determine the characteristics of a sinusoidal AC waveform	**M4** Compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram	**D2** Analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors
P11 Use an oscilloscope to measure and determine the inputs and outputs of a single-phase AC circuit		

Unit content

What needs to be learned
Learning outcome 1: Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits
• DC circuit theory: voltage, e.g. potential difference, electromotive force (emf); resistance, e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source, e.g. cell, battery, stabilised power supply; resistors, e.g. function, types, values, colour coding; diodes, e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae, e.g. V = IR, P = IV, W = Pt, application of Kirchhoff's voltage and current laws. • DC networks: networks with one DC power source and at least five components, e.g., DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement; diode resistor circuit with DC power source, series resistors and diodes. • Measurements in DC circuits: safe use of a multimeter, e.g., setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source, testing a diode's forward and reverse bias).
Learning outcome 2: Be able to apply the concepts of capacitance in DC circuits
• Capacitors: types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function, e.g., energy stored, circuits (series, parallel, combination); working voltage. • Charging and discharging of a capacitor: measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants. • DC network that includes a capacitor: e.g., DC power source with two/three capacitors connected in series, DC power source.
Learning outcome 3: Know the principles and properties of magnetism
• Magnetic field: magnetic field patterns, e.g., flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis. • Electromagnetic induction: principles, e.g., induced electromotive force (emf), eddy currents, self and mutual inductance; applications (electric motor/generator, e.g., series and shunt motor/generator; transformer, e.g. primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws.

What needs to be learned
Learning outcome 4: Be able to use single-phase alternating current (AC) theory
• Single-phase AC circuit theory: waveform characteristics, e.g., sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/ peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities e.g., graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components. • AC circuit measurements: safe use of an oscilloscope, e.g., setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values); circuits, e.g., half and full wave rectifiers.

Essential information for tutors and assessors

Essential resources

It is essential that learners have access to a well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013) ISBN 9781466501096

Robertson C R – *Fundamental Electrical and Electronic Principles* (Routledge, 2008) ISBN 9780750687379

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	DC Circuit Theory/ Resistor Networks and Kirchhoff's Laws	An activity requiring learners to complete two tasks, one for each criterion. Task 1 involves learners evaluating current, voltage and resistance in a DC network. Task 2 uses Kirchhoff's laws to determine the current and power dissipated in a load resistor.	A report containing the results of calculations to evaluate current, voltage, resistance and power for a DC network using DC circuit theory and Kirchhoff's laws. Carried out under controlled conditions.
P2, P3	DC Circuit Theory/ Measurement and Diodes	A practical activity requiring learners to complete measurements using a multimeter in a DC network for task 1 and compare the forward and reverse characteristics of two different types of semi-conductor diode for Task 2.	For both tasks, learners will be required to complete pre-prepared response sheets with their measurements and make required responses, together with a brief conclusion. Carried out under controlled conditions.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M2	Capacitors	A mixed activity comprising four tasks. The first being of a descriptive nature to describe the types and function of capacitors. Second, an experiment to determine the relationship between voltage and current for a charging and discharging capacitor. The third and fourth involve the learner carrying out calculations to evaluate capacitance, charge voltage and energy in DC networks.	A written report containing written responses to the descriptive task, tabulated results and graphs for the practical, together with calculations for the DC networks.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, M3, D1	Magnetism, Transformers and Motor/Generators	A mixed activity comprising four tasks. The first three are to describe the characteristics of a magnetic field, explain the relationship between flux density and field strength, and describe the principles and applications of electromagnetic induction. The final task is to evaluate the performance of a motor and generator.	A written report containing labelled diagrams illustrating magnetic fields, graphical plots of BH curves and diagrams with descriptions to illustrate principles and applications of electromagnetic induction. For the distinction criteria it would be envisaged that comprehensive answers to pre-prepared response sheets together with diagrams, graphs and calculations need to be submitted.

Criteria covered	Assignment title	Scenario	Assessment method
P10, P11, M4, D2	Single Phase AC	A practical activity requiring learners to complete four tasks. First, using single-phase AC theory to consider the characteristics of a sinusoidal AC waveform and second, use an oscilloscope to evaluate the inputs and outputs of a single-phase AC circuit. Third, to compare the results of the addition and subtraction of two sinusoidal AC waveforms. Fourth, to analyse the operation of a power supply.	A written report using pre-prepared response sheets and graph paper carried out under controlled conditions.

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and circuits and computer-based software packages, where appropriate.

It is likely that at least five assessment instruments will be required for this unit. If practical work and tests are also used, then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Clearly, the ability to safely use a multimeter (P2) will require process evidence, i.e, it will need to be observed by the tutor during relevant practical activities. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The assessment of the use of circuit theory to calculate current, voltage and resistance in DC networks (P1) could be achieved by using a paper-based or computer-based method. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, centres need to ensure that sufficient product evidence is available of the circuit being used/developed and the formulae selected/used to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where printouts do not show sufficient detail to meet the criteria.

The description of the forward and reverse characteristics of two types of semi-conductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box.

For P4, learners will need to describe the full range of types of capacitor (electrolytic, mica, plastic and paper, ceramic, fixed and variable), including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages.

P5 requires learners to carry out a laboratory experiment to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500 μF electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor. Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

P6 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel.

The characteristics of magnetic fields for P7 could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. For P8, learners need to explain the relationship between flux density (B) and field strength (H) with particular emphasis on BH curves and the use of different materials such as silicon iron and mild steel.

The evidence for P9 will be descriptive and requires learners to provide basic explanations of the principles and concepts of electromagnetic induction such as the movement of a conductor within a magnetic field.

P10 and P11 could link AC theory and practice with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit. This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and rms values.

M1 relates to the use of Kirchhoff's laws and here again learners should be encouraged to check their results by using a computer software package and/or practical experiment. This criterion naturally follows on from the work on resistors in series and parallel in DC circuits and, as such, could perhaps be incorporated into an assignment covering P1, P2 and M1.For M2, learners need to explain capacitance, charge, voltage and energy for specific capacitors in a series parallel combination. This extends the understanding from the pass grade criterion and could naturally form a next step in an assignment/assessment activity devised for P6.M3 is an extension of P9 requiring an explanation of the application of electromagnetic induction in motors and generators. M4 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. This criterion could be linked to *Unit 4: Mathematics for Engineering Technicians* and, once learners have been taught the sine and cosine rules, could be used to provide evidence for both units.

D1 requires learners to evaluate the performance of motors and generators by referencing electrical theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines.

For D2, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

As suggested earlier, and illustrated in the assignment grid, it would be appropriate to use a five-assessment model to assess this unit.

The first is a theoretical assignment under controlled conditions could assess P1 and M1.

A second practical assignment could be used to assess P2 and P3, again possibly under controlled conditions.

Assignment 3 is to assess P4, P5, P6 and M2 and could be a mixed assignment, preferably not done under controlled conditions.

The fourth assignment could again be a mixed assignment to assess P7, P8, P9, M3 and D1.

Finally, assignment 5 assesses P10, P11, M4 and D2, and could be of a practical nature carried out under controlled conditions.

Unit 28: Additive Manufacturing Processes

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Learners cover the principles and practical methods used in additive manufacturing (AM) and develop a component using additive processes.

Additive manufacturing (AM) processes are set to revolutionise the manufacturing industry and provide mass customisation of products and components for consumers. For example, a human jawbone can be manufactured to the exact specification of a patient needing a transplant. In addition, additive processes are more sustainable than traditional subtractive manufacturing processes, such as computer numeric controlled machining.

In this unit, you will examine the technology and characteristics of the additive and finishing processes that are needed to manufacture a product or component. You will investigate design changes required to move from a traditional manufacturing process, such as machining and casting, to an additive process and the additional finishing processes that may be needed as a result. Finally, you will design a component that is suitable for manufacture using an additive process and manufacture your component using a 3D printer.

Technology is transforming our lives; therefore, as an engineer it is important that you understand the new manufacturing processes that are providing opportunities in product design, mass customisation and sustainability. In the United Kingdom, additive AM processes have been estimated to be worth around £6 billion per annum and are expected to employ 63000 people by 2020. This unit helps to prepare you for employment, for example as a manufacturing engineering technician, for an apprenticeship, or for entry to higher education to study, for example manufacturing engineering.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Examine the technology and characteristics of additive manufacturing processes as used in industry

2 Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes

3 Develop a component using additive manufacturing processes safely.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably	**M1** Compare the technology and characteristics of at least two additive processes used to manufacture components safely and sustainability	**D1** Justify, using vocational language, the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably
P2 Explain how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes	**M2** Analyse how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes, including a justification for the finishing processes required	**D2** Evaluate how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes, including a justification for the finishing processes required
P3 Explain what finishing processes could be applied to two components if they were manufactured using additive processes instead of traditional manufacturing processes		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Design a component encompassing a hollow section and/or a support that can be manufactured safely using an additive process	**M3** Design a component encompassing a hollow section and/or a support that can be manufactured safely and effectively using an additive process	**D3** Optimise the development of a component encompassing a hollow section and/or a support using additive manufacturing and finishing processes safely, effectively and efficiently, while checking the finished component for dimensional accuracy
P5 Manufacture a component encompassing a hollow section and/or a support, safely using an additive and suitable finishing process	**M4** Manufacture a component encompassing a hollow section and/or a support safely and effectively using an additive and suitable finishing processes, while checking the finished component for dimensional accuracy	
P6 check the finished component for dimensional accuracy against the original design		

Unit content

What needs to be learned
Learning outcome 1: Examine the technology and characteristics of additive manufacturing processes as used in industry
AM processes: • Technology and characteristics, such as complexity, surface texture, and tolerances, of AM processes, including: o material extrusion – fused deposition modelling (FDM) o powder bed fusion – electron beam melting, laser powder bed, plasma powder bed, laser sintering o photo polymerisation – Selective Laser Sintering (LS), stereolithography (SLA), Digital Light Processing (DLP) o material jetting – binder jetting o wire deposition (wire arc manufacturing), including plasma, electron beam and laser. • Capacity of AM processes, including: o component size is limited by the capacity of the AM machine, including physical machine footprints and base size and working area and swept volume o manufacturing volume is determined by the processing speed of the machines, e.g., wire deposition has a relatively high throughput speed (at several kilograms of material per hour but geometrical accuracy reduces at faster speeds) and powder bed fusion processes have relatively low throughput speed (around 0.1 kilograms per hour). • Sustainability of the processes, including: o the recycling of metallic powder and polymer-based materials as part of the powder bed fusion process o limited waste material is produced as a result of the process o less energy is required to manufacture components o localisation of manufacturing reduces the need for transportation. • Applications of AM processes, including: o manufacture of aerospace and automotive components – using powder bed technologies and wire deposition processes o rapid prototyping of products and components – using FDM and LS processes

What needs to be learned
o moulds and tooling, e.g., moulds – for casting near net shapes, patterns, jigs – using FDM and LS o digital manufacturing, e.g., industrial components, consumer products – using powder bed technologies and wire deposition o personalised fabrication, e.g., customisation, personal products, home and machine repairs – using FDM o biomedical, e.g., dental, prosthetics, hearing aids and human tissue – using FDM. • Typical materials, including: o polymers, e.g., Acrylonitrile Butadiene Styrene (ABS), polylactic acid (PLA), polyamides o metals, e.g., titanium (Ti), aluminium (Al), steel, gold, silver o composites, e.g., glass fillers within polymers, cermets, carbon fibre, epoxy resins. o Safe working practices for AM processes: • Key features of health and safety regulations, or other relevant international equivalents, including: o Control of Substances Hazardous to Health (COSHH) Regulations, e.g., requirements on the safe storage and use of hazardous substances, manufacturers' safety data sheets, hazard symbols, protection from contact with hazardous substances o Personal Protective Equipment (PPE) at Work Regulations, e.g. employer responsibility to provide appropriate equipment, e.g. eye protection, heat-resistant apparatus, disposable gloves, protective clothing, dust masks, respirators o safety hazards, including x-rays, ultraviolet rays, metal powders (e.g., flammability, explosions), handling materials, e.g. polymer wire, powders (polymers and metals) and high temperatures.

What needs to be learned
Learning outcome 2: Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes
Design considerations for AM processes: • Advantages of AM processes over traditional manufacturing processes, e.g., machining and casting, including: o reduction in mass and cost by redesigning the component for AM processes, whereas using traditional processes, e.g., machining from billet, requires a different design approach o further reduction in mass and an improvement in part performance can be achieved by using a mathematical approach called topology optimisation o the integration of parts, the ability to manufacture assembled items together that cannot be manufactured together using traditional processes without multiple operations o reduced time to manufacture as specialist tooling, e.g., moulds, are typically not required o reduced costs as there is typically no need for expensive tooling, e.g., moulds o design freedom comes at no extra cost o material properties are similar to those achieved using forging and casting processes. • The disadvantages of AM processes over traditional manufacturing processes, e.g., secondary machining and casting, including: o products and components need to be redesigned to realise the advantages o materials choice can be limited o the process is currently only suitable for jobbing or small batch manufacturing volumes (unless the product or component is high value) o the initial capital cost is quite high o slow process speed, high part cost, innovations to overcome these factors to create high volume production of parts on AM. • Design considerations required for additive processes, including: o distortion, including warping, shrinkage o surface finish considerations, including aliasing (stepping), creation of edges, effect on radii, and sharp corners

What needs to be learned
○ support structures required to maintain rigidity during manufacture that need to be removed after manufacture ○ scanning existing or modelled physical components to capture the shape in a computer-aided design (CAD) system for manipulation and manufacture using AM processes. *Component finishing processes post-additive manufacturing:* • Characteristics of common finishing processes, including: ○ shot blasting involves directing a high-speed stream of particles, e.g., plastic, glass, or ceramic, at the product to clean, strengthen (peen) and polish a product ○ vibro-energy grinding involves vibrating products with cylindrical or ball shape material, e.g., wet and dry, surfactants, chemicals, powder dispersion ○ chemical processes, e.g., vapour smoothing involves exposing a part to vaporised solvent for a few seconds to melt its outer layer to give it a smooth, glossy finish ○ hot isostatic processing (HIPping) involves heating components to an elevated temperature under pressure to remove internal porosity and voids. The benefits include removing residual stresses, densifying and eliminating voids and occlusions ○ machining (traditional subtractive process) involving the removal of material by cutting, e.g., milling. The benefits include improving the surface texture and dimensional accuracy. • A limitation of some component finishing processes, e.g., shot blasting, is that they require line of sight to work.
Learning outcome 3: Develop a component using additive manufacturing processes safely
Component design for additive manufacture: • Design a component or product suitable for an AM process, including: ○ form complexity, to include a hollow section and section needing support/ powder removal during manufacture ○ material, e.g., suitable mechanical properties, single or multiple materials, availability, multiple colours ○ consideration of the structural integrity, including: – laminar build-up of layer structure – shrinkage allowed for and warping tolerances

What needs to be learned
– cooling of the finished product – support of overhanging surfaces o functionality of the product, e.g., moving parts operate as intended o additive machine characteristics, including: – swept volume and the capacity of the machine – stepping (aliasing) surface finish with regards to resolution – accuracy within machine parameters – resolution within machine parameters – processing time considerations to achieve the desired quality and resolution o transfer of data, e.g., Wi-Fi, direct link, SD card, program file size o multiple components. • Creation of a component drawing suitable for transfer to an AM system, including: o 3D model created on a CAD software package o image created in a photo-editing software package o a component scanned in three dimensions and uploaded into a CAD or photo-editing software package o process the CAD or photo-edited image into a file suitable for manufacturing on an additive system. *Manufacture of a component using an AM process:* • Manufacturing process set up and implemented, including: o data transfer – CAD to a programming language (standard tessellation language, STL), resolution within machine parameters, transfer rate and memory size o component set-up to include physical size, swept volume, scale, orientation and datum o safe working practices, including: – use of personal protective equipment (PPE), e.g., overalls, safety glasses, safety boots – in place and secure machine guards o additive machine set-up, to include single or multiple materials, binders, fillers and support structures o additive machine parameters during operation, e.g., infill, layer height, feed rate, travel feed rate, temperature, resolution

What needs to be learned
o finishing processes, e.g., chemically rated, sanded, and shot blasted. • Quality control checks, including: o components to be free from burrs, and sharp edges o checks for accuracy, e.g., external micrometer.

Essential information for tutors and assessors

Essential resources

For this unit, learners must have access to:

- an AM machine, for example FDM
- software suitable to produce and process 3D models, for example AutoCAD, AutoCAD Inventor, Tinkercad, Adobe Photoshop, Adobe Illustrator, Google SketchUp, plus post-processing software and software to control the AM process
- auxiliary equipment, for example that required to finish the components or for the AM process
- a range of equipment suitable for measuring the dimensional accuracy, for example vernier callipers
- a range of health and safety regulations, as required by the learning aims and unit content.

Textbooks

Barnatt C – *3D Printing* (CreateSpace, 2016) ISBN 9781539655466

Hopkinson N et al – *Rapid Manufacturing: An Industrial Revolution for the Digital Age* (Wiley, 2005) ISBN 9780470016138

Websites

www.caduser.com	Information and up-to-date articles related to computer aided design
www.renishaw.com/en/additive-manufacturing-case-studies-44452	Case studies related to additive manufacturing across several engineering sectors
www.stratasys.com	Information on additive manufacturing machines, materials, applications and industries

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Additive Manufacturing Processes in Industry	You are employed as an apprentice machinist at an engineering firm producing a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems. As part of your training within the company you have been asked to perform an investigation into additive manufacturing processes to better understand their benefits, the technology involved and typical applications, with a view to developing the use of additive manufacturing within the company	Technical report including diagrams where applicable, giving a balanced justification of the technology and characteristics of additive machining when operated safely and used sustainably

Criteria covered	Assignment title	Scenario	Assessment method
P2, P3, M2, D2	Design Considerations for Additive Manufacturing Processes in Industry	You are employed as an apprentice machinist at an engineering firm producing a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems. As part of your training within the company you have been asked to perform an investigation into additive manufacturing processes to find out how designs for traditionally manufactured components need to be changed if they are produced using AM processes	Technical report, and diagrams where appropriate, to cover the design considerations and finishing processes of additive machining

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M3, M4, D3	Design and Manufacture of a Component Using Additive Manufacturing	You are employed as an apprentice machinist at an engineering firm that produces a range of small prototype components. The company is currently using computer numerical control and computer aided manufacturing systems and processes. As part of your training within the company you have been asked to perform an investigation of additive manufacturing processes to better understand the benefits. In order to support this, you are now going to design and manufacture a product using additive manufacturing system and processes.	An optimised design for a component and the manufacture of the component or product. Annotated photographs, screenshots, sketches, CAD or photo-editing software screen shots and drawings. Inspection documents, logbook, records of QC checks, observation records or witness statements.

Learning outcome 1

For distinction standard, learners will provide a balanced justification of at least two AM processes. For example, the evidence may cover why some prototype component manufacturers choose binder jetting for prototype manufacture instead of Fused Deposition Modelling (FDM), because binder jetting enables the manufacture of prototypes using different materials, such as steels, polymers and glass, while the latter process is limited to polymers. Therefore, it can better meet customer needs through using a range of materials. Also, binder jetting requires little support during manufacture due to the binder, while FDM often requires structural support, which means that it requires more post-processing. Learners will also cover the accuracy and surface finish capabilities of the processes and will justify the sustainability of the process and the safe working practices applied.

Overall, the evidence will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will compare the characteristics and technology of at least two AM processes, breaking them down into logical topics. For example, learners investigating the wire deposition and powder bed fusion processes will determine that the former process has a relatively high throughput speed (several kilograms per hour) and is more suited to larger components (well over a metre in length is possible) and the latter process has a low throughput speed (around 0.1 kilograms per hour) and is limited to smaller components (up to 500 × 500 × 500mm build volume).

Learners must also cover typical sustainability considerations and safe working practices. For example, when metal powder is being manipulated full face respirators should be used with high-efficiency particulate arrestance (HEPA) air cartridges to protect the technician.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain how at least two AM processes are used to manufacture components safely and sustainably. For example, the wire deposition process uses a high-powered laser to deposit molten material layer by layer into the shape of a component and inert gas is used to shield the material. Appropriate machine guarding is needed to protect operators during the process.

Overall, the evidence, such as a report, will be logically structured although basic in parts. Evidence may contain minor technical inaccuracies relating to engineering terminology such as mentioning ‘subtractive processes’ instead of ‘additive processes’.

Learning outcome 2

For distinction standard, learners will provide a balanced evaluation of the design of at least two components that could be adapted and improved if they were manufactured using additive processes. For example, learners could suggest that the machines are calibrated to produce accurate results and recalibrating or refining the design to accommodate improvements. Learners will justify how the components would be finished so that they meet the design requirements. For example, a component manufactured by wire deposition processes could be milled and polished following manufacture to ensure that critical dimensions and surface finish requirements are met.

Overall, the evidence should be easy to read and understand by a third party who may or may not be an engineer. It will be structured and presented in a logical way and will use the correct technical engineering terms. Also, it will show all design suggestions and modifications, for example component form, material choice, and suggested and rejected ideas, including the reasons why.

For merit standard, learners will analyse how the design of at least two components manufactured using traditional processes could be improved and adapted using additive processes. Learners will be methodical and break down the design considerations into smaller parts and examine them one at a time. For example, learners will specify an additive process that is capable of manufacturing the components, including the physical dimensions of the component and the required accuracy. Learners will then justify the type of finishing processes required and what is involved in these processes.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain how the design of two components manufactured using traditional processes, such as machining and casting, could be improved and adapted using additive process. Suitable components include automotive and aerospace brackets and automotive valves. For example, learners will explain that the additive process reduces the amount of waste material compared to the traditional machining process.

Learners will also explain what finishing processes are required on the two components if they were manufactured using additive processes. For example, hot isostatic processing may be used to reduce internal porosity and voids in components, which would improve the in-service performance of the component in safety-critical aerospace applications.

Overall, the evidence, such as a report, will be logically structured although basic in parts. Evidence may contain minor technical inaccuracies relating to engineering terminology, such as mentioning ‘sodium chloride’ instead of ‘sodium hydroxide’.

Learning outcome 3

For distinction standard, learners will optimise the design and manufacture of a component or product, including a hollow section and/or support using additive and finishing processes. An optimised component will be one that is designed and manufactured safely, effectively and efficiently. Efficiency mainly applies to the manufacturing process, for example learners will have set the machine parameters, such as layer height, so that the manufacturing time is reasonable while ensuring dimensional tolerances and surface finish are within the machine’s capabilities.

Overall, the evidence should be presented clearly and in a way that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will design a component, including a hollow section and/or support that can be manufactured effectively using additive processes. They will use an iterative process to adapt and improve the design of the component, for example by reducing the mass or by combining components together.

Learners will manufacture a component safely and effectively using an additive process. They will also apply an appropriate finishing process, for example to remove any ‘aliasing’ by sanding. The effectiveness of the process will be demonstrated by checking the critical dimensions against the design.

Overall, the evidence, including observation records, will clearly demonstrate how learners worked safely throughout the process, for example by using appropriate personal protective equipment.

For pass standard, learners will consider the design of a component that will be manufactured using the available AM process and include a hollow section and/or support. For example, learners should take account of the machines swept volume and that support would be needed, such as the wings of a model aeroplane. Suitable components include 3D jewellery, a scale model car, a scale model aeroplane, a scale architectural model, a child's model figurine and scale models of larger components or products are also acceptable.

Learners will use AM and finishing processes to create the component or product and will check the accuracy of critical dimensional against the design. Finishing processes will include the appropriate removal of supports. The final artefact may have some dimensional errors, for example a model may be distorted due to the heat generated during manufacture.

Overall, learner evidence, such as a logbook, will record the activities they have completed, along with the results. For example, learners will show all design iterations, modifications to size, material, suggested ideas and rejected ideas, and the reasons why each decision was taken.

Unit 29: Industry 4.0

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Industry 4.0 is the term that has been adopted to describe the fourth industrial revolution that is reshaping manufacturing. It is not based solely on the mechanical and then electronic technologies that dominated previous industrial revolutions but on the integration of physical systems with internet connectivity and cloud computing. In manufacturing, this integration of cyber-physical systems and the Internet of Things (IoT) has enabled more efficient and responsive production systems.

The aim of this unit is to give learners an understanding of the factors enabling Industry 4.0 and how smart factories are changing the face of manufacturing. Learners will look at how a series of industrial revolutions have led up to Industry 4.0, as well as the characteristics of smart factories and the technology that enables them. Learners will then consider what is involved in the transition from Industry 3.0 to 4.0 and will have the opportunity to look at real-world case studies of organisations that have made the change.

Learners will gain a broad understanding of the technologies, systems and benefits of Industry 4.0 production systems. The unit is suitable for all engineering students from a wide range of disciplines and could lead to further study of engineering, an apprenticeship or employment in the manufacturing sector.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the factors shaping the fourth industrial revolution and the characteristics of an Industry 4.0 smart factory

2 Understand the role that the Internet of Things (IoT) plays in an Industry 4.0 smart factory

3 Understand the range of technologies that enable Industry 4.0 and their benefits

4 Understand the factors that manufacturers need to consider when transitioning from Industry 3.0 to 4.0.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the impact and enabling technologies of the industrial revolutions that shaped Industry 4.0	**M1** Analyse how the impact and enabling technologies of industrial revolutions have shaped the characteristics of an Industry 4.0 smart factory	**D1** Evaluate how the impact and enabling technologies of industrial revolutions have shaped the characteristics of an Industry 4.0 smart factory
P2 Describe the characteristics of an Industry 4.0 smart factory		
P3 Describe the technologies enabling the Internet of Things (IoT)	**M2** Analyse how Internet of Things (IoT) technologies are applied in an Industry 4.0 smart factory and their benefits	**D2** Evaluate how Internet of Things (IoT) technologies are applied in an Industry 4.0 smart factory and their benefits
P4 Describe a range of manufacturing applications of the Internet of Things (IoT) in an Industry 4.0 smart factory		
P5 Describe a range of technologies that enable Industry 4.0	**M3** Analyse how Industry 4.0 technologies are applied in a smart factory and their benefits.	**D3** Evaluate how Industry 4.0 technologies are applied in a smart factory and their benefits.
P6 Describe a range of manufacturing applications of Industry 4.0 technologies in a smart factory.		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P7 Describe a range of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.	**M4** Analyse the potential impact of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.	**D4** Evaluate the potential impact of factors to be considered when transitioning from Industry 3.0 to an Industry 4.0 smart factory.

Unit content

What needs to be learned
Learning outcome 1: Understand the factors shaping the fourth industrial revolution and the characteristics of an Industry 4.0 smart factory
• Technologies enabling industrial revolutions: 1.0 mechanisation, water and steam power, transport; 2.0 work sharing, mass production, assembly lines, oil, gas and electrical power; 3.0 information technology, electronics, automation, computerisation; 4.0 (current) cyber physical systems, the Internet of Things (IoT), cloud computing; 5.0 (future) cognitive computing, Artificial Intelligence (AI), mass customisation/personalisation. • The impact of successive industrial revolutions on manufacturing: workforce; skills; efficiency; flexibility; processes; integrated techniques, quality, repeatability. • Characteristics of a smart factory: connectivity; flexibility; scalability; agility; autonomous systems; efficiency; intelligent automation, e.g., self-optimisation, self-diagnostics; robotics; workforce skills; collaborative systems; cobots; systems monitoring. • Systems that underpin the operations of smart factories: data analytics; forecasting; data visualisation; quality control.
Learning outcome 2: Understand the role that the Internet of Things (IoT) plays in an Industry 4.0 smart factory
• Internet of Things (IoT) technologies: wireless connectivity; radio frequency identification (RFID); sensors; system monitoring; cloud computing; data analysis; mobile devices; 5G. • Benefits of the use of IoT to improve manufacturing systems: productivity; safety and security; efficiency and effectiveness; quality; flexibility; responsiveness. • Application of IoT systems in manufacturing: energy monitoring and control; motion tracking; workforce monitoring; real-time machine monitoring, control and optimisation; RFID in supply chain management; warehouse management systems; inventory and materials management; manufacturing applications, intelligent scheduling, geo-fencing. • Principles that underpin IoT systems and services: sensor technology; data collection and analysis; cloud computing; internet and telecommunications infrastructure; wireless connectivity. • Important considerations when using IoT: risks, e.g., security threats, hacking, ethics, data protection, cybercrime; sustainability, e.g. 'always on' systems, data storage; benefits, e.g. efficiency, productivity gains, waste reduction, optimisation, real-time responsiveness.

What needs to be learned
Learning outcome 3: Understand the range of technologies that enable Industry 4.0 and their benefits
• Characteristics, applications, importance and benefits of technologies that enable Industry 4.0: Cyber-Physical Production Systems (CPPS); Internet of Things (IoT); Artificial Intelligence (AI); digital twin technology; telecommunications and internet infrastructure; wireless connectivity, e.g. RFID, Bluetooth, Wi-Fi; data analytics; Big Data; cloud computing; cyber-security; additive manufacturing; computer-aided design (CAD); computer-aided manufacturing (CAM); simulation; augmented reality; autonomous robotics; collaborative robotics; blockchain, e.g. traceability, compliance, audit trail.
Learning outcome 4: Understand the factors that manufacturers need to consider when transitioning from Industry 3.0 to 4.0
• Key factors that need to be considered and their potential impact when transitioning to Industry 4.0: technologies, e.g. selection, implementation, appropriateness to manufacturing needs; infrastructure, e.g. networking, wireless connectivity, sensors; data management, e.g. collection, storage, analysis, visualisation; cyber-security, e.g. integrated security, encryption, risk analysis, authorisation to collect and store data; processes, e.g. managing optimisation; supply chains; customers; workforce, e.g. new roles, skills gap, training, re-deployment, redundancy; change management; restructuring of organisations; employment demographics; health and safety, e.g. safety of autonomous robotic systems.

Essential information for tutors and assessors

Essential resources

For this unit, centres need to provide access to a range of Industry 4.0 case studies.

Textbooks

Barkai J – *The Outcome Economy: How the Industrial Internet of Things is Transforming Every Business* (CreateSpace Independent Publishing Platform, 2016) ISBN 9781530381463

Gilchrist A – *Industry 4.0: The Industrial Internet of Things* (Apress, 2016) ISBN 9781484220467

Windpassinger N – *Digitize or Die: Transform your Organization, Embrace the Digital Evolution, Rise above the Competition* (IoT Hub, 2017) ISBN 9791097580032

Yanez F – *The Goal is Industry 4.0: Technologies and Trends of the Fourth Industrial Revolution* (Independent Publisher, 2017) ISBN 9781973413172

Yanez F – *The 20 Key Technologies of Industry 4.0 and Smart Factories: The Road to the Digital Factory of the Future* (Independent Publisher, 2017) ISBN 9781973402107

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Industrial Revolutions and the Industry 4.0 Smart Factory	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The first in this collection of training materials will consider how a series of industrial revolutions and enabling technologies led up to this point and the characteristics of an Industry 4.0 smart factory.	A written report or presentation
P3, P4, M2, D2	The Technology and Industrial Applications of the Internet of Things (IoT)	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The second in this collection of training materials will consider the technologies enabling the Internet of Things (IoT) and their applications in an Industry 4.0 smart factory.	A written report or presentation

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M3, D3	The Technologies Enabling Industry 4.0	You are a second-year production engineering trainee working for a company planning the transition to Industry 4.0 and the implementation of smart factory technologies. Your manager has asked you to create a collection of training materials for your fellow trainees. The third in the series of training materials will consider a range of other non-IoT technologies that are important to the operation of an Industry 4.0 smart factory and their applications.	A written report or presentation
P7, M4, D4	Transitioning from Industry 3.0 to Industry 4.0	You are a second-year production engineering trainee and have undergone training on the development of Industry 4.0 and its enabling technologies and applications. Your manufacturing facility is planning the transition to a smart factory over the next 2–3 years. Your training supervisor has asked you to prepare a report evaluating the key factors to be considered during this transition and to justify which of these factors should take precedence.	A written report or presentation based on a given case study

P1, P2, M1, D1

Learners will provide a historical overview of the four industrial revolutions that have shaped manufacturing industry, including their enabling technologies and their impact.

For distinction standard, learners will:

- Evaluate, with examples, how at least three technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time. A written conclusion should justify the most important and influential of these technologies.
- Evaluate, with examples, how at least four successive technologies have helped to shape Industry 4.0. For example, steam power, electricity generation, the

development of electronics and computing were all vital steps in the development of internet connectivity that is now crucial to Industry 4.0. A written conclusion should justify the most important and influential series of successive technologies.

- Evaluate, with examples, at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies. A written conclusion should justify the most important technologies that underpin and enable these characteristics.
- Use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- Analyse, with examples, how at least three technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time.
- Analyse, with examples, how at least three successive technologies have helped to shape Industry 4.0.
- Analyse, with examples, at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies.

For pass standard, learners will:

- Describe how at least two technologies from each of the four industrial revolutions had an impact on manufacturing industry at the appropriate time.
- Describe how at least two successive technologies have helped to shape Industry 4.0.
- Describe at least three characteristics of a smart factory and how these are made possible by Industry 4.0 technologies.

P3, P4, M2, D2

For distinction standard, learners will:

- Use suitable examples derived from case studies to evaluate how at least three IoT technologies and their applications can be used in an Industry 4.0 smart factory and the benefits they provide. A written conclusion should justify the IoT application that has the most impact and provides the greatest benefits in a specific manufacturing context.
- Use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- Use suitable examples derived from case studies to analyse how at least three IoT technologies and their applications can be used in an Industry 4.0 smart factory and the benefits they provide.

For pass standard, learners will:

- Describe at least three IoT technologies and their applications as used in an Industry 4.0 smart factory.

P5, P6, M3, D3

Learners must not use IoT technologies and examples for learning outcome 3, as IoT is the focus of learning outcome 2.

For distinction standard, learners will:

- Use suitable examples derived from case studies to evaluate how at least three Industry 4.0 technologies (not including IoT technologies) are applied in an Industry 4.0 smart factory and the benefits they provide. A written conclusion should identify the Industry 4.0 technology and application that has the most impact and provides the greatest benefits in a specific manufacturing context.
- Use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- Use suitable examples derived from case studies to analyse how at least three Industry 4.0 technologies (not including IoT technologies) are applied in an Industry 4.0 smart factory and the benefits they provide.

For pass standard, learners will:

- Describe at least three Industry 4.0 technologies and their applications (not including IoT technologies) as used in an Industry 4.0 smart factory.

P7, M4, D4

For distinction standard, learners will:

- Use suitable examples derived from case studies to evaluate the potential impact of at least three factors (such as data management, supply chains and workforce) that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory. For example, when considering the impact on the workforce (one factor), aspects such as skills development, retraining, redeployment and potentially redundancy need to be addressed before significant changes to processes or infrastructure can be made. A written conclusion should justify which of the three factors must take precedence during the transition, given the specific manufacturing context.
- Use appropriate technical terminology. The response should be suitable for an audience of non-specialists.

For merit standard, learners will:

- Use suitable examples derived from case studies to analyse the potential impact of at least three factors that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory.

For pass standard, learners will:

- Describe at least three factors that need to be considered by an organisation making the transition from Industry 3.0 to an Industry 4.0 smart factory.

Unit 30: Environmental Engineering and Sustainability

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

In this unit, learners will gain an understanding of environmental engineering and sustainability in their sector and will cover analyses that can be used to reduce the environmental impact of an engineering process, product or system.

They will learn about the environmental issues that face engineers, from the use of finite resources and materials, through the ways in which products are manufactured, to the disposal of engineered products at the end of their useful life. Learners will look at the approaches that can be taken to reduce the environmental impact of engineering processes, products and systems, for example through redesigning a component to allow it to be manufactured using a different process that reduces material and energy usage.

Learners will also gain an understanding of the processes involved when completing a life cycle analysis and a system analysis. They will apply these approaches to assess a product or system that is manufactured or serviced in the workplace and then redesign a component or part of the product or system in order to reduce its environmental impact.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Know about sustainability in engineering

2 Understand design, system and product-based approaches to reducing environmental impact

3 Be able to carry out an environmental impact analysis of an engineered product or system

4 Be able to carry out a redesign of an engineered product or system to reduce environmental impact.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe environmental issues faced by engineers and sustainable approaches that can be used to address them	**M1** Compare the benefits of alternative sustainable solutions to address environmental issues	**D1** Evaluate alternative sustainable solutions to address environmental issues and suggest improvements that might make each solution more effective
P2 Explain why engineers need to consider energy use, demand and storage when developing sustainable solutions		
P3 Describe how engineers can use life cycle analysis and systems analysis to reduce the environmental impact of an engineering process or product	**M2** Explain how engineers can use life cycle analysis, systems analysis and approaches to sustainable design to reduce the environmental impact of an engineering process or product	**D2** Evaluate the benefits of completing a life cycle analysis and a systems analysis when selecting approaches to sustainable design for an engineering process or product
P4 Describe approaches to sustainable design that can be used to reduce the environmental impact of an engineering process or product		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Define the parameters and scope for an environmental impact analysis for an engineering product or system	**M3** Explain the outcomes of a completed environmental impact analysis on an engineering product or system	**D3** Evaluate the outcomes of a completed environmental impact analysis with respect to its parameters and scope
P6 Carry out an environmental impact analysis on an engineering product or system		
P7 Interpret the results of an environmental impact analysis to produce a design specification for the redesign of an engineering product or system	**M4** Assess the chosen design solution against the results of an environmental impact analysis and design specification.	**D4** Evaluate the chosen design solution against the results of an environmental impact analysis and design specification and suggest further improvements.
P8 Produce design proposals that meet the requirements of the design specification		
P9 Present, using a range of techniques, details of how the chosen design solution reduces environmental impact.		

Unit content

What needs to be learned
Learning outcome 1: Know about sustainability in engineering
• Environmental issues facing engineers: climate change, pollution, energy use, carbon emissions/capture, use of finite natural resources. • Natural resources: materials, fossil fuels, water resources. • Principles and approaches to reduce the impacts of engineering activities: international protocols and agreements: Paris Agreement, Kyoto Protocol, UN Climate Change Conference; government policies: Climate Change Act. • Sustainable approaches and solutions in engineering: low-carbon solutions, reductions in material and energy use, recycling, energy recovery, sustainable supply chains, methods of reducing pollution. • Alternative and renewable energy sources: solar, wind, tidal, HEP, nuclear, waste-to-energy. • Energy storage methods: batteries, mechanical storage, flywheels, pumped storage. • Energy demand: trends, changes in demand for energy, changes in energy use, capacity for energy generation. • Energy reduction: energy-saving schemes, smart meters, incentives, approaches to energy efficiency. • Energy management: energy management audits, energy use, monitoring and targeting energy savings. • Alternative fuels and power sources for vehicles: hydrogen fuel cells, biodiesel, natural gas, electricity, solar energy, hybrid vehicles, electrified railways, synthetic jet fuels.
Learning outcome 2: Understand design, system and product-based approaches to reducing environmental impact
• Life cycle analysis: raw material extraction, processing/manufacturing/production, transportation, use/reuse, end of life/recycling. • Types of life cycle analysis: cradle to grave, cradle to gate, cradle to cradle, well to wheel. • Systems analysis: inputs to the system, system components, connections between components, outputs from the system, consumables, connections to other systems. • Energy-based approaches to sustainable design: increased efficiency of plant and equipment, use of renewable energy sources, reduction in energy losses.

What needs to be learned
• Materials-based approaches to sustainable design: use of renewable materials, use of recycled/recyclable materials, selecting materials with desirable properties to allow for a long service life, reduction in waste. • Product-based approaches to sustainable design: e.g. utilising new parts with lower energy requirements, simplifying systems or products so there are fewer moving parts to lessen the need to cool and/or use oil-based lubrication, building flywheel energy storage into processes, reducing the number of components or parts, designing for recycling. • Technology-based approaches: e.g. use of advanced manufacturing techniques, use of newly developed materials, use of innovative technologies, use of modern manufacturing systems.
Learning outcome 3: Be able to carry out an environmental impact analysis of an engineered product or system
• Life cycle assessment stages: raw material extraction; processing and manufacturing; transportation; use, repair and maintenance; end of life. • System analysis stages: inputs; processes, components, mechanisms; connections with other systems; outputs; operating principles and parameters. • System analysis techniques: block diagrams, event trees, cause-consequence diagrams, SWOT analysis. • Parameters of the analysis: identification of a product/system to analyse, system boundaries, factors to include, expected outcomes. • Scope of the analysis: which stages to include, which components/processes to include. • Environmental impact analysis processes: define the scope of the analysis, analyse the problem, analyse the requirements of the system/product, design/redesign the system/product, assess designs, propose a solution. • Results of the analysis: e.g. meeting objectives, identification of trends, opportunities to reduce environmental impacts, graphical representations of results; interpretation of results to produce a design specification for the redesign of a product or system.
Learning outcome 4: Be able to carry out a redesign of an engineered product or system to reduce environmental impact
• Identification of potential approaches to reduce environmental impact of an engineering product or system: e.g. reduction in waste, reduction in processing, improved life span of the product/system, improved efficiency, design for manufacture, design for recycling/reuse.

What needs to be learned
• Design specification/criteria: e.g. quantity, maintenance, finish, materials, weight/mass, capacity, aesthetics, product life cycle, sustainability, carbon footprint, reliability, safety, ergonomics, usability, manufacturing, system parameters. • Initial and developed ideas and solutions to reduce the environmental impact of an engineering product or system: technical design criteria; idea generation; initial design proposals (fitness for purpose, refinements, meeting design criteria); developed design idea/chosen solution (purpose and function, mechanical/electronic principles, material requirements, manufacturing processes, assembly arrangements). • Communication of designs: freehand sketching and diagrams (2D and 3D, illustrations, technical); CAD; annotations; documentation (detail and assembly drawings, specifications, parts list, material lists). • Reporting: evaluation of the outcomes; assessment of reduced environmental impact; presentation of solution to third parties.

Essential information for tutors and assessors

Essential resources

Learners will need access to appropriate engineering products or systems for the completion of the environmental impact analysis. They will need access to CAD and equipment for producing formal drawings for learning outcome 4.

Textbooks

Allen D, Shonnard D – *Green Engineering* (Prentice Hall, 2016) ISBN 9780132657075

Allen D, Shonnard D – *Sustainable Engineering: Concepts, Designs and Case Studies* (Pearson, 2011) ISBN 9780132756587

Boyle G – *Energy Systems and Sustainability: Power for a Sustainable Future,* 3rd edition (Oxford University Press, 2021) ISBN 9780198767640

Ciambrone, D – *Environmental Life Cycle Analysis* (CRC Press, 2018) ISBN 9781351450430

Gibson A, Johnson A – *Sustainability in Engineering Design* (Elsevier, 2014) ISBN 9780124045910

Gibson J et al – *How to Do Systems Analysis* (Wiley, 2007) ISBN 9780470130582

Klemes, J – *Assessing and Measuring Environmental Impact and Sustainability* (Elsevier, 2015) ISBN 9780128022337

Zindani D, Davim J – *Sustainable Manufacturing and Design* (Elsevier, 2021) ISBN 9780128221617

Websites

www.eao.stanford.edu/research-areas/life-cycle-assessment	Background information about life cycle assessments
www.medium.com/disruptive-design/quick-guide-to-sustainable-design-strategies-641765a86fb8	Article introducing methods for sustainable design that could be applied to engineering systems and products
www.sustainabledevelopment.un.org	United Nations Sustainable Development Knowledge Platform (general reference)
www.carbontrust.com	Carbon Trust: information about carbon footprinting
www.greenspec.co.uk/life-cycle-assessment-lca	Background information about life cycle assessments

www.tutorialspoint.com/system_analysis_and_design/system_analysis_and_design_overview.htm	Overview of methods of completing a systems analysis

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Environmental Issues Faced by Engineers	You are an apprentice engineer, and your supervisor has asked you to investigate environmental issues, including those associated with energy, that are faced by engineers, and to produce a report that includes details of approaches that could be used to address these issues. They want you to do this as reducing environmental impact is a key objective for your company.	A written report containing details of environmental issues faced by engineers and the sustainable solutions that could be used to address them.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2, D2	Approaches to Reducing Environmental Impacts	You are an apprentice engineer, and your supervisor has asked you to produce a report investigating the use of life cycle analysis and systems analysis and how both can be used to select suitable approaches to produce sustainable solutions to engineering problems. They want you to do this as reducing environmental impact is a key objective for your company.	A written report containing details of how life cycle analysis and systems analysis can be used by engineers to identify approaches that will reduce the environmental impact of engineering products or processes.
P5, P6, M3, D3	Environmental Impact Analysis	You are an apprentice engineer and have been asked by your supervisor to identify a product or system that you work with, whose environmental impact you think could be reduced. You then need to complete an environmental impact analysis and present the outcomes to your supervisor. They want you to do this as reducing environmental impact is a key objective for your company.	A report that includes a completed environmental impact analysis of an engineering product or system plus the outcomes from the analysis.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, M4, D4	Redesigning an Engineering Product or System	You are an apprentice engineer and have been asked by your supervisor to produce a design specification and to then redesign aspects of the product or system so that it has a reduced impact on the environment. They want you to do this as reducing environmental impact is a key objective for your company.	A portfolio of evidence that includes a design specification, initial proposals/ideas and a chosen/presented design solution, along with an evaluation that considers further improvements to the product or system.

Assessment of this unit will be based both on reports and on practical investigation and design activities. While a theoretical approach is suitable for learning outcomes 1 and 2, the assessment activities for learning outcomes 3 and 4 should be linked to an engineering product or system with which the learner is familiar. Ideally, the product or system would be one that the learner works with regularly, either in a manufacturing or a servicing capacity.

For learning outcome 3, learners might need to add their own sketches, drawings/circuit diagrams, notes, lists, charts, photographs, etc to support their environmental impact analysis. The product or system should be sufficiently complicated to allow for a number of different possible improvements to be made but should not be excessively complex. For more complicated systems or products, either a component or a sub-system could be considered, and learners will need to make decisions related to the scope of the analysis. For example, for a product, will they cover all stages of a product life cycle or focus on raw material extraction through to transportation to customers? For a system, will all inputs and outputs be considered, or only the ones which are key to the operation of the system?

Employed learners should be encouraged to work closely with their own company/ employer when deciding on a product or system to analyse, so that the activity is meaningful and has sufficient scope to allow access to all the relevant assessment criteria.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require answers that demonstrate additional depth and/or breadth of treatment.

Learning outcome 1

For P1, learners will need to describe at least two environmental issues that face engineers, for example those associated with the use of finite resources or pollution from engineering processes. They will also need to consider sustainable approaches that could be taken with respect to these environmental issues, for example through the use of alternative materials to reduce the need for extraction of finite materials or the use of filtering to remove particulates from emissions. P2 requires learners to explain why engineers need to consider the way that energy is used, both in engineering and in the wider world, including changes such as increased demand for electricity, for example as a result of more electric vehicles being sold. Learners will need to include details of how energy can be stored and the implications of these methods when developing sustainable solutions.

For M1, learners will develop their responses to P1 and P2 by comparing the benefits of different approaches to address at least two environmental issues. For example, for one of the environmental issues learners may consider different energy sources as one solution and different manufacturing processes as a second solution. Learners will need to do something similar for the second environmental issue.

To achieve D1, learners will need to evaluate the alternative solutions that have been identified for M1 and suggest further possible improvements that would make each of their selected sustainable solutions more effective.

Learning outcome 2

For P3, learners will need to describe how engineers can use life cycle analysis and systems analysis to reduce the environmental impact of an engineering process or product. As part of this they will consider the five main stages of a life cycle assessment and what is focused on during these stages; they will also describe the stages of a systems analysis, for example for a piece of equipment that they use in their workplace. They will give details of different approaches to carrying out the analyses and give brief reasons why, for example, an engineering organisation might consider cradle to gate as being more appropriate for the products they produce. For P4, learners will describe examples of energy-based, materials-based, product-based and technology-based approaches that can be used to achieve sustainable designs. Again, these could be associated with a process or product that learners have experience of in their workplace; however, not all the approaches need to relate to the same process or product.

To achieve M2, learners will need to develop their responses for P3 and P4 to explain how the life cycle and systems analyses can be used in combination with the four different approaches to achieving sustainable design for an engineering process or product in order to reduce environmental impact.

For D2, learners will need to evaluate the benefits of carrying out a life cycle analysis and a systems analysis, for example being able to identify the stages in the process where there are the greatest opportunities to implement sustainable design solutions, or where the greatest benefit could be achieved, and how the outcomes of an analysis can inform decisions as to which sustainable design approach to take.

Learning outcome 3

Learners will need to select either an engineering product or system on which to carry out an analysis. The product or system should allow them to identify a number of possible opportunities to redesign features and reduce the environmental impact (for learning outcome 4). The product or system should be something that the learner is familiar with, and not overly complex. For example, learners should not investigate a car as a product, but might consider the lighting system or wheels.

For P5, learners will need to define the parameters and scope for an environmental impact analysis. For example, they might decide that cradle to gate is appropriate for a car wheel given the relatively long life of such a product, and also what the scope will be, such as focusing on the materials and processes used in making the wheel but not the tyre. For P6, learners will then carry out the environmental impact analysis on their selected product or system, and they will identify which aspects of the product or system have negative effects on the environment.

For M3, learners will need to explain the outcomes of their completed environmental impact analysis, including the implications of the outcomes, for example indicating the stages of the life cycle or system operation that have the greatest negative effects on the environment and should be focused on to reduce the environmental impact of the engineering product or system.

This will need to be developed for D3, where learners will evaluate these outcomes with respect to the parameters and scope of the analysis. For example, they might recognise that there is a large negative impact related to extraction of raw materials for batteries; however, there are no alternative sources, so mitigation measures are needed to reduce impacts.

Learning outcome 4

Learners will make use of the outcomes of their environmental impact analysis to redesign part of the product or the system. The redesign should address more than one aspect where the environmental impact of the product or system could be reduced. For example, focusing only on the type of material used would not be sufficient.

For P7, learners will need to interpret the results of their environmental impact analysis to produce a design specification for the redesign of the engineering product or system. The design specification need not cover all the factors in the unit content for learning outcome 4; however, it will be sufficiently detailed to allow objective judgements to be made about the improved/chosen design solution and whether it is fit for purpose.

For P8, the design specification will need to be used to produce a range of ideas/proposals for improvements to the design of the engineering product or system.

Learners will need to present a portfolio of evidence that includes initial design ideas/proposals and a developed/chosen design solution using freehand sketches, formal drawings and CAD. The developed/chosen design solution should show a reduction in environmental impact and be presented using formal drawings, parts lists and materials lists to a third party (P9).

For M4, learners will need to assess the chosen design solution when compared to the original design, the outcomes of the environmental impact analysis and also the requirements of the design specification, giving reasons as to why their chosen design offers environmental impact improvements and how this is achieved.

This will need to be developed for D4, where learners will evaluate the chosen solution holistically, considering areas where environmental impact improvements have been made and also where further improvements might be possible. For example, developments in additive manufacturing might allow more reductions in the mass of a component if it could be produced with a honeycomb structure that provides the same structural integrity as a solid component.

Unit 31: Simulation and Digital Twinning

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

This unit aims to give learners an understanding of the application of simulation and digital twinning as used in advanced manufacturing and the skills needed to produce and simulate digital manufacturing process or system models.

Digital twinning allows manufacturing organisations to test modifications or innovations virtually without the need to suspend production or set up additional test assembly lines. For example, the use of 3D modelling software helps create digital twins for physical objects where connected sensors can collect the data from a physical system and update the digital twin with physical model dynamic conditions. Therefore, a digital twin can be used for monitoring and diagnostics to optimise process or system performance.

This unit will give learners an understanding of recent advances in new technologies and their applications for advanced manufacturing. Learners will also develop an understanding of the benefits and limitations of digital twinning and will consider the software and data collection implications for digital twinning. They will have the opportunity to produce and simulate a digital twin model of a manufacturing process or system and will consider how to adjust parameters to improve its performance.

The unit encompasses both theoretical teaching and practical work. It aims to enhance learners' awareness of the general concepts and principles associated with the use of digital twinning simulation software for advanced manufacturing.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the benefits and limitations of using digital twinning during advanced manufacturing

2 Understand the software and data collection implications for digital twinning

3 Be able to produce and simulate a digital twin for a manufacturing process or system.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe how digital twinning is used during advanced manufacturing	**M1** Explain the use of digital twinning to enhance quality and efficiency during advanced manufacturing	**D1** Analyse how digital twinning is used to justify a range of improvements during advanced manufacturing
P2 Describe the limitations of digital twinning during advanced manufacturing		
P3 Explain how simulation software can be used to create a digital twin	**M2** Justify the choice of digital twinning simulation software for an advanced manufacturing process or system	**D2** Evaluate the collection and use of appropriate data for a digital twin of an advanced manufacturing process or system
P4 Explain why successful digital twinning is based on the collection and use of appropriate data		
P5 Produce a 3D digital twin model of a manufacturing process or system	**M3** Produce accurately a 3D digital twin model of a manufacturing process or system.	**D3** Analyse the effect of changing parameters when using the 3D digital twin model to simulate the operation of a manufacturing process or system, and recommend improvements that will optimise the function of the manufacturing process or system.
P6 Simulate the operation of a manufacturing process or system using the 3D digital twin model, determining the effect of changing parameters.		

Unit content

What needs to be learned
Learning outcome 1: Understand the benefits and limitations of using digital twinning during advanced manufacturing
• Industry 4.0: enabling technologies including the Internet of Things (IoT), cloud computing, cyber physical systems. • Digital twinning: use of simulation software to produce a 3D digital twin model and how it is used to enhance quality and efficiency and justify a range of improvements during advanced manufacturing, e.g., simulating small amendments to a range of parameters in a manufacturing process or system digitally and observing the positive and negative effects to decide whether to implement the modifications or make further/different modifications to help reach the desired effect. • Benefits of using digital twinning: a lower-cost alternative to physical solutions, e.g., 'what if' analysis in virtual factories to observe the impact on manufacturing processes, data analytics, forecasting, improved human factors such as compliance with health and safety regulations, workforce combined with machine efficiency, decision-making support, data visualisation, enhancing quality and efficiency. • Limitations of using digital twinning: the possibilities of inaccurate modelling, e.g., disassembly of machinery to accurately replicate all features of it, inaccurate representation of an object, unrealistic/theoretical nature of the simulation, not accounting for unprecedented future scenarios in the workplace.
Learning outcome 2: Understand the software and data collection implications for digital twinning
• Characteristics of a smart factory: features of advanced manufacturing, e.g., connectivity, flexibility, scalability, agility, autonomy, efficiency, sensors and actuators, IoT featuring Artificial Intelligence, wireless communication protocols, cloud computing. • Digital twinning software: definition, use and selection of digital twinning simulation software for a manufacturing process or system, e.g., 2D and 3D CAD modelling, Solidworks, Autodesk, 3D animation software, SAP PEI, Mindsphere, Ansys, Matlab/ Simulink, etc. • Data collection: evaluation of the accuracy and appropriateness of data collection and use for successful digital twinning, e.g., sensors, cameras, other interface devices, reference to the digital virtual product, the physical product and the connection between both the digital and the physical product, AI, machine learning, IoT, health and safety, communication protocols (NFC, RFID, Bluetooth, Zigbee, Wi-Fi).

What needs to be learned
Learning outcome 3: Be able to produce and simulate a digital twin for a manufacturing process or system
• Utilisation of digital twin modelling software: using virtual and augmented reality as well as 3D graphic and data modelling to accurately produce a virtual model of a manufacturing process or system, enhanced by real-time process data and analytics based on accurate configurations. • Simulating digital twin models: checking the model for accurate replication of all process or system activities from the physical to the digital world by collating all live application data from application logs and devices to then replicate all live application issues in test, using logs which will enable the analysis of the effects of adjusting parameters for the future prediction and prevention of system failures and the optimal function of the manufacturing process or system.

Essential information for tutors and assessors

Essential resources

For this unit, centres should have sufficient facilities so that learners can carry out practical activities associated with digital twinning. Relevant software packages should be available to permit simulation and modelling.

A visit to an engineering company that utilises digital twinning applications would be a good way for learners to see how the applications work in practice and to gather research information. This could involve talking to a CAD designer/3D modeller and being shown the processes of specifying, producing and simulating digital twin models to give learners a basis of knowledge and understanding before they produce their own models.

Indicative reading for learners

Gilchrist A – *Industry 4.0: The Industrial Internet of Things* (Apress, 2016) ISBN 9781484220467

Tao F, Zhang M, Nee A – *Digital Twin Driven Smart Manufacturing* (Academic Press, 2019) ISBN 9780128176306

Yanez F – *The 20 Key Technologies of Industry 4.0 and Smart Factories: The Road to the Digital Factory of the Future* (Independent Publisher, 2017) ISBN 9781973402107

Websites

www.control.com/technical-articles/digital-twinning-leaders-in-the-emerging-technology/	Digital Twinning: Leaders in the Emerging Technology
www.challenge.org/insights/digital-twinning/	What is the meaning of digital twinning and how it is applied
www.ibm.com/topics/what-is-a-digital-twin	What is a digital twin?
www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/digital-twins/	Digital Twin: rise of the digital twin in Industrial IoT and Industry 4.0
www.networkworld.com/article/3280225/what-is-digital-twin-technology-and-why-it-matters.html	What is a digital twin and why it's important to IoT

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Using Digital Twinning during Advanced Manufacturing	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering how the use of digital twinning could enhance quality and efficiency during manufacturing. They want you to do this because they are aware that a range of improvements could be implemented.	A written report

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2, D2	Software and Data Collection Implications for Digital Twinning	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the use of software and data collection/use for digital twinning. They want you to do this to help identify improvements that could be made to enhance the suitability of digital twin models.	A written report
P5, P6, M3, D3	Produce and Simulate a Digital Twin Model of a Manufacturing Process or System	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to produce and simulate a digital twin model of a given manufacturing process or system. They want you to do this because they want to understand the effects of changing parameters to improve the function of the manufacturing process or system.	A written report/ portfolio based on practical activities supported by annotated photos and observation records.

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

The first assignment could cover P1, P2, M1 and D1 holistically.

To achieve P1, learners need to describe how digital twinning is used during advanced manufacturing. Learners are expected to describe in detail how modelling a potential modification to a manufacturing process or system using digital software can be beneficial to companies in terms of saving time, money and resources. When describing the benefits, learners should also cover the environment in which the manufacturing process or system operates, the capital required to maintain effective operation and examples of potential modification requirements.

For P2, learners must describe at least two limitations of digital twinning during advanced manufacturing. Learners could refer to inaccurate/simplistic modelling of the real system, the theoretical nature of the simulation or not accounting for unprecedented future scenarios in the workplace. Learners must also cover the possible implications of both limitations during advanced manufacturing.

For M1, the explanation must demonstrate a good understanding of the reasons why, in a global market environment, a manufacturing organisation can maximise the quality and efficiency of its processes or systems by incorporating digital twinning applications into its developmental processes, with particular reference to the specific effects on productivity.

To achieve D1, learners must provide a detailed analysis of the ways in which digital twinning is used to justify a range of improvements to a manufacturing process or system. For example, learners should cover how a manufacturing organisation can make small amendments to a range of parameters in a manufacturing process or system digitally, and can then observe the positive and negative effects, which can then provide evidence to either implement those modifications (if they produce the desired effect) or make different/further modifications to help reach the desired effect. Specific examples must be provided.

A second assignment could cover P3, P4, M2 and D2 holistically.

To achieve P3, learners must explain how simulation software can be used to create a digital twin model of a manufacturing process or system. This could include the use of 2D and 3D CAD modelling, Solidworks, Autodesk, 3D animation software, SAP PEI, Mindsphere, Ansys, Matlab/Simulink, etc. Learners need to give a detailed, step-by-step explanation of how the software functions to produce the digital twin model of a manufacturing process or system. For example, this may include defining the process or system that is being digitised, geometry, and the appropriate utilisation of strategically placed sensors to replicate/simulate the physical process or system in real time.

In order to achieve P4, learners will need to explain why successful digital twinning is based on the accurate collection and use of appropriate data. Learners need to explain the effectiveness of at least two data acquisition methods used (such as sensors and cameras) to collect the appropriate data accurately. As part of this, learners must also cover how the data collected is used, for example to simulate simple process or system modifications or to build a longer-term picture to predict where failures may occur.

For the merit and distinction criteria, learners must be given a specific example of an advanced manufacturing process or system (such as a detailed flow diagram for a manufacturing cell or a production line producing a component) so that they can justify and evaluate in context.

The achievement of M2 requires learners to select the digital twinning software that they deem the most suitable for producing a digital twin of the given advanced manufacturing process or system and then justify their choice. This justification could include the benefits of the specific software, the limitations of other software and the ease of producing a digital twin with the chosen software.

For D2, learners must evaluate the collection and use of appropriate data for a digital twin of the given advanced manufacturing process or system. Learners should evaluate different methods of acquiring accurate and appropriate data for the given advanced manufacturing process or system to minimise the inaccuracies of the digital twin model compared to the real process or system. They must also evaluate how the data collected could be used, by providing specific examples of potential process or system modifications that could be simulated using the digital twin model.

A third assignment could cover P5, P6, M3 and D3 holistically.

For this assignment, learners must be given the details of a manufacturing process or system and it should not be overly complex – for example, a manufacturing cell or a production line producing a standard component.

To achieve P5, learners must produce a 3D digital twin model of the given manufacturing process or system using simulation software. For M3, learners are required to accurately produce a 3D digital twin model of the given manufacturing process or system using simulation software.

For P5, the model will function but may be too simplistic, with some errors that affect the way it operates, meaning that when process or system parameters are amended, the model may not produce results that can be trusted. For M3, the model should be appropriately detailed and should function well, with only minor errors present, meaning that when process or system parameters are amended, the model can be analysed so that the function of the manufacturing process or system can be optimised.

In order to achieve P6, learners need to determine the effect of changing parameters by simulating the operation of the produced 3D digital twin model to ensure that it is a suitable representation of the given physical manufacturing process or system. For example, they need to test whether the digitised objects are the same size and design as the physical objects, and whether the function is identical to truly replicate the dynamic conditions of the given manufacturing process or system. Learners should also determine where changing parameters can improve the accuracy of the operation of the digital twin in order to function identically to the real system.

The achievement of D3 links to M3. For D3, learners need to analyse the effects of changing parameters when using the 3D digital twin model to simulate the operation of the given manufacturing process or system, and recommend improvements that will optimise the function of the given manufacturing process or system. For example, if the production time is slower than initially predicted, the learner may choose to remove a stage from the production process and simulate this to see if it works better, or amend other parameters to optimise the agility of the given manufacturing process or system. The learner must include what-if analysis of this choice and the possible impacts (both positive and negative) that it could have on the given manufacturing process or system, in order to recommend suitable improvements.

Unit 32: Cyber Security in Engineering

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Learners will investigate the cyber security for engineering computer systems, and will install and configure security measures to protect a system from malicious threats.

Cyber security is an important issue for the economy and for engineering organisations. For example, engineering organisations undertake cutting-edge research and need to invest in sophisticated systems to protect information and intellectual property with passwords, security passes and sophisticated physical locks. Organisations have a responsibility to create secure products, so all the engineers involved in the development and testing process must have an understanding of security issues.

Learners will investigate a range of computer security threats, computer system vulnerabilities, and security-protection measures that are used in the industry. They will also investigate the legal requirements placed on organisations to protect information and systems. They will plan for and then install and configure protection measures for an engineering computer system and test the effectiveness of the measures.

All engineers need to understand why cyber security is important and how it can be implemented in products and systems of all types. This unit helps learners prepare for an engineering apprenticeship, for higher education and for technician-level roles, such as an information technology (IT) technician, engineering technician or IT operations technician.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the threats to computer systems in engineering organisations and the organisations' legal responsibilities

2 Know computer system vulnerabilities and protection measures used in engineering organisations

3 Be able to plan security measures to protect an engineering computer system from threats

4 Be able to implement security measures to protect an engineering computer system from threats.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe the different security threats that may affect contrasting engineering computer systems and the impact of any loss	**M1** Assess the different security threats, the impact of any loss, and legal requirements that apply to contrasting engineering computer systems, including how they interrelate	**D1** Evaluate the effectiveness of security measures used to protect vulnerabilities in contrasting computer systems from threats, considering the impact of loss and the legal requirements that apply
P2 Explain the legal responsibilities that at least one engineering organisation has for the security of its computer systems		
P3 Explain what vulnerabilities exist in contrasting engineering computer systems	**M2** Justify how the physical, software, hardware and policy security measures protect vulnerabilities in contrasting engineering computer systems from loss	
P4 Explain how the physical, software, hardware and policy security measures protect contrasting engineering computer systems from loss		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Produce a plan to protect an engineering computer system from possible threats	**M3** Produce a detailed plan to protect an engineering computer system from possible threats, justifying the recommendations	**D2** Optimise the effectiveness of the plan and of the protected engineering computer system safely, testing how well the system is protected by the measures and that users are not unreasonably hindered by the measures.
P6 Undertake security measures safely to protect an engineering computer system	**M4** Undertake security measures safely to fully protect severe vulnerabilities in an engineering computer system, testing how well the system is protected by the measures.	
P7 test how well the engineering computer system is protected by the measures.		

Unit content

What needs to be learned
Learning outcome 1: Understand the threats to computer systems in engineering organisations and the organisations' legal responsibilities

Computer system security threats:
• All computer systems are vulnerable to attack from external and internal threats.
• Internal threats include:
  o employee sabotage and theft, e.g., changing parameters via remote access causing machine failure, theft of physical equipment or data, and damage, such as fire, flood, power loss, terrorism or other disaster
  o unauthorised access by employees and other users to secure areas and administration functions, including security levels and protocols, e.g., to remote systems, to engineering machines controlled by computer
  o weak security measures and unsafe practices, e.g., security of computer equipment, engineering machines and storage devices, security vetting of visitors, visiting untrusted websites, limited encryption
  o accidental loss or disclosure of data, e.g., poor staff training on system access and engineering device operation, limited internal protocols and monitoring of equipment and access.
• External threats include:
  o malicious software (malware) and how it functions, including viruses, worms, spyware, adware, rootkits and Trojan horses
  o hacking, e.g., commercial, government or individuals
  o sabotage, e.g., commercial, government, terrorism, individuals
  o social-engineering techniques used to obtain secure information by deception.
• The impact of a successful threat to an organisation is some form of loss, such as operational loss, e.g., manufacturing output; financial loss, e.g. organisational, compensation and liability; reputation loss, e.g. lack of service and employee or customer information; and intellectual property loss, e.g. new product design.
Legal responsibilities:
• United Kingdom legislation or other relevant international equivalents, including:
  o data protection legislation and amendments, requirements for organisations to keep data secure such as General Data Protection Regulations (GDPR)

What needs to be learned
computer misuse legislation and amendments, its definitions of illegal practices and applications.
• Telecommunications (Lawful Business Practice) (Interception of Communications) regulations and amendments, requirements to allow companies to monitor an employee’s communication and internet use while at work.
• EU Cyber Security Directive: o fraud legislation and amendments, requirements to deal with services using IT-based methods to steal information for fraudulent purposes.
Learning outcome 2: Know computer system vulnerabilities and protection measures used in engineering organisations
Computer system vulnerabilities: • Understand that different types of computer system are exposed to different threats and contain different vulnerabilities. Possible vulnerabilities include: o network, e.g., open firewall ports, Wi-Fi passwords, encryption o organisational, e.g., inappropriate file permissions or privileges, password policy o software, e.g., from an untrusted source, torrent-downloaded software, illegal copies, insecure product software o operating system, e.g., unsupported versions, updates not installed o physical, e.g., theft of equipment, USB storage devices with sensitive data, collection of passwords and other information by social-engineering methods o process of how people use the system, e.g., leaks and sharing security details. • Different security threats exploit different computer/system vulnerabilities, e.g., hackers can exploit open firewall ports to obtain sensitive information, such as passwords, or to manipulate engineering process and/or products. *Physical security measures:* • Physical security measures and their effectiveness, including: o site security, e.g., locks, card entry, biometrics, closed circuit television (CCTV) o data storage, data protection and backup procedures, including planned automated backup, on- and off-site data storage, cloud storage.

What needs to be learned
Software and hardware security measures: • Software security measures and their effectiveness, including: o anti-virus software and detection techniques, including virus signatures, heuristics techniques used to identify potentially suspicious file content, techniques for dealing with identified threats o software and hardware firewalls and the filtering techniques they use, including packet filtering and inspection, application layer awareness, inbound and outbound rules, and network address o user authentication, including user log-on procedures; strong password; text and graphical password; biometric authentication; two-step verification; security tokens, e.g., USB-based keys; knowledge-based authentication, e.g., question and response pairs; Kerberos network authentication for Windows and Linux-based operating systems; certificate-based authentication o access controls and the methods to restrict authorised/unauthorised users' access to resources, e.g., user groups and the access rights allocated to resources, such as folders, files and physical resources including printers, automated PLCs and/or microprocessor controller systems on the network o the principles of encryption, including shift ciphers, one-time pads, hashing, symmetric and public key encryption, file/folder encryption, disk encryption products o precautions that can be taken to protect a wireless local area network (LAN) from unauthorised access, e.g., MAC address filtering and hiding the service set identifier (SSID); wireless encryption such as Wired Equivalent Privacy (WEP), Wi-Fi Protected Access (WPA) and Wi-Fi Protected Setup (WPS), mitigating known wireless vulnerabilities o consideration of security issues during network and system design, and remote access product design, to ensure security is built in from the development stage. *Policy security measures:* • Policy security measures and their effectiveness, including: o organisation policies and their application, including policies on internet and email use, security and password procedures, staff responsibilities, staff IT security training o security audits and their application to check compliance against policies o backup of data o ensuring no detrimental impact on the safe use of engineering equipment and processes.

What needs to be learned
Learning outcome 3: Be able to plan security measures to protect an engineering computer system from threats

Assessment of computer system vulnerabilities:

- Tools and methods to assess the vulnerabilities in computer systems, including port scanners, e.g. NMAP, Angry IP scanner; checkers (Windows Registry Checker Tool, CCleaner); website vulnerability scanners, e.g. Acunetix, w3af; general vulnerability detection and management software, e.g. OpenVAS, QualysGuard, Firesheep; and assessing user vulnerabilities, e.g. training and staff vetting.
- Audits of system and network designs prior to implementation.
- Penetration testing for common threats, e.g. those in the OWASP (Open Web Application Security Project) top 10, including Structured Query Language (SQL) Injection.

Assessment of the risk severity for each threat:

- A risk is a threat that could result in some form of loss at some point in time.
- Risk severity = probability of the threat occurring × expected size of the loss.
- Measures for risk severity include:
  - risk severity = low, medium, high and extreme
  - probability of the threat occurring = unlikely (e.g. every two years), likely (e.g. every month) and very likely (e.g. once or more a day)
  - size of the loss = minor (e.g. under one hundred pounds), moderate (e.g. hundreds or thousands of pounds) and major (e.g. tens of thousands of pounds).
- The resultant risk severity is illustrated in the following matrix:

Probability of threat occurring	*Very likely*	*Medium*	*High*	*Extreme*
	Likely	*Low*	*Medium*	*High*
	Unlikely	*Low*	*Low*	*Medium*
		Minor	*Moderate*	*Major*
	Size of the loss			

What needs to be learned
- Risk assessment approach: - risk assessments are undertaken during system design and at regular intervals or following a security breach, as threats are constant and ever changing   - a risk assessment method should: - identify possible threats and assess the probability of different threats occurring   - assess the vulnerabilities of a computer or engineering technology system to specific threats   - determine the risk severity (low, medium, high and extreme)   - identify ways to prevent severe risks (medium, high and extreme) from occurring and reduce the severity of the risk if it does occur.   *A security plan for a computer system:*   - A plan for a computer system, including: - a risk assessment.   - System protection measures for the most severe risks, including: - a summary of how the system will be protected   - user security policy, e.g., with access rights and information and functional change availability   - hardware protection measures, e.g., firewalls, routers, wireless access points   - software protection measures, e.g., anti-malware, firewall, port scanning   - a description of policies, e.g., scheduled backups and running anti-virus scans   - alternative solutions, including risk transfer to a third party, risk avoidance by stopping an activity, and risk acceptance, e.g., a low risk   - any technical and financial constraints, e.g., software licence costs   - a test plan to check that the protection measures work as intended   - methods to detect security breaches, response plans.
Learning outcome 4: Be able to implement security measures to protect an engineering computer system from threats
Installation and configuration of security measures for a computer system: - Consideration of security issues during the design and development of the engineering system.   - Installation and configuration of security software, e.g., anti-virus, firewall.   - Hardware and/or operating system-embedded firewalls, including configuration of:

What needs to be learned
- inbound and outbound rules to control network connections that are allowed and prevent all other unauthorised connections   - firewall events and interpretation of log entries.   - Wireless security, including: - wireless encryption methods, e.g., WEP, WPA (1 and 2)   - configuration of wireless router security settings   - adding clients to a wireless network.   - Access control, including: - design and implementation of hardware and software access-control regimes, including permission settings on files, folders, functional control changes and resources   - defining legitimate users, groups and the resources they need to access and the levels of access they need (read, modify, delete)   - defining password policies, e.g., length, complexity, age and reuse   - whitelisting of applications' trusted signed binaries   - data hiding when viewing logs and visibility of sensitive data   - defining users with special privileges, e.g., administrator rights.   *Testing a computer system's security measures:*   - Test the effectiveness of the protection measures and make recommendations for further improvement, including: - firewall testing using penetration-testing software to check that the firewall blocks unauthorised traffic and allows legitimate traffic through   - wireless penetration testing using stumblers to find and identify access points, cracking software to test passwords   - viewing and interpreting activity logs   - checking that the normal operation of the computer system/engineering system is not hindered.

Essential information for tutors and assessors

Essential resources

For this unit, learners must have access to:

- case study materials from different organisations describing the purpose of some of the computer systems, the configuration and security protection measures
- appropriate legislation and regulations as listed in the unit content
- computer systems (real, mock-up or virtualised) to which security measures can be applied
- appropriate security software such as anti-virus and firewall software.

Textbooks

Colbert E – *Cyber-security of SCADA and Other Industrial Control Systems: 66* (Advances in Information Security) (Springer, 2018) ISBN 9783319812038

Diogenes Y, Ozkaya E – *Cybersecurity – Attack and Defense Strategies: Counter Modern Threats and Employ State-of-the-Art Tools and Techniques to Protect Your Organization Against Cybercriminals*, 2nd edition (Packt Publishing, 2019) ISBN 9781838827793

Easttom C – *Computer Security Fundamentals*, 4th edition (Pearson IT Certification, 2019) ISBN 9780135774779

Hodson C – *Cyber Risk Management: Prioritize Threats, Identify Vulnerabilities and Apply Controls* (Kogan Page, 2019) ISBN 9780749484125

Russell B – *Practical Internet of Things Security: Design a Security Framework for an Internet Connected Ecosystem*, 2nd edition (Packt Publishing, 2018) ISBN 9781788625821

Thames L – *Cybersecurity for Industry 4.0: Analysis for Design and Manufacturing* (Springer, 2017) ISBN 9783319506593

Websites

www.cisa.gov	United States of America CyberSecurity, Infrastructure & Security Agency equivalent to UK GCHQ – overviews, education, advice and guidance
www.insidetechlaw.com/internet-of-things	Overview of IoT and world legal requirements, including publications and blogs
www.ncsc.gov.uk	UK Government site for GCHQ and cyber security – overviews, education, advice, and guidance

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, M2, D1	System Threats and Vulnerabilities: Legal Requirements and Methods of Protection	You are an apprentice security engineer, and your supervisor has asked you to review two contrasting computer systems and to carry out an investigation into the effectiveness of the security measures used to protect the vulnerabilities from threats. They also want you to consider the impact of any potential loss and the legal requirements that apply.	A detailed report

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M3, M4, D2	Planning and Implementation of Security Measures	You are an apprentice security engineer and your supervisor has asked you to produce a structured plan to protect an engineering computer system from threats. You must also implement the plan and test how effectively the system is protected.	Written plan Written report, annotated photographs, screenshots, etc and an observation record related to the practical demonstration of the implementation and testing.

Learning outcomes 1 and 2

For distinction standard (D1), learners will evaluate the vulnerabilities in two contrasting computer systems. The evaluation will be detailed, well balanced and comprehensive, and will cover the full range of internal and external threats and suitable protection measures. Learners' evaluation will consider protection measures that are likely to be effective and those that are not, explaining why each measure would or would not be effective, or what factors might reduce its effectiveness. For example, choices made in the selection of a password policy will dictate the effectiveness of the policy. Learners will also cover the impact of the loss and the legal requirements that apply.

Overall, the evidence, such as a report, will be easy to read and understand by a third party who may or may not be an engineer. It will be logically structured and use correct technical engineering terms.

For merit standard (M1, M2), learners will assess the threats, the likely impact of the threat and legal requirements for contrasting engineering computer systems and will assess how they interrelate. For example, an engineering organisation is required by data protection legislation to keep sensitive information, such as customer bank details, secure, thereby assuring customers that any malware threat to obtain sensitive information would be unsuccessful.

Learners will justify how the physical, software, hardware and policy measures would protect vulnerabilities in contrasting engineering computer systems, which would prevent loss. For example, anti-malware software can protect against malware threats either by scanning incoming files and blocking threats it identifies or by scanning existing files in a computer system, identifying any suspicious files for deletion, thereby preventing loss.

Overall, the evidence must be technically accurate and demonstrate good-quality written communication.

For pass standard (P1, P2, P3, P4), learners will provide evidence that describes what security threats commonly apply to contrasting engineering computer systems and they will cover at least three internal and external threats to each system. They will also describe the impact of the threat should it succeed, for example employee theft of sensitive information – for example, designs for a new product or changes to equipment parameters leading to productivity or system failure could result in financial loss to the organisation from lost revenue and compensation to and reputational loss with customers.

Learner evidence will explain the legal responsibilities covering contrasting engineering computer systems, and they will cover at least one requirement from all five of the pieces of legislation and regulations. For example, data protection legislation and amendments place a requirement on organisations to keep data about customers secure and stored for no longer than is necessary for the purpose for which it was provided.

Learners will explain the possible vulnerabilities in contrasting engineering computer systems. For example, insufficient file permissions control could be exploited to obtain information by employees working in an organisation, which may result in financial fraud or disruption to an engineering process, which may affect productivity or cause loss.

Learners will also explain the physical, software, hardware and policy measures that are available to protect contrasting engineering computer systems from threats. For example, an employee policy that outlines access rights and information availability would help to prevent fraud.

Overall, the evidence will be logically structured. It may be basic in parts, for example the requirements of the regulations may not be fully explained or may contain minor technical inaccuracies relating to terminology. For example, the difference between ‘rootkits’ and ‘worms’ may not be clear.

Learning outcomes 3 and 4

For distinction standard (D2), learners will optimise the effectiveness of the plan and of the protected engineering computer system safely. For example, they might adjust virus-scanning schedules to avoid scanning the system when it is heavily used. The testing will demonstrate that the system is protected and that users are not unduly hindered by the measures. For example, if specific access controls are applied for certain users, they would need to show how effective the measure is in terms of granting access to the right users and preventing access to others.

Other examples include setting scheduled virus scans at appropriate times, and password policies to balance protection of the engineering system with the convenience of the remote monitoring and control. If the measures implemented are ineffective then learners must also mention what they would do differently next time.

Overall, the evidence will be logically structured, technically accurate and easy to understand by a third party who may or may not be an engineer.

For merit standard (M3, M4), learners will provide a detailed plan to protect an engineering computer system that covers all the severe risks and they will include a suitable test plan. The plan will also provide a clear, reasoned justification of the recommendations made to protect the system. This must include technical reasons why particular protection methods and configurations were selected and others were rejected. For example, learners might justify the Wi-Fi configuration choices they have made.

Learners will implement and configure a coherent set of computer-security measures safely as outlined in the plan. As demonstrated by the test results, the measures will protect the system from the severe risks. For example, learners should set firewall settings to allow legitimate programs to operate and place user accounts in groups that provide appropriate levels of access and restriction and balance protection of the engineering system with the convenience of remote monitoring and control.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard (P5, P6, P7), learners will produce a plan to protect an engineering computer system from a range of possible threats. The plan may not identify all the severe risks and some of the protection measures may be unsuitable to fully protect the system. For example, learners may omit to mention how a firewall can be effectively configured to prevent unauthorised access to the system. The evidence will also include a test plan.

Learners will undertake security measures safely to protect the engineering computer system from threats by implementing the plan. For example, they will install and configure anti-malware software to protect a network computer system. The system may be a mock-up or virtualised version of a real networked engineering system.

Learners will test that the computer system is protected by the measures implemented and configured safely. For example, they will test that shared folder permissions are set correctly and work as intended.

Overall, the evidence will be logically structured, although it may be basic in parts, for example supporting evidence may lack detail and it may unnecessarily hinder the operation of users. File or folder permissions may unnecessarily restrict users' ability to save or update files.

Unit 33: Data Analytics/Big Data

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

Learners will explore how engineering organisations use data and models to make decisions, develop products and improve performance.

Engineering organisations collect vast amounts of data from a wide range of sources about their operations, products and customers, and much of this data is unplanned and/or unstructured. The resulting datasets can be so large that they are now known as big data. For example, airlines and aircraft/engine manufacturers use sensors that can capture data during flights, which enables them to predict issues and optimise the operation and maintenance of aircraft, while sensors linked to production machines can be used for real-time management of engineering processes. Big Data and data analytics are also used to improve engineering systems and products, such as using telematic information from vehicles to allow congestion to be avoided and allowing real-time data to be available on smartphones and similar devices.

Learners will investigate how and why engineering organisations collect data and the methods they use to store and analyse it. They will explore a range of methods to present data for different audiences and purposes, and statistical methods used to analyse data. They will use software to analyse a dataset to provide information that could be used, for example, to identify potential causes of failure for an engineering system or product.

The analytical and problem-solving skills and knowledge that learners develop in this unit will prepare them for entry to higher education or higher-level engineering roles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the role of Big Data and data analytics to improve performance, for benchmarking and/or to trigger innovation in engineering organisations

2 Know about the statistical software tools and techniques used to analyse data in engineering organisations

3 Be able to carry out analysis of statistical data to meet the needs of an engineering organisation.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Explain why engineering organisations use data analytics and Big Data, including the benefits and challenges that they may bring	**M1** Assess how an engineering organisation can use data analytics and Big Data to improve performance, benchmark and/or innovate	**D1** Evaluate how an engineering organisation can use data analytics and Big Data to improve performance, benchmark and/or innovate
P2 Explain how an engineering organisation can use data analytics to improve performance, benchmark and/or innovate		
P3 Solve problems for a given engineering dataset involving routine central tendency, dispersion and probability distribution operations, using appropriate software	**M2** Solve problems accurately for a given engineering dataset involving routine and non-routine central tendency, dispersion and probability distribution operations, using appropriate software	**D2** Evaluate the correct synthesis, and accurate application of, routine and non-routine statistical and probability operations, using calculations and appropriate software to solve problems for a given engineering dataset
P4 Solve problems for a given engineering dataset involving routine linear regression operations, using appropriate software	**M3** Solve problems accurately for a given engineering dataset involving routine and non-routine regression operations, using appropriate software	

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Prepare an appropriate raw dataset to meet the needs of an engineering organisation	**M4** Prepare effectively an appropriate raw dataset to meet the needs of an engineering organisation	**D3** Present concise, valid and relevant conclusions and recommendations from an accurate evaluation of the effectively cleansed and formatted dataset that are fit for different audiences and purpose to meet the needs of an engineering organisation.
P6 Analyse, using appropriate software, the dataset by applying routine statistical, probability and mathematical operations	**M5** Analyse accurately, using appropriate software, the dataset by applying routine and non-routine statistical, probability and mathematical operations	
P7 Present conclusions from the analysis of a dataset to meet the needs of an engineering organisation.	**M6** Present concise and valid conclusions and recommendations from the accurate analysis of the dataset that are fit for different audiences and purpose to meet the needs of an engineering organisation.	

Unit content

What needs to be learned
Learning outcome 1: Understand the role of Big Data and data analytics to improve performance, for benchmarking and/or to trigger innovation in engineering organisations
Organisation information: • The tools and systems that play a key role in the decision-making process in an engineering organisation. The reasons why engineering organisations analyse data, including: o strategy planning and implementation, e.g., to identify market trends, to identify technological advances and developments, to inform production planning, to allow for more accurate preventative maintenance, to understand the behaviour of products/systems over time o improving departmental productivity, e.g., research and development, design, manufacture, supply chain management, production planning, maintenance, quality assurance and control o product and/or service benchmarking, development and triggering innovation, e.g., to increase output, to gain a competitive edge, to develop new or improved products and/or services, to improve product/service quality, to produce more accurate simulations of products/systems in use. • General challenges of analysing data, including: o high costs of design and implementation to gather, store and analyse the data o staff skills and training needs o data security compliance and maintenance. • Legislative, ethical and security issues, including: o current and relevant legislative issues, including the data protection legislation or other international equivalents o ethical issues, including individual and organisational rights and responsibilities, e.g., guaranteeing individual anonymity while maintaining the quality of data, access to personal and sensitive data o security of commercial and personal data, e.g., accidental or malicious loss, damage or corruption of data, password policy, data encryption, and maintenance of IT systems.

Data analytics infrastructure and types and storage of data:

- Types of data, including:
  - qualitative data: descriptive information, not a number (NaN) data
  - quantitative data: numerical information
  - internal data: data created by the functions of an engineering organisation, e.g., sales, production, maintenance, customer service department and/or embedded electronic devices, e.g., sensors and actuators (via the Internet of Things [IoT])
  - external data: data that originates from outside the organisation, e.g., data from suppliers, data from embedded sensors/RFID tags, data from end customers, data collected during use of products, maintenance records, warranty and rectification records, data from on-board diagnostics in vehicles.
- Storing data, including:
  - structured data: data in a fixed field in a record or file, e.g., data contained in relational databases and spreadsheets
  - unstructured data: data not in a relational database, e.g., text and/or email messages, photographs, graphs/charts, web pages, data captured by sensors on IoT
  - system-based factors, including:
    - volume: the quantity of data that is generated
    - velocity: the speed of generation of data
    - variety: the mixture of data to be processed
    - variability: inconsistencies in data
    - veracity: the quality and cleanliness of the data
  - security of data, e.g., password protection, data encryption, secure processes, and sufficient maintenance of IT systems
  - data warehouse, including:
    - holds very detailed information on multiple subject areas
    - works to integrate data from multiple sources
    - transforms data into meaningful and useful information
  - data mart, including:
    - often holds only summarised data on one subject area, e.g. machining, fuel consumption or capacity
    - concentrates on integrating information from a given subject area or a set of source systems

What needs to be learned
– stand-alone data mart focuses on one subject area and it is not designed in a whole organisational context, e.g. manufacturing have their data mart, research and development have theirs and so on – conformed data mart: facts and measures are categorised and described in the same way across multiple data marts, ensuring consistent reporting across an engineering organisation. • Accessing data, including: o sharing data across an engineering organisation o ensuring that the right people have readily available access to: – data – analytical software, e.g., spreadsheet, database, commercial statistical application, e.g. JMP®, Python – data-management processes. *Analysing Big Data:* • Specific challenges analysing Big Data (large datasets) to aid engineering organisations in making future decisions, including: o the need for high-level skills in using specialised software tools, e.g., JMP, Python and applications for predictive analytics, data mining, text mining, forecasting and data optimisation to analyse large amounts of data o online analytical processing (OLAP) technology to analyse multidimensional data quickly (manage volume, velocity, compatibility of datasets, accessing all data), e.g., to complete complex calculations, carry out 'what if' scenarios, produce reports in different formats o ensuring that data is valid, accurate, current, relevant, sufficient. *Types of data analytics:* • Four stages (or levels) of data analytics: o descriptive analytics (or data mining) analyses data to uncover patterns. It can use data in real time to give a current picture, e.g., using real-time data from sensors in aircraft engines to monitor performance o diagnostic analytics uses techniques, including data mining, to identify the reasons for past success and failure o predictive analytics uses data mining and statistical modelling to analyse past and current data to identify potential challenges and opportunities for an organisation to make forecasts

What needs to be learned
◦ prescriptive analytics uses data mining, statistical modelling and forecasts to identify actions to be taken to improve performance.
Learning outcome 2: Know about the statistical software tools and techniques used to analyse data in engineering organisations
Statistical techniques: • Routine operations, including: ◦ discrete data, continuous data, ungrouped data, grouped data ◦ presentation of data: bar charts, pie charts, histograms, spectra diagrams ◦ use of spreadsheet and industry-standard software to present data in appropriate formats for audience and purpose ◦ measures of central tendency: arithmetic mean, median, mode. • Non-routine operations, including: ◦ measures of dispersion: variance, standard deviation, range, interquartile and inter-percentile ranges ◦ use of spreadsheet and industry-standard software to calculate measures of dispersion. *Probability distributions:* • Routine operations, including: ◦ normal distribution: shape, symmetry, mean. • Non-routine operations, including: ◦ areas under the normal distribution curve relating to integer values of standard deviation ◦ use of industry-standard software, including spreadsheets and specialist software, e.g., JMP, Python and MATLAB®, to determine if data represents a normal distribution ◦ comparison of the mean of two samples using software to carry out a t-test. *Mathematical modelling of data to find a goodness of fit:* • Linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ graphically. • Use of spreadsheet and industry-standard software to calculate an equation of the line of regression and the correlation coefficient. • Use of spreadsheet and industry-standard software to identify the most appropriate type of regression line for a non-linear relationship.

What needs to be learned
Learning outcome 3: Be able to carry out analysis of statistical data to meet the needs of an engineering organisation

Selecting data for analysis:

- Selection of a suitable dataset to produce information to support an organisational decision. The process will involve:
  - identifying the objectives of the analysis and framing a clear, specific, well-defined question to identify what you want to know
  - defining the system requirements
  - defining other factors to be considered, e.g., constraints, access, security issues, e.g. data protection and reliability
  - identifying valid, accurate, current, relevant and sufficient Big Data
  - use of data and data analytics to complete a cause–effects model.

Evaluating a dataset and presenting the outcomes:

- Use of appropriate software techniques to analyse datasets for a defined audience or purpose, including:
  - preparation of the data for analysis, where data should be:
    - 'clean' – the data is consistent, accurate and complete
    - 'formatted' – the data is in a standard format that most commercial software is capable of interpreting, and suitable for data interchange and transformation
    - use of industry-standard software to analyse the data to produce appropriate reports for different audiences and purposes
  - the need for the outcomes of the analysis to be:
    - valid: conclusions and recommendations correctly drawn from the analysis of the dataset
    - accurate: values are exact and correct
    - relevant: conclusions and recommendations address the initial question(s)
  - presentation of the outcomes from the dataset analysis in an appropriate format for the audience and purpose, including:
    - the ability to convey intended meaning, e.g., written and verbal
    - graphical and numerical data
    - recording documentation, reports, visual aids for presentation use; verbal communication requirements (one-to-one and group informal and formal situations)

What needs to be learned
– use of tone and language for verbal and written communications to convey intended meaning and make a positive and constructive impact on audience, e.g., positive and engaging tone, technical/vocational language suitable for intended audience, and avoidance of jargon – responding constructively to the contributions of others, e.g., supportive, managing.

Essential information for tutors and assessors

Essential resources

For this unit, centres need to provide learners with access to:

- a wide range of research resources, largely text and internet based. There are many free-to-use large datasets available
- at least two different pre-selected datasets (one for learning outcome 1, the other for learning outcome 2)
- industry-standard software, such as spreadsheets and specialist software, e.g., JMP, MATLAB®, and access to sufficient secure storage space to complete the analysis.

Textbooks

Bird J – *Bird's Basic Engineering Mathematics*, 8th edition (Routledge, 2021) ISBN 9780367643676

Crickard P – *Data Engineering with Python* (Packt, 2020) ISBN 9781839214189

Marr B – *Big Data in Practice* (Wiley, 2016) ISBN 9781119231387

Websites

www.ibm.com/downloads/cas/ONBGKB82	How Big Data is used in manufacturing
www.jmp.com	Website for JMP data analysis software – trial downloadable version available
www.linkedin.com/pulse/big-data-analytics-tesla-inc-bipin-karki?articleId=6623446918821404672	Article about how Tesla uses Big Data
www.machinemetrics.com/blog/big-data-in-manufacturing	Use of Big Data in the manufacturing sector
www.rolls-royce.com/products-and-services/civil-aerospace/intelligentengine.aspx	Rolls-Royce – how the IoT and data are used for aircraft engines

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Evidence of achievement of the criteria can be collected from written reports and practical data analysis activities. Case studies might also be used to support assessment activities that allow learners to explore how Big Data and data analytics are used by engineering organisations to improve efficiencies or to innovate.

The pass grade specifies the minimum acceptable level required by learners. Assessment will need to cover all the learning outcomes but not necessarily all the topics included in the unit content. Achievement of a merit or a distinction grade will require evidence that demonstrates additional depth and/or breadth of knowledge and understanding.

This unit could be assessed through three assignments.

The first assignment should offer learners an opportunity to meet the assessment requirements of P1, P2, M1 and D1.

To achieve a pass, learners will explain why engineering organisations use Big Data and data analytics, including the benefits and challenges that they may bring, and they must cover ethical and legislative factors, access to and storage of data. They will identify alternative types of data and sources available to engineering organisations and how they may be used. Learner explanations will need to cover data analysis infrastructure challenges faced by engineering organisations that use and process data, including big data (P1). Learners will also define different types of data analytics, the type of information that may be generated by each type of data analytic and how engineering organisations may use that information. They will explain the benefits to engineering organisations that may arise from the collection, storage and analysis of data in terms of improving performance, benchmarking and/or innovation (P2).

Evidence for merit and distinction will build on that presented for pass. For merit, learners will also assess how engineering organisations use big data and data analytics, for example to improve processes or efficiency. They will assess how the alternative types of data listed in the unit content for learning outcome 1 are used by engineering organisations and the infrastructure choices based on the volume, variety and velocity of data (M1).

For distinction, learners will develop their assessment of the use of Big Data and data analytics by evaluating the types of data and sources available to engineering organisations and the infrastructure challenges associated with the use and processing of big data. They will make valid, accurate and relevant judgements on the usefulness of descriptive, diagnostic, predictive and prescriptive analytics and give examples of where each could be used in a real-world engineering application, for example to improve the efficiency of an aircraft engine (D1).

For the second assignment, covering P3, P4, M2, M3 and D2, learners will need to be given a dataset related to an engineering activity or process, for example mean time to failure data for a sample of components, measurements from an engine oil temperature sensor or data related to tolerances for a manufacturing operation. The dataset should include information for learners to be able to draw conclusions and identify potential problems with the process or product.

For pass, learners will solve problems for the given engineering dataset using routine central tendency, dispersion and probability distribution operations, using industry-standard software. They will tabulate data, present data graphically and calculate representative values for central tendency (mean, mode and median) (P3). They will also use software to solve problems for the given dataset involving routine linear regression operations and will use data to determine the equation of linear regression and the correlation coefficient (P4).

For merit, learners will accurately solve problems for the given engineering dataset using routine and non-routine operations. For example, they will tabulate grouped data and generate annotated charts. In addition to accurately calculating representative values for central tendency, they will calculate variance, standard deviation, range, interquartile and inter-percentile values of normally distributed data. Learners will carry out a t-test on two sets of given data and draw a simple conclusion from the result (M2). They will also accurately determine the equation of linear regression and correlation coefficient, predicting the value of the dependent variable for a non-measured value. Learners will compare the value with the corresponding value from the graph. They will select and use a suitable type of regression for a non-linear relationship, such as a power relationship. Each calculation will be supported by a brief explanation of the method used (M3).

For distinction, learners will complete all calculations with accuracy and evaluate the correct synthesis of results obtained by the accurate application of routine and non-routine statistical and probability operations, using industry-standard software to solve problems. They will evaluate the accuracy of the predicted value of the dependent variable with the value obtained from the graph for a non-measured value, in relation to the value of the correlation coefficient (D2).

For the third assignment, covering P5, P6, P7, M4, M5, M6 and D3, learners will need to be given a dataset related to an engineering process or service, but the data must be ‘as collected’ and not be sorted or classified in any way. The data should be provided electronically and must include at least 500 records.

For pass, learners will need to prepare the large dataset by cleaning and formatting it, for example by removing some unwanted data and formatting some of the units, such as voltage or current values (P5). They will use industry-standard software to analyse the supplied dataset by applying routine statistical, probability and mathematical operations. For example, they will present data, calculate central measures (mean, mode and median) and calculate the line of best fit of a linear relationship (P6). Learners will then present straightforward conclusions from the analysis of the dataset that are fit for audience and purpose to meet the needs of an engineering organisation. They will state the purpose of the analysis and the intended audience (P7).

For merit, learners will develop their work for pass, for example by removing most of the unwanted data and formatting the units for the dataset (M4). They will apply routine and non-routine statistical, probability and mathematical operations accurately (M5) in order to arrive at conclusions and recommendations from the accurate analysis of the dataset that are appropriate for the intended audience and an engineering organisation (M6).

For distinction, learners will evaluate the outcomes and produce accurate, valid and relevant judgements from the analysis of the effectively cleansed and formatted dataset. The analysis must include appropriate and accurate presentation of data, calculations of central measures, dispersion and probability functions, comparison of datasets and regression. Overall, the evidence will be easily understood by a third party with a mathematical background. There will be correct use of mathematical terminology and application of relevant units (D3).

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	The Role of Big Data in Engineering	You are an apprentice engineer and your manager has asked you to produce a report about how using Big Data and data analytics could benefit your engineering organisation, as well as some of the challenges it brings.	A written report that covers the role of Big Data and data analytics in engineering organisations, with clear referencing to the use of data for performance improvements, benchmarking and/or innovation.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2, M3, D2	Data Analysis	You are an apprentice engineer and your manager has given you an engineering dataset to study. Your manager wants you to use the dataset to draw conclusions and solve problems.	A report that analyses a given engineering dataset and includes supporting calculations, charts and tables, engineering sketches and diagrams.
P5, P6, P7, M4, M5, M6, D3	Using Data Analytics to Meet the Needs of an Engineering Organisation	You are an apprentice engineer and your manager has asked you to report on your findings from an investigation into faults in a piece of engineering equipment or an engineering process, based on a large, collected dataset.	A report that includes the interpretation and presentation of data in order to provide conclusions/ recommendations for an engineering organisation.

Unit 34: Autonomous Systems

Level:	3
Unit type:	Optional
Guided learning hours:	60

Unit introduction

This unit aims to give learners an understanding of the increasing role autonomous systems play in advanced manufacturing, how the software and hardware are integrated in autonomous systems, and the skills needed to build and test an autonomous system.

Autonomous systems can adapt by making decisions based on the information gathered about their environment, removing the need for human intervention. In a manufacturing context, an autonomous system may control a particular aspect of the production process or even the whole supply chain. Autonomous systems have the capability to work collaboratively with machines, humans or other autonomous systems using Artificial Intelligence (AI) and machine learning, which can significantly advance manufacturing capabilities.

Learners will develop an understanding of the benefits and limitations of these types of system and how software and hardware can be utilised to design and realise autonomous system solutions that meet advanced manufacturing requirements.

Learners will build and test an autonomous bot, which is a type of autonomous system, and will develop some skills in microcontroller programming, hardware assembly and problem solving.

The unit encompasses both theoretical teaching and practical work. It aims to enhance learner awareness of the general concepts and principles associated with the use of autonomous systems in advanced manufacturing.

Note that the use of ‘e.g.’ in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an ‘e.g.’ needs to be taught or assessed.

Learning outcomes and assessment criteria

To pass this unit, learners need to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria determine the standard required to achieve the unit.

On completion of this unit a learner should:

1 Understand the concept, applications, benefits and limitations of autonomous systems used in advanced manufacturing

2 Understand the integration of software and hardware to design and realise autonomous system solutions to meet advanced manufacturing requirements

3 Be able to develop an autonomous bot for an advanced manufacturing application.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	**To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:**	**To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:**
P1 Describe two applications of autonomous systems in advanced manufacturing	**M1** Explain how an autonomous system can be used to enhance the efficiency and productivity of a given advanced manufacturing application	**D1** Analyse how autonomous systems are effectively utilised in two given advanced manufacturing applications
P2 Describe the benefits and limitations of using autonomous systems in advanced manufacturing		
P3 Describe how software and hardware are used in an autonomous system for an advanced manufacturing application	**M2** Explain how an autonomous system for an advanced manufacturing application can be improved using AI and machine learning	**D2** Analyse how model-based and data-driven approaches can be combined to enhance the functionality and performance of an autonomous system for a given advanced manufacturing application
P4 Design an adequate high-level control program for an autonomous bot in an advance manufacturing application	**M3** Develop an autonomous bot safely for an advanced manufacturing application that functions as intended.	**D3** Optimise the performance and/or efficiency of an autonomous bot for an advanced manufacturing application
P5 Build and program a partially functioning autonomous bot safely for an advanced manufacturing application, using a microcontroller and at least two input devices, and one output device		

To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Test a partially functioning autonomous bot safely for an advanced manufacturing application, recording the outcomes of the tests		

Unit content

What needs to be learned
Learning outcome 1: Understand the concept, applications, benefits and limitations of autonomous systems used in advanced manufacturing
• Concept: systems and machines that are capable of performing a series of operations where the sequence is determined by the outcome of the previous operation or by reference to external circumstances that are monitored and measured within the system itself; systems and machines that can adapt to changes by making decisions based on the information gathered about their environment, which removes the need for human intervention, e.g. building blocks of autonomous systems, gathering information from sensors, analysing that information to plan an action, executing an action to achieve a goal; autonomous bots, humanoids and drones. • Applications: understanding the applications of autonomous systems to meet Industry 4.0 expectations and for advanced manufacturing, e.g., ability to compensate for system failures, self-regulation in uncertain situations, condition monitoring, gripping, picking and packing bots, dealing with obstacles, materials, parts or product recognition, transportation of parts and products to and from the assembly line. • Benefits of autonomous systems: the improvements that autonomous systems offer for advanced manufacturing, e.g. enhancing efficiency, effectiveness, agility, productivity, repeatability, reproducibility, flexibility, ability to compensate for ageing workforce, minimising waste, ability to augment capabilities of human workforce, less human intervention needed, augmenting collaborative working with both humans and other autonomous systems leading to advances in physical and intelligent capabilities, safety improvements by deploying autonomous systems for dangerous tasks. • Limitations of autonomous systems: the drawbacks of autonomous systems for advanced manufacturing, e.g. expensive, not accurately meeting the desired system requirements, malfunctions, costs of fault-finding and correction, highly skilled human maintenance may be required to ensure the smooth functioning of the system, building public acceptance, meeting health and safety regulations, costs of training, workforce morale, streamlining all aspects of production to be sustainable in order to please customers and avoid negative publicity, cybersecurity risks, compliance with standards.

What needs to be learned
Learning outcome 2: Understand the integration of software and hardware to design and realise autonomous system solutions to meet advanced manufacturing requirements
• Characteristics of a smart factory: definition and features of advanced manufacturing processes, e.g., connectivity, flexibility, scalability, agility, autonomy, efficiency, sensors and actuators, autonomous robots, Internet of Things (IoT) featuring artificial intelligence (AI), wireless communication protocols, cloud computing, 5G, 6G, HoloLens, augmented reality (AR), virtual reality (VR), mixed reality. • Software and hardware: integration of software and hardware for an autonomous system to learn, make decisions, adapt and autocorrect to improve flexibility and reconfigurability, combining sensors and control systems to enable sequences of operations, e.g. AI, machine learning, neural network, fuzzy logic, software (e.g. Raspberry Pi OS, Arduino software [IDE], MPLAB [IDE], GENIE Studio, Atmel studio, Tinkercad, Matlab/Simulink), microcontrollers (e.g. Raspberry Pi, Arduino, PIC, Beagle Board), PLCs, microprocessors, sensors and actuators, human-machine interface (HMI), block chain, data acquisition, data security. • Improvements to autonomous systems: methods that can be used to improve the functionality, performance and efficiency of autonomous systems, e.g. using AI and machine learning to train autonomous machines via repetitive tasks to eliminate the occurrence of faults, data collection and analysis and using deep learning-based algorithms for decision-making tasks. • Model-based and data-driven approaches: using the knowledge and understanding of data to develop accurate models that can help select the most suitable solution, e.g., using model predictive controllers, deep learning, reinforcement learning, neural networks, statistical analysis, pattern recognition, simulating uncertainties, integrating machine learning and mathematical programming for more efficient data-driven optimisation frameworks.

What needs to be learned
Learning outcome 3: Be able to develop an autonomous bot for an advanced manufacturing application
• Build an autonomous bot: build simple autonomous bot for useful advanced manufacturing applications using an educational kit, e.g. grip bot, picking and packing bots, materials, parts or products recognition bots, transportation bots for delivering parts and products to and from the assembly line. • Assembly of an autonomous bot: the assembly of hardware structures that make an autonomous bot from the available educational kit, e.g. protective/aesthetic shell, chassis/framework, axles, wheels; microcontrollers that can read from input devices (e.g. sensors) and control output devices (e.g. actuators, motors) and can store and process data (e.g. Raspberry Pi, Arduino, PIC, Atmel AT89C52, Beagle Board); input devices, e.g. light-dependent resistors, touch sensors, switches, accelerometers, infrared sensors, potentiometers, sound sensors, touch sensors, temperature sensors, position-sensing circuit, colour-sensing circuit, cameras, tilt sensors; output devices, e.g. LEDs and LED arrays, lights, motors (e.g. servo and stepper), actuators, audio/sound emitters (e.g. piezo speakers, buzzers, amplifiers), solenoids, relays (e.g. H-bridge integrated circuits (ICs) for motor control); power source, e.g. photovoltaic cells and batteries; data storage, e.g. solid-state storage device. • Software development: production of original code using a development environment and editing of a program and adapting library code snippets – suitable languages include flowchart, C (including derivatives) and basic, e.g. Raspberry Pi OS, Arduino software [IDE], MPLAB [IDE], GENIE Studio, Atmel Studio, Tinkercad, Matlab/ Simulink; programming construction techniques including: program flow and control, e.g. using program libraries, subroutines/functions, control structure (sequence, selection, iteration – if, else, switch, case, for, do, while, until, end), delays and timing; logic and arithmetic functions, e.g. variables, comparative operators (equal, not equal, less than, more than, less than or equal, more than or equal); Boolean operators (AND, OR, NOT); arithmetic operations (adding, subtracting, multiplication, division, increment, decrement, random); development and refinement of control programs using suitable programming language constructions and techniques; annotation of code to allow effective repair/debugging of the program and for maintainability. • Test, debug and analyse: testing an autonomous bot for functionality against the expected outcome, producing formal documentation of the test results, analysing test results to identify where faults can be corrected and where improvements can be made to the performance and efficiency of the autonomous bot to meet the original requirements, recording changes that improve the software program and/ or hardware.

Essential information for tutors and assessors

Essential resources

A visit to a factory that utilises autonomous systems would be a good way for learners to see how these systems work in practice and to gain insight.

Centres delivering this unit must be equipped with, or have access to, educational programmable bot kits or centres could alternatively develop, including testing, their own bot kit for each learner to assemble and use.

Learners are expected to build/assemble bots and undertake programming exercises to replicate advanced manufacturing applications.

Educational bot kits

www.uk.rs-online.com/web/c/raspberry-pi-arduino-development-tools/stem-education/stem-robot-kits	STEM educational robot kits
www.amazon.co.uk/Robot-Kit/s?k=Robot+Kit	Robot kits
www.nvidia.com/en-gb/autonomous-machines/embedded-systems/jetbot-ai-robot-kit/	AI robot kits from NVIDIA Jet Bot Partners
www.ti.com/tool/TIRSLK-EVM	TI-RSLK MAX low-cost robotics system learning kits

Textbooks

Blokdyk G – *Autonomous Systems, a Complete Guide* (5STARCooks, 2021) ISBN 9780655821601

Blum R – *Arduino Programming in 24 Hours – Sams Teach Yourself* (Sams, 2014) ISBN 9780672337123 A good, detailed guide to programming using the Arduino IDE.

Buckenham A, et al – *BTEC National Engineering Student Book: For the 2016 Specifications* (Pearson, 2017) ISBN 9781292141008

Ibrahim D – *PIC Microcontroller Projects in C: Basic to Advanced*, 2nd edition (Newnes Elsevier, 2014) ISBN 9780080999241 This book demonstrates how to develop a range of microcontroller applications using a project-based approach.

Mouloua M, Hancock P – *Human Performance in Automated and Autonomous Systems: Emerging Issues and Practical Perspectives* (CRC Press, 2019) ISBN 9781138312296

Sauceda S, Cruz J, Perez O – *Manufacturing 4.0: The Use of Emergent Technologies in Manufacturing* (Palibrio, 2018) ISBN 9781506526188

Siegesmund M – *Embedded C Programming: Techniques and Applications of C and PIC MCUS* (Newnes Elsevier, 2014) ISBN 9780128013144 A hands-on introductory course on concepts of C programming using a PIC® microcontroller and CCS Compiler.

Upton E J – *2 IN 1: Rasberry Pi Master Series: Beginner's Guide + Projects Workbook*, Rasberry Pi 4 Updated 2020 (independently published, 2019) ISBN 9781672837019

Van Dam B – *PIC Microcontrollers: 50 Projects for Beginners and Experts* (Elektor Electronics, 2008) ISBN 9780905705705 This book has a hands-on approach to projects and gives several useful examples for assessor and learner.

Wodecki A – *Artificial Intelligence in Management: Self-learning and Autonomous Systems as Key Drivers of Value* Creation (Edward Elgar Publishing Ltd, 2020) ISBN 9781839104947

Websites

www.global.hitachi-solutions.com/blog/industry-4-0-technologies-outcomes-and-the-future-of-manufacturing	Industry 4.0: technologies, outcomes, and the future of manufacturing
www.ottomotors.com/blog/5-industry-4-0-technologies	Five key Industry 4.0 technologies
www.new.siemens.com/us/en/company/press/siemens-stories/corporate-technology/ai-enhanced-robotics-and-the-future-of-manufacturing.html	Robotics and the future of manufacturing, Siemens
www.arduino.cc/en/Main/Software_	Site for learners to download Arduino IDE, access documents to conduct research
www.i-scoop.eu/industry-4-0/	Industry 4.0: the fourth industrial revolution
www.manufacturing.net/technology/blog/21207750/how-autonomous-manufacturing-will-step-beyond-industry-40	How autonomous manufacturing will step beyond Industry 4.0
www.microsoft.com/en-gb/ai/autonomous-systems	Autonomous systems – Microsoft AI
www.microsoft.com/en-gb/ai/autonomous-systems-solutions?activetab=pivot1%3aprimaryr5	Case studies: bringing autonomy to industrial control systems – Microsoft AI
www.microchip.com	Site for learners to download the free MPLAB® IDE and conduct research

www.nokia.com/networks/insights/autonomous-systems-their-place-in-our-future/	Autonomous systems: their place in our future
www.raspberrypi.org/software/	Site for learners to download Raspberry Pi OS (previously called Raspbian) and access books and magazines to conduct research
www.tinkercad.com/	Site for learners to design, build, test circuits, program and simulate microcontrollers

Videos

www.youtube.com/watch?v=S1QCZW92fU4	Tutorial to support using MPLAB® IDE
www.youtube.com/watch?v=PhJKhV5l-i4	Tutorial to support creating a project in MPLAB® IDE
www.youtu.be/BpJCAafw2qE	Raspberry Pi 4: getting started
www.youtube.com/watch?v=fJWR7dBuc18	Arduino Tutorial 1: Setting up and programming Arduino for absolute beginners

Assessment

This unit is internally assessed. To pass this unit, the evidence that learners present for assessment must demonstrate that they have met the required standard specified in the learning outcomes and assessment criteria.

The assessment for this unit should be set in a specific organisational context, it should draw on learning from the unit and be designed in a way that enables learners to meet all the assessment criteria.

A recommended assessment approach is given below. Centres are free to create their own assessment as long as they are confident it enables learners to provide suitable and sufficient evidence to meet the stated standard of the assessment criteria and achieve the learning outcomes.

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

The first assignment could cover P1, P2, M1 and D1 holistically.

To achieve P1, learners need to describe two applications of autonomous systems in advanced manufacturing, for example a gripping bot, a picking and packing bot, a transportation bot to and from an assembly line, or a material, part or product recognition bot. Learners may choose any two applications of autonomous systems and the response must be explicitly linked to a specific purpose in advanced manufacturing.

For P2, learners must describe in detail the benefits and limitations of using autonomous systems in advanced manufacturing. Learners should use their examples of applications from P1 to contextualise their response. Learners could refer to the improvements that autonomous systems provide for advanced manufacturing, such as improved efficiency, productivity, flexibility, agility and functionality. At least four benefits should be described. For the limitations, learners may cover the high initial costs, fault-finding and self-correction issues/costs, possibilities of malfunctions, the impact they have on workforce morale, cybersecurity risks and enhanced maintenance requirements. At least four limitations should be described. Learners should also cover the possible implications of each of the limitations during advanced manufacturing. When describing both the benefits and limitations, learners must also refer to the environment in which the autonomous systems operate, and the capital required to maintain effective operation.

For M1, learners need to give a detailed explanation of how an autonomous system can be used to enhance the efficiency and productivity of an advanced manufacturing application. This explanation should be based on a given application and an industry-specific case study given to the learner, around which the learner should contextualise their response.

The explanation must demonstrate a good understanding of why, in a global market environment, a manufacturing company can maximise the quality and efficiency of its systems and processes by incorporating an autonomous system into its production processes.

Learners must provide detail related to the specific effects on efficiency (in terms of time, money and resources) and productivity (both of the human workforce and the production process in general).

For D1, learners are expected to provide a detailed analysis of how autonomous systems are effectively utilised in two given advanced manufacturing applications. This analysis should be based on given applications and industry-specific case studies given to the learner, around which the learner should contextualise their response. One of the two given applications can be the same as the given application for M1. Learners should refer to aspects like greater productivity, efficiency, agility, scalability and accuracy for each given advanced manufacturing application, but they must also refer to other more technical aspects, such as the ability to compensate for system failures, self-regulation and condition monitoring. The learner's response must clearly show how the autonomous system is utilised to make each specific advanced manufacturing application more effective.

A second assignment could cover P3, M2 and D2 holistically.

To achieve P3, learners must describe how software and hardware are used in an autonomous system for an advanced manufacturing application. The application could be a gripping bot, a picking and packing bot, a transportation bot to and from an assembly line, or a material, part or product recognition bot. Learners need to give a detailed step-by-step description of how elements of software and hardware are combined in the autonomous system. For example, they might describe how the software and hardware are integrated to enable an autonomous system to learn, make decisions, adapt and autocorrect to improve flexibility and reconfigurability, and how control systems are linked to sensors to enable sequences of operations.

For M2, learners need to explain how an autonomous system for an advanced manufacturing application can be improved using artificial intelligence (AI) and machine learning. Learners could give examples of how AI can be utilised to help machines respond better to unprecedented changes in the environment and to monitor conditions themselves, meaning there is even less need for human intervention. They could give examples of how machine learning can be incorporated into autonomous systems to help machines adapt, monitor parameters and make appropriate corrections to meet the manufacturing system/process functional requirements so that the set goal is achieved.

To achieve D2, learners must give a detailed analysis of how model-based and data-driven approaches can be combined to enhance the functionality and performance of an autonomous system for a given advanced manufacturing application. This analysis should be based on a given application and an industry-specific case study given to the learner, around which the learner should contextualise their response.

Learners could refer to the use of model predictive controllers, deep learning, reinforcement learning, neural networks, statistical analysis, pattern recognition, simulating uncertainties and integrating machine learning and mathematical programming. Learners also need to cover why a combination of model-based and data-driven approaches is more effective for enhancing the functionality and improving the performance of the autonomous system instead of just one approach.

A third assignment could cover P4, P5, P6, M3 and D3 holistically.

The specification and minimum functionality of the autonomous bot must be defined for learners so that they are able to test whether it meets requirements set. Learners should assemble the autonomous bot from the educational kit available at the centre. Note that learners must not use 'visual block and text' programming languages, such as Scratch and Picaxe Blockly, to program the bot.

To achieve P4, learners will design an adequate control program for the bot, by using a flow chart and/or pseudocode. An adequate design will show the key areas of functionality (inputs, outputs and processes) and how they link together with some commentary. The design of the control program may have some elements of functionality omitted and may be at a high level.

To achieve P5, learners are expected to build and program an autonomous bot safely for an advanced manufacturing application using a microcontroller and at least two input devices and one output device. As a minimum the bot will partially function, for example a bot may not always avoid obstacles, or it may not transport products in an assembly line as it should do. The annotation of the control program may also be inconsistent and patchy. Overall, the assembled autonomous bot will function but may have some errors that affect the way it operates, or some elements of required functionality may have been omitted.

To achieve P6, learners should test their autonomous bot for an advanced manufacturing application safely, recording the outcomes of the tests. Learners must highlight where there are any faults or where the bot only partially functions given the requirements of the specification. They must also cover how the errors could be resolved.

For M3, learners will develop, by designing an appropriate control program, building and programming appropriately an autonomous bot safely for an advanced manufacturing application. The bot will function as intended, as throughout the development process the learner will correct software and hardware faults identified during the testing. Learners will also compare the functionality of their autonomous bot against the specification and update it accordingly. They will annotate the code appropriately to explain how the program works. The updated autonomous bot will be appropriately detailed and should work well, with only minor errors present, meaning that when the autonomous bot operates it functions as intended.

The achievement of D3 links to M3. For D3, learners will optimise the performance and/or efficiency of the autonomous bot for an advanced manufacturing application. For example, learners could implement at least one hardware change and one software change that would improve the efficiency and performance of the autonomous bot overall. This could involve learners using a more sensitive input device, or by changing the program codes to increase the velocity of the bot.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Applications of Autonomous Systems for Advanced Manufacturing	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the benefits and limitations of autonomous systems, with examples of how they could be effectively utilised in advanced manufacturing applications. They want you to do this because they are aware that a range of improvements could be implemented to the current manufacturing systems and processes.	A written report.

Criteria covered	Assignment title	Scenario	Assessment method
P3, M2, D2	Software and Hardware for Autonomous Systems	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to write a report for your managers covering the use of software and hardware for autonomous systems, with specific reference to AI, machine learning and model-based and data-driven approaches. They want you to do this in order to help to identify improvements that can be made to ensure that the autonomous systems used in their advanced manufacturing applications meet their requirements.	A written report
P4, P5, P6 M3, D3	Develop an Autonomous Bot to Solve a Problem for an Advanced Manufacturing Application	You are an apprentice for a manufacturing engineering company and your supervisor has asked you to build, program and test a prototype autonomous bot. They want you to do this because they are aware that autonomous systems, such as bots, have the potential to improve efficiency and productivity, and to increase profitability, and they want examples that can be shown to more senior staff.	A written report/ portfolio based on practical activities, including evidence of the control program code, annotated photographs/video of the functioning autonomous bot, test results, updated documentation and photographs/ video showing optimisation and changes and observation records.

10 Appeals

Centres must have a policy for dealing with appeals from learners. Appeals may relate to assessment decisions being incorrect or assessment not being conducted fairly. The first step in such a policy is a consideration of the evidence by a Lead Internal Verifier or other member of the programme team. The assessment plan should allow time for potential appeals after learners have been given assessment decisions.

Centres must document all learners' appeals and their resolutions. Further information on the appeals process can be found in the document *Internal assessment in vocational qualifications: Reviews and appeals policy*, available on our website.

11 Malpractice

Dealing with malpractice in assessment

Malpractice refers to acts that undermine the integrity and validity of assessment, the certification of qualifications and/or may damage the authority of those responsible for delivering the assessment and certification.

Pearson does not tolerate actual or attempted actions of malpractice by learners, centre staff or centres in connection with Pearson qualifications. Pearson may impose penalties and/or sanctions on learners, centre staff or centres where malpractice or attempted malpractice has been proven.

Malpractice may occur or be suspected in relation to any unit or type of assessment within a qualification. For further details on malpractice and advice on preventing malpractice by learners, please see Pearson's *Centre Guidance: Dealing with Malpractice* available on our website.

Centres are required to take steps to prevent malpractice and to investigate instances of suspected malpractice. Learners must be given information that explains what malpractice is for internal assessment and how suspected incidents will be dealt with by the centre. The *Centre Guidance: Dealing with Malpractice* document gives full information on the actions we expect you to take.

Pearson may conduct investigations if we believe a centre is failing to conduct internal assessment according to our policies. The above document gives further information and examples. It details the penalties and sanctions that may be imposed.

In the interests of learners and centre staff, centres need to respond effectively and openly to all requests relating to an investigation into an incident of suspected malpractice.

Learner malpractice

The head of centre is required to report incidents of suspected learner malpractice that occur during Pearson qualifications. We ask centres to complete *JCQ Form M1* (www.jcq.org.uk/malpractice) and email it with any accompanying documents (signed statements from the learner, invigilator, copies of evidence, etc) to the Investigations Processing team at candidatemalpractice@pearson.com. The responsibility for determining appropriate sanctions or penalties to be imposed on learners lies with Pearson.

Learners must be informed at the earliest opportunity of the specific allegation and the centre's malpractice policy, including the right of appeal. Learners found guilty of malpractice may be disqualified from the qualification for which they have been entered with Pearson.

Failure to report malpractice constitutes staff or centre malpractice.

Teacher/centre malpractice

The head of centre is required to inform Pearson's Investigations team of any incident of suspected malpractice (which includes maladministration) by centre staff before any investigation is undertaken. The head of centre is requested to inform the Investigations team by submitting a *JCQ M2* Form (downloadable from www.jcq.org.uk/malpractice) with supporting documentation to pqsmalpractice@pearson.com. Where Pearson receives allegations of malpractice from other sources (for example Pearson staff, anonymous informants), the Investigations team will conduct the investigation directly or may ask the head of centre to assist.

Pearson reserves the right in cases of suspected malpractice to withhold the issuing of results/certificates while an investigation is in progress. Depending on the outcome of the investigation, results and/or certificates may not be released or they may be withheld.

You should be aware that Pearson may need to suspend certification when undertaking investigations, audits and quality assurances processes. You will be notified within a reasonable period of time if this occurs.

Sanctions and appeals

Where malpractice is proven, we may impose sanctions or penalties, such as:

- mark reduction for affected external assessments
- disqualification from the qualification
- debarment from registration for Pearson qualifications for a period of time.

If we are concerned about your centre's quality procedures we may impose sanctions such as:

- working with centres to create an improvement action plan
- requiring staff members to receive further training
- placing temporary suspensions on certification of learners
- placing temporary suspensions on registration of learners
- debarring staff members or the centre from delivering Pearson qualifications
- suspending or withdrawing centre approval status.

The centre will be notified if any of these apply.

Pearson has established procedures for considering appeals against penalties and sanctions arising from malpractice. Appeals against a decision made by Pearson will normally be accepted only from the head of centre (on behalf of learners and/or members or staff) and from individual members (in respect of a decision taken against them personally). Further information on appeals can be found in the *JCQ Appeals booklet* (www.jcq.org.uk/exams-office/appeals).

12 Understanding the qualification grade

This section explains the rules that we apply in providing an overall qualification grade for each learner. It shows how all the qualifications in this sector are graded. The final grade awarded for a qualification represents a holistic performance across all of the qualification. As the qualification grade is an aggregate of the total performance, there is some element of compensation in that a higher performance in some units will be balanced by a lower outcome in others.

In the event that a learner achieves more than the required number of optional units, the mandatory units along with the optional units with the highest grades will be used to calculate the overall result, subject to the eligibility requirements for that particular qualification title.

Awarding and reporting for the qualification

The awarding and certification of these qualifications will comply with the requirements of the Office of Qualifications and Examinations Regulation (Ofqual).

Eligibility for an award

To achieve any qualification grade learners must:

- achieve a Pass grade or higher in all units, and
- achieve the minimum number of points at a grade threshold.

It is the responsibility of the centre to ensure that a correct unit combination is adhered to.

Calculation of the qualification grade

The qualification grade is an aggregation of a learner's unit level performance. The calculations are divided into two parts based on the competency or knowledge-based units. Grade ranges are shown below:

Unit	Available grade range
Unit 1 (Competency)	P
Units 2-34 (Knowledge)	P to D

The *Calculation of Qualification Grade* table, shown further on in this section, shows the minimum thresholds for calculating these grades.

Learners who do not meet the minimum requirements for a qualification grade to be awarded will be recorded as Unclassified (U) and will not be certificated. They may receive a Notification of Performance for individual units. Our Information Manual (available on our website) gives more information.

Points available for internal units

The table below shows the number of points available for internal units. For each internal unit, points are allocated depending on the grade awarded.

	Unit size
	60 GLH
U	0
Pass	6
Merit	10
Distinction	16

Unit 1 has no points awarded to it, however must be passed as part of the overall assessment grade. All units must be passed to achieve a Pass or above.

Claiming the qualification grade

Subject to eligibility, Pearson will automatically calculate the qualification grade for your learners when the internal unit grades are submitted and the qualification claim is made. Learners will be awarded qualification grades for achieving the sufficient number of points within the ranges shown in the applicable *Calculation of Qualification Grade* table.

To allow for a weaker performance in some units to be balanced by a stronger performance in others, there is an element of compensation built into the grading model.

Points thresholds

Applicable for registration from December 2022.

Diploma	
720 GLH	
Grade	**Points threshold**
U	0
P	60
M	86
D	120

Examples of grade calculations

Example 1: Achievement of a Diploma with a Pass grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Int	Pass	NA
Unit 2	60	Int	Merit	10
Unit 3	60	Int	Pass	6
Unit 4	60	Int	Merit	10
Unit 5	60	Int	Pass	6
Unit A	60	Int	Pass	6
Unit B	60	Int	Pass	6
Unit C	60	Int	Pass	6
Unit D	60	Int	Pass	6
Unit E	60	Int	Merit	10
Unit F	60	Int	Pass	6
Totals	**720**		**P**	**72**

The learner has exceeded the 60-point Pass threshold and has passed all units.

Example 2: Achievement of a Diploma with a Distinction grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Int	Pass	NA
Unit 2	60	Int	Distinction	16
Unit 3	60	Int	Distinction	16
Unit 4	60	Int	Merit	10
Unit 5	60	Int	Distinction	16
Unit A	60	Int	Merit	10
Unit B	60	Int	Distinction	16
Unit C	60	Int	Pass	6
Unit D	60	Int	Merit	10
Unit E	60	Int	Pass	6
Unit F	60	Int	Distinction	16
Totals	**720**		**D**	**122**

The learner has exceeded the 120 threshold for Distinction and has passed all units.

Example 3: An Unclassified result for a Diploma

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Int	Fail	NA
Unit 2	60	Int	Distinction	16
Unit 3	60	Int	Distinction	16
Unit 4	60	Int	Merit	10
Unit 5	60	Int	Pass	6
Unit A	60	Int	Merit	10
Unit B	60	Int	Distinction	16
Unit C	60	Int	Pass	6
Unit D	60	Int	Merit	10
Unit E	60	Int	Pass	6
Unit F	60	Int	Distinction	16
Totals	**720**		**U**	**90**

The learner has sufficient points for Merit (112), but has not passed all units. Hence, the grade is U.

13 Further information and publications

- Edexcel, BTEC and Pearson Work Based Learning contact details: qualifications.pearson.com/en/contact-us.html.
- Books, software and online resources for UK schools and colleges: www.pearsonschoolsandfecolleges.co.uk.
- Our publications catalogue lists all the material available to support our qualifications. To access the catalogue and order publications, please visit our website.

All centres offering external assessments must comply with the Joint Council for Qualifications (JCQ) document *Instructions for conducting examinations.*

Further documents that support the information in this specification:

- *Access arrangements and reasonable adjustments* (JCQ)
- *A guide to the special consideration process* (JCQ)
- *Collaborative and consortium arrangements for the delivery of vocational qualifications policy* (Pearson)
- *UK information manual* (updated annually and available in hard copy) **or** *Entries and information manual* (available online) (Pearson)
- *Distance learning and assessment policy* (Pearson).

Publisher information

Any publisher can seek endorsement for their resources and, if they are successful, we will list their BTEC resources on our website.

14 Glossary

Part A – General terminology used in specification

Term	Description
Level	Units and qualifications have a level assigned to them. The level assigned is informed by the level descriptors defined by Ofqual, the qualifications regulator.
Guided Learning Hours (GLH)	This indicates the number of hours of activities that directly or immediately involve tutors and assessors in teaching, supervising, and invigilating learners, for example lectures, tutorials, online instruction and supervised study. Units may vary in size.
Total Qualification Time (TQT)	This indicates the total number of hours that a typical learner will take to complete the qualification. This is in terms of both guided learning hours but also unguided learning, for example private study, time spent in the workplace to master skills.
Learning outcomes	The learning outcomes of a unit set out what a learner knows, understands or is able to do as the result of a process of learning.
Assessment criteria	The assessment criteria specify the standard the learner is required to meet to achieve a learning outcome.
Unit content	This section sets out the required teaching content of the unit and specifies the knowledge, skills and understanding required for achievement of the unit. It enables centres to design and deliver a programme of learning that will enable learners to achieve each learning outcome and to meet the standard determined by the assessment criteria.
Valid assessment	The assessment assesses the skills or knowledge/understanding in the most sensible, direct way to measure what it is intended to measure.
Reliable assessment	The assessment is consistent and the agreed approach delivers the correct results on different days for the same learners and different cohorts of learners.

Part B – Terms used in knowledge and understanding criteria

Term	Description
Analyse	Examine methodically and in detail, typically in order to interpret.
Assess	Consideration of all factors or events that apply, to identify those which are the most important or relevant and make a judgement.
Compare	Identify the main factors relating to two or more items/situations, explaining the similarities and differences or advantages and disadvantages, and in some cases say which is best and why.
Describe	Give a clear account in their own words, including all the relevant information (e.g. qualities, characteristics or events, etc.). Description shows recall and in some cases application.
Detailed	Having additional facts or information beyond a simple response.
Evaluate	Bring together all information and review it to form a supported conclusion, drawing on evidence, including strengths, weaknesses, alternative actions, relevant data or information.
Explain	Provide details and give reasons and/or evidence to support an opinion, view or argument. **OR** Provide details and give relevant examples to clarify and extend a point. This would usually be in the context of learners showing their understanding of a technical concept or principle.
Identify	Shows the main features or purpose of something. Can recognise it and/or name characteristics or facts that relate to it.
Outline	Provide a summary or overview or brief description.
State	Express information in clear and precise terms.

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For information about Pearson qualifications, including Pearson Edexcel and BTEC qualifications visit qualifications.pearson.com

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