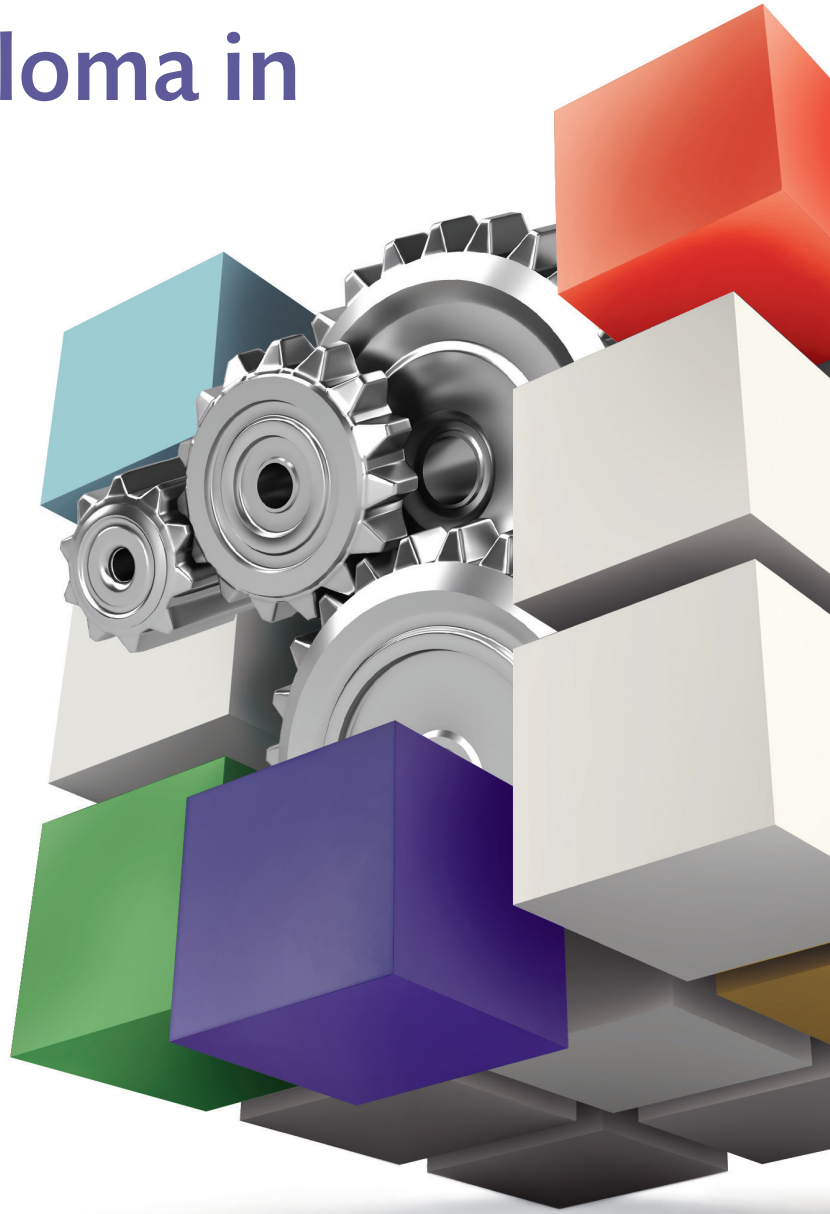


Pearson BTEC Level 3 National Foundation Diploma in Engineering



Specification

First teaching from September 2016

First certification from 2018

Issue 9

Pearson BTEC Level 3 National Foundation Diploma in Engineering

Specification

First teaching September 2016

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About Pearson

We are the world's learning company operating in 70 countries around the world with more than 22,500 employees. We provide content, assessment and digital services to schools, colleges and universities, as well as professional and vocational education to learners to help increase their skills and lifelong employability prospects. We believe that wherever learning flourishes so do people.

This specification is Issue 9. 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. We do 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.)

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Welcome

With a track record built over 30 years of learner success, BTEC Nationals are widely recognised by industry and higher education as the signature vocational qualification at Level 3. They provide progression to the workplace either directly or via study at a higher level. Proof comes from YouGov research, which shows that 62% of large companies have recruited employees with BTEC qualifications. What's more, well over 100,000 BTEC students apply to UK universities every year and their BTEC Nationals are accepted by over 150 UK universities and higher education institutes for relevant degree programmes either on their own or in combination with A Levels.

Why are BTECs so successful?

BTECs embody a fundamentally learner-centred approach to the curriculum, with a flexible, unit-based structure and knowledge applied in project-based assessments. They focus on the holistic development of the practical, interpersonal and thinking skills required to be able to succeed in employment and higher education.

When creating the BTEC Nationals in this suite, we worked with many employers, higher education providers, colleges and schools to ensure that their needs are met. Employers are looking for recruits with a thorough grounding in the latest industry requirements and work-ready skills such as teamwork. Higher education needs students who have experience of research, extended writing and meeting deadlines.

We have addressed these requirements with:

- a range of BTEC sizes, each with a clear purpose, so there is something to suit each learner's choice of study programme and progression plans
- refreshed content that is closely aligned with employers' and higher education needs for a skilled future workforce
- assessments and projects chosen to help learners progress to the next stage. This means some are set by you to meet local needs, while others are set and marked by Pearson so that there is a core of skills and understanding that is common to all learners. For example, a written test can be used to check that learners are confident in using technical knowledge to carry out a certain job.

We are providing a wealth of support, both resources and people, to ensure that learners and their teachers have the best possible experience during their course. See *Section 10* for details of the support we offer.

A word to learners

Today's BTEC Nationals are demanding, as you would expect of the most respected applied learning qualification in the UK. You will have to choose and complete a range of units, be organised, take some assessments that we will set and mark, and keep a portfolio of your assignments. But you can feel proud to achieve a BTEC because, whatever your plans in life – whether you decide to study further, go on to work or an apprenticeship, or set up your own business – your BTEC National will be your passport to success in the next stage of your life.

Good luck, and we hope you enjoy your course.

Collaborative development

Students completing their BTEC Nationals in Engineering will be aiming to go on to employment, often via the stepping stone of higher education. It was, therefore, essential that we developed these qualifications in close collaboration with experts from professional bodies, businesses and universities, and with the providers who will be delivering the qualifications. To ensure that the content meets providers' needs and provides high-quality preparation for progression, we engaged experts. We are very grateful to all the university and further education lecturers, teachers, employers, professional body representatives and other individuals who have generously shared their time and expertise to help us develop these new qualifications.

Employers, professional bodies and higher education providers that have worked with us include:

Cisco Systems

Engineering Council

Network Rail

Nottingham Trent University

Parafix

Royal Academy of Engineering

University of Exeter

University of Northampton.

These qualifications have been approved by the engineering professional bodies on behalf of the Engineering Council as contributing to the requirements for professional registration as an Engineering Technician (EngTech).

The professional bodies include:

The Institution of Engineering and Technology (IET)

The Institution of Mechanical Engineers (IMechE)

The Society of Operations Engineers (SOE).

In addition, universities, professional bodies and businesses have provided letters of support confirming that these qualifications meet their entry requirements. These letters can be viewed on our website.

Summary of Pearson BTEC Level 3 National Foundation Diploma in Engineering Specification Issue 9 changes

Summary of changes made between the previous issue and this current issue	Page number
The <i>Structures of the qualifications at a glance</i> table has been updated to include units that have been added to the Extended Certificate, Diploma and Extended Diploma.	Pages 10 and 13
Removal of references to MyBTEC, as that service is retiring.	Pages 294, 298, 303, 317, 318

Summary of Pearson BTEC Level 3 National Foundation Diploma in Engineering Specification Issue 8 changes

Summary of changes made between Issue 7 and Issue 8	Page number
The last paragraph of the <i>Qualification and unit content</i> section has been amended to allow centres delivering the qualification above to alter the content to reflect the context of the country where it is being delivered.	Page 14
A new unit <i>Unit 57: Sustainable Transport</i> has been added to the Pearson BTEC Level 3 National Foundation Diploma in Engineering in this specification.	Pages 13, 20 and 285-292
Changes made to <i>Unit 19: Electronic Devices and Circuits</i> Content for B3, Assessment criteria for Learning aim B and Essential information for assessment decisions section Learning aim B Distinction and Merit standard.	Pages 144, 146, 149

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

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Introduction to BTEC National qualifications for the engineering sector

This specification contains the information you need to deliver the Pearson BTEC Level 3 National Foundation Diploma in Engineering. The specification signposts you to additional handbooks and policies. It includes all the units for this qualification.

This qualification is part of the suite of engineering qualifications offered by Pearson. In the suite there are qualifications that focus on different progression routes, allowing learners to choose the one best suited to their aspirations.

All qualifications in the suite share some common units and assessments, allowing learners some flexibility in moving between sizes. The qualification titles are given below.

Some BTEC National qualifications provide a broad introduction that gives learners transferable knowledge and skills. These qualifications are for post-16 learners who want to continue their education through applied learning. The qualifications prepare learners for a range of higher education courses and job roles related to a particular sector. They provide progression either by meeting entry requirements in their own right or by being accepted alongside other qualifications at the same level and adding value to them.

In the engineering sector these qualifications are:

Pearson BTEC Level 3 National Certificate in Engineering (180 GLH) 603/1197/6

Pearson BTEC Level 3 National Extended Certificate in Engineering (360 GLH) 601/7584/9

Pearson BTEC Level 3 National Foundation Diploma in Engineering (540 GLH) 601/7591/6.

Some BTEC National qualifications are for post-16 learners wishing to specialise in a specific industry, occupation or occupational group. The qualifications give learners the specialist knowledge and skills, enabling entry to an apprenticeship or other employment, or progression to related higher education courses. Learners taking these qualifications must have a significant level of employer involvement in their programmes.

In the engineering sector these qualifications are:

Pearson BTEC Level 3 National Diploma in Engineering (720 GLH) 601/7580/1

Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering (720 GLH) 601/7579/5

Pearson BTEC Level 3 National Diploma in Mechanical Engineering (720 GLH) 601/7583/7

Pearson BTEC Level 3 National Diploma in Computer Engineering (720 GLH) 601/7578/3

Pearson BTEC Level 3 National Diploma in Manufacturing Engineering (720 GLH) 601/7582/5

Pearson BTEC Level 3 National Diploma in Aeronautical Engineering (720 GLH) 601/7577/1

Pearson BTEC Level 3 National Extended Diploma in Engineering (1080 GLH) 601/7588/6

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering (1080 GLH) 601/7587/4

Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering (1080 GLH) 601/7590/4

Pearson BTEC Level 3 National Extended Diploma in Computer Engineering (1080 GLH) 601/7586/2

Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering (1080 GLH) 601/7589/8

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering (1080 GLH) 601/7585/0.

This specification signposts all the other essential documents and support that you need as a centre in order to deliver, assess and administer the qualification, including the staff development required. A summary of all essential documents is given in *Section 7*. Information on how we can support you with this qualification is given in *Section 10*.

The information in this specification is correct at the time of publication.

Total Qualification Time

For all regulated qualifications, Pearson specifies a total number of hours that it is estimated learners will require to complete and show achievement for the qualification: this is the Total Qualification Time (TQT). Within TQT, Pearson identifies the number of Guided Learning Hours (GLH) that we estimate a centre delivering the qualification might provide. Guided learning means activities, such as lessons, tutorials, online instruction, supervised study and giving feedback on performance, that directly involve teachers and assessors in teaching, supervising and invigilating learners. Guided learning 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 teachers or assessors will include private study, preparation for assessment and undertaking assessment when not under supervision, such as preparatory reading, revision and independent research.

BTEC Nationals have been designed around the number of hours of guided learning expected. Each unit in the qualification has a GLH value of 60, 90 or 120. There is then a total GLH value for the qualification.

Each qualification has a TQT value. This may vary within sectors and across the suite depending on the nature of the units in each qualification and the expected time for other required learning.

The following table shows all the qualifications in this sector and their GLH and TQT values.

Qualifications, sizes and purposes at a glance

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Certificate in Engineering	180 GLH (260 TQT) Equivalent in size to 0.5 of an A Level. 2 units of which both are mandatory and 1 is external. Mandatory content (100%). External assessment (67%).	This qualification is intended for post-16 learners who want to continue their education through applied learning and who aim to progress to higher education and ultimately employment. It aims to provide a coherent introduction to study of the engineering sector.
Pearson BTEC Level 3 National Extended Certificate in Engineering	360 GLH (465 TQT) Equivalent in size to one A Level. 4 units of which 3 are mandatory and 2 are external. Mandatory content (83%). External assessment (67%).	This qualification provides a broad basis of study for the engineering sector. It has been designed to support progression to higher education when taken as part of a programme of study that includes other appropriate BTEC Nationals or A Levels.
Pearson BTEC Level 3 National Foundation Diploma in Engineering	540 GLH (740 TQT) Equivalent in size to 1.5 A Levels. 7 units of which 4 are mandatory and 2 are external. Mandatory content (67%). External assessment (44%).	This qualification has been designed as a one-year, full-time course that supports progression to an apprenticeship in engineering or to a further year of study at Level 3. If taken as part of a programme of study that includes other BTEC Nationals or A Levels, it supports progression to higher education.
Pearson BTEC Level 3 National Diploma in Engineering	720 GLH (975 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).	This qualification is aimed at learners preparing for roles in engineering, for example engineering technician or engineering operative. Learners gain relevant skills and knowledge from studying a range of content focused on electrical/electronic and mechanical disciplines, for example electrical machines and maintenance of mechanical systems. The qualification has been designed to be the substantive part of a 16–19 study programme for learners who want a strong core of sector study and a focus on the wider engineering industry. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.

Title	Size and structure	Summary purpose
<p>Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering</p>	<p>720 GLH (980 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).</p>	<p>This qualification is aimed at learners preparing for roles in electrical and electronic engineering, for example electrical engineering technician or electronic engineering operative. Learners gain relevant skills and knowledge from studying a range of units, for example in electronic devices and circuits, power and energy systems and printed circuit board design and manufacture. The qualification is designed to be the substantive part of a 16–19 study programme for learners wanting a strong core of electrical and electronic engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.</p>
<p>Pearson BTEC Level 3 National Diploma in Mechanical Engineering</p>	<p>720 GLH (985 TQT) Equivalent in size to two A Levels. 10 units of which 5 are mandatory and 2 are external. Mandatory content (58%). External assessment (33%).</p>	<p>This qualification is aimed at learners preparing for roles in mechanical engineering, for example mechanical engineering technician or mechanical fitter. Learners gain relevant skills and knowledge from studying a range of units, for example in metallic and non-metallic materials, fluid mechanics and/or thermodynamic practices. The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of mechanical engineering. The qualification may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.</p>

Title	Size and structure	Summary purpose
<p>Pearson BTEC Level 3 National Diploma in Computer Engineering</p>	<p>720 GLH (985 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).</p>	<p>This qualification is aimed at learners preparing for roles in computer engineering, for example computer engineering technician or computer support analyst. Learners gain relevant skills and knowledge from studying a range of units, for example in computer programming, website design and/or cyber security.</p> <p>The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of knowledge in computer engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.</p>
<p>Pearson BTEC Level 3 National Diploma in Manufacturing Engineering</p>	<p>720 GLH (980 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).</p>	<p>This qualification is aimed at learners preparing for roles in manufacturing engineering, for example manufacturing engineering technician or welding operative. Learners gain relevant skills and knowledge from studying a range of units, for example in computer-aided manufacturing, modern manufacturing systems, additive manufacturing and machining.</p> <p>The qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of knowledge of manufacturing engineering. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.</p>

Title	Size and structure	Summary purpose
<p>Pearson BTEC Level 3 National Diploma in Aeronautical Engineering</p>	<p>720 GLH (990 TQT) Equivalent in size to two A Levels. 10 units of which 6 are mandatory and 2 are external. Mandatory content (67%). External assessment (33%).</p>	<p>This qualification is aimed at learners preparing for roles in aeronautical engineering, for example aeronautical engineering technician or aerospace fitter. Learners gain relevant skills and knowledge from studying a range of units, for example in aircraft workshop principles, gas turbine engines, airframe construction and first-line maintenance.</p> <p>The qualification is designed to be the substantive part of a 16–19 study programme for learners who want to focus on the specific aspects that relate to the aeronautical industry. It may be complemented with other BTEC Nationals or A Levels or non-qualification elements to support progression to specific job roles or to higher education courses in engineering.</p>
<p>Pearson BTEC Level 3 National Extended Diploma in Engineering</p>	<p>1080 GLH (1475 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).</p>	<p>This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in engineering. Learners gain relevant skills and knowledge from studying a range of content focused on electrical/electronic and mechanical disciplines, for example electrical machines and maintenance of mechanical systems.</p> <p>Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.</p>

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in electrical and electronic engineering, such as a power engineering technician. Learners gain relevant skills and knowledge from studying a range of units, for example in electronic devices and circuits, power and energy systems, printed circuit board design and manufacture, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.
Pearson BTEC Level 3 National Extended Diploma in Mechanical Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 7 are mandatory and 3 are external. Mandatory content (56%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners who want to progress to employment in mechanical engineering, such as a mechanical maintenance technician. Learners gain relevant skills and knowledge from studying a range of units, for example in metallic and non-metallic materials, fluid mechanics, thermodynamic practices, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.



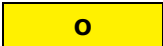






Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Computer Engineering	1080 GLH (1485 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in computer engineering, such as a computer support technician. Learners gain relevant skills and knowledge from studying a range of units, for example in computer programming, microcontrollers, website design, cyber security, microcontrollers and/or calculus. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.
Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering	1080 GLH (1475 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in manufacturing engineering, such as a quality control technician. Learners gain relevant skills and knowledge from studying a range of units, for example in computer-aided manufacturing, modern manufacturing systems, microcontrollers, additive manufacturing, and machining. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering	1080 GLH (1495 TQT) Equivalent in size to three A Levels. 15 units of which 8 are mandatory and 3 are external. Mandatory content (61%). External assessment (33%).	This qualification has been designed as a two-year, full-time course that meets entry requirements in its own right for learners wanting to progress to employment in aeronautical/aerospace engineering, for example in aerospace manufacturing or as a systems fitter or aircraft maintenance operative. Learners gain relevant skills and knowledge from studying a range of units, for example in aircraft workshop principles, microcontrollers, calculus, gas turbine engines, airframe construction and first-line maintenance. Progression could be either directly to employment in Level 3 job roles, higher apprenticeship programmes or via higher education courses in engineering.

Structures of the qualifications at a glance

This table shows all the units and the qualifications to which they contribute. The full structure for this Pearson BTEC Level 3 National in Engineering is shown in *Section 2*. **You must refer to the full structure to select units and plan your programme.**

Key

	Unit assessed externally		Mandatory units		Optional units
	Engineering		Electrical/Electronic		Mechanical
	Manufacturing		Aeronautical		Computer

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
1 Engineering Principles	120	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
2 Delivery of Engineering Processes Safely as a Team	60	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
3 Engineering Product Design and Manufacture	120		M	M	M	M	M	M	M	M	M	M	M	M	M	M
4 Applied Commercial and Quality Principles in Engineering	60			M	M	M	M	M	M	M	M	M	M	M	M	M
5 A Specialist Engineering Project	60				M	M	M	M	M	M	M	M	M	M	M	M
6 Microcontroller Systems for Engineers	120										M	M	M	M	M	M
7 Calculus to Solve Engineering Problems	60		O	O	O	O	O	O	O	O	M	M	M	M	M	M
8 Further Engineering Mathematics	60				O	O	O	O	O	O	O	O	O	O	O	O
9 Work Experience in the Engineering Sector	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O
10 Computer Aided Design in Engineering	60		O	O	O		O	O	O	O	O		O	O	O	O
11 Engineering Maintenance and Condition Monitoring Techniques	60		O	O	O		O	O	O	O	O		O	O	O	O
12 Pneumatic and Hydraulic Systems	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
					13 Welding Technology	60			0	0		0		0	0	0
14 Electrical Installation of Hardware and Cables	60				0	0		0			0	0		0	0	
15 Electrical Machines**	60			0	0	0	0			0	0	0	0	0		0
16 Three Phase Electrical Systems	60				0	0		0	0	0	0	0		0	0	0
17 Power and Energy Electronics	60				0	0					0	0				
18 Electrical Power Distribution and Transmission	60				0	0		0			0	0	0	0		
19 Electronic Devices and Circuits	60		0	0	0	0	0	0	0	0	0	0	0	0	0	0
20 Analogue Electronic Circuits	60				0	0	0	0			0	0	0	0		
21 Electronic Measurement and Testing of Circuits	60			0	0	0	0	0			0	0	0	0	0	0
22 Electronic Printed Circuit Board Design and Manufacture	60			0	0	0		0	0		0	0		0	0	
23 Digital and Analogue Electronic Systems	60				0	0					0	0				
24 Maintenance of Mechanical Systems	60			0	0	0	0	0	0		0	0	0	0	0	
25 Mechanical Behaviour of Metallic Materials	60		0	0	0	0	0	0	0	0	0	0	0	0	0	0
26 Mechanical Behaviour of Non-metallic Materials	60				0		0		0	0	0	0	0		0	0
27 Static Mechanical Principles in Practice	60			0	0	0	0	0	0		0	0	0	0	0	
28 Dynamic Mechanical Principles in Practice	60				0		0		0		0	0	0		0	0
29 Principles and Applications of Fluid Mechanics	60				0		0			0	0		0		0	0
30 Mechanical Measurement and Inspection Technology	60		0	0	0	0	0		0		0	0	0	0	0	

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
					31 Thermodynamic Principles and Practice	60				O		O			O	O
32 Computer System Principles and Practice	60				O			M			O			M		
33 Computer Systems Security	60				O	O		O			O	O	O	O		
34 Computer Systems Support and Performance	60				O	O	O	O	O		O	O	O	O	O	
35 Computer Programming	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O
36 Programmable Logic Controllers	60			O	O	O	O	O	O	O	O	O	O	O	O	O
37 Computer Networks	60				O	O		O			O	O		O		
38 Website Production to Control Devices	60				O	O		O			O	O		O		
39 Modern Manufacturing Systems	60				O				M		O				M	
40 Computer Aided Manufacturing and Planning	60				O			O	O		O		O	O	O	
41 Manufacturing Secondary Machining Processes	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O
42 Manufacturing Primary Forming Processes	60				O		O		O		O		O		O	
43 Manufacturing Computer Numerical Control Machining Processes	60			O	O	O	O	O	O	O	O	O	O	O	O	O
44 Fabrication Manufacturing Processes	60		O	O	O	O	O		O		O	O	O		O	O
45 Additive Manufacturing Processes	60		O	O	O	O	O	O	O	O	O	O	O	O	O	O
46 Manufacturing Joining, Finishing and Assembly Processes	60				O				O		O				O	
47 Composites Manufacture and Repair Processes	60				O				O	O	O				O	O

continued overleaf

Unit (number and title)	Unit size (GLH)	Certificate (180 GLH)	Extended Certificate (360 GLH)	Foundation Diploma (540 GLH)	Diploma (720 GLH)						Extended Diploma (1080 GLH)					
					E	EE	ME	C	MA	AE	E	EE	ME	C	MA	AE
					48 Aircraft Flight Principles and Practice	60									M	
49 Aircraft Workshop Methods and Practice	60									O						O
50 Aircraft Gas Turbine Engines	60									O						O
51 Aircraft Propulsion Systems	60									O						O
52 Airframe Construction and Repair	60									O						O
53 Airframe Mechanical Systems	60									O						O
54 Aircraft Electrical and Instrument Systems	60									O						O
55 Aircraft First Line Maintenance Operations	60									O						O
56 Industrial Robotics	60				O	O	O	O	O	O	O	O	O	O	O	O
57 Sustainable Transport	60			O	O						O					
58 Energy Management	60				O						O					
59 Principles of Electrical Machines**	60				O	O					O	O				
60 Autonomous Mobile Robotics	60				O	O	O				O	O	O			

** Learners may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, they cannot take both.

Qualification and unit content

Pearson has developed the content of the new BTEC Nationals in collaboration with employers and representatives from higher education and relevant professional bodies. In this way, we have ensured that content is up to date and that it includes the knowledge, understanding, skills and attributes required in the sector.

Each qualification in the suite has its own purpose. The mandatory and optional content provides a balance of breadth and depth, while retaining a degree of choice for individual learners to study content relevant to their own interests and progression choices. Also, the content may be applied during delivery in a way that is relevant to local employment needs.

The proportion of mandatory content ensures that all learners are following a coherent programme of study and acquiring the knowledge, understanding and skills that will be recognised and valued. Learners are expected to show achievement across mandatory units as detailed in *Section 2*.

BTEC Nationals have always required applied learning that brings together knowledge and understanding (the cognitive domain) with practical and technical skills (the psychomotor domain). This is achieved through learners performing vocational tasks that encourage the development of appropriate vocational behaviours (the affective domain) and transferable skills. Transferable skills are those such as communication, teamwork, research and analysis, which are valued in both higher education and the workplace.

Our approach provides rigour and balance, and promotes the ability to apply learning immediately in new contexts. Further details can be found in *Section 2*.

Centres should ensure that delivery of content is kept up to date. Some of the units within the specification may contain references to legislation, policies, regulations and organisations, which may not be applicable in the country you deliver this qualification in (if teaching outside of England), or which may have gone out-of-date during the lifespan of the specification. In these instances, it is possible to substitute such references with ones that are current and applicable in the country you deliver subject to confirmation by your Standards Verifier.

Assessment

Assessment is specifically designed to fit the purpose and objective of the qualification. It includes a range of assessment types and styles suited to vocational qualifications in the sector. There are three main forms of assessment that you need to be aware of: external, internal and synoptic.

Externally-assessed units

Each external assessment for a BTEC National is linked to a specific unit. All of the units developed for external assessment are of 90 or 120 GLH to allow learners to demonstrate breadth and depth of achievement. Each assessment is taken under specified conditions, then marked by Pearson and a grade awarded. Learners are permitted to resit external assessments during their programme. You should refer to our website for current policy information on permitted retakes.

The styles of external assessment used for qualifications in the Engineering suite are:

- examinations – all learners take the same assessment at the same time, normally with a written outcome
- set tasks – learners take the assessment during a defined window and demonstrate understanding through completion of a vocational task.

Some external assessments include a period of preparation using set information. External assessments are available once or twice a year. For detailed information on the external assessments please see the table in *Section 2*. For further information on preparing for external assessment see *Section 5*.

Internally-assessed units

Most units in the sector are internally assessed and subject to external standards verification. This means that you set and assess the assignments that provide the final summative assessment of each unit, using the examples and support that Pearson provides. Before you assess you will need to become an approved centre, if you are not one already. You will need to prepare to assess using the guidance in *Section 6*.

In line with the requirements and guidance for internal assessment, you select the most appropriate assessment styles according to the learning set out in the unit. This ensures that learners are assessed using a variety of styles to help them develop a broad range of transferable skills. Learners could be given opportunities to:

- write up the findings of their own research
- use case studies to explore complex or unfamiliar situations
- carry out projects for which they have choice over the direction and outcomes
- demonstrate practical and technical skills using appropriate processes, devices, components, equipment, materials, consumables.

You will make grading decisions based on the requirements and supporting guidance given in the units. Learners may not make repeated submissions of assignment evidence. For further information see *Section 6*.

Synoptic assessment

Synoptic assessment requires learners to demonstrate that they can identify and use effectively, in an integrated way, an appropriate selection of skills, techniques, concepts, theories and knowledge from across the whole sector as relevant to a key task. BTEC learning has always encouraged learners to apply their learning in realistic contexts using scenarios and realistic activities that will permit learners to draw on and apply their learning. For these qualifications we have formally identified units which contain a synoptic assessment task. Synoptic assessment must take place after the teaching and learning of other mandatory units in order for learners to be able to draw from the full range of content. The synoptic assessment gives learners an opportunity to independently select and apply learning from across their programmes in the completion of a vocational task. Synoptic tasks may be in internally or externally assessed units. The particular unit that contains the synoptic tasks for this qualification is shown in the structure in *Section 2*.

Language of assessment

Assessment of the internal and external units for these qualifications will be available in English. All learner work must be in English. A learner taking the qualifications may be assessed in British or Irish Sign Language where it is permitted for the purpose of reasonable adjustment. For information on reasonable adjustments see *Section 7*.

Grading for units and qualifications

Achievement in the qualification requires a demonstration of depth of study in each unit, assured acquisition of a range of practical skills required for employment or progression to higher education, and successful development of transferable skills. Learners achieving a qualification will have achieved across mandatory units, including external and synoptic assessment.

Units are assessed using a grading scale of Distinction (D), Merit (M), Pass (P), Near Pass (N) and Unclassified (U). The grade of Near Pass is used for externally-assessed units only. All mandatory and optional units contribute proportionately to the overall qualification grade, for example a unit of 120 GLH will contribute double that of a 60 GLH unit.

Qualifications in the suite are graded using a scale of P to D*, **or** PP to D*D*, **or** PPP to D*D*D*. Please see *Section 9* for more details. The relationship between qualification grading scales and unit grades will be subject to regular review as part of Pearson's standards monitoring processes on the basis of learner performance and in consultation with key users of the qualification.

UCAS Tariff points

The BTEC Nationals attract UCAS points. Please go to the UCAS website for full details of the points allocated.

1 Qualification purpose

Pearson BTEC Level 3 National Foundation Diploma in Engineering

In this section you will find information on the purpose of this qualification and how its design meets that purpose through the qualification objective and structure. We publish a full 'Statement of Purpose' for each qualification on our website. These statements are designed to guide you and potential learners to make the most appropriate choice about the size of qualification suitable at recruitment.

Who is this qualification for?

The Pearson BTEC Level 3 National Foundation Diploma in Engineering is intended to be an Applied General qualification for post-16 learners wanting to continue their education through applied learning and who aim to progress to higher education, and ultimately to employment, possibly in the engineering sector. The qualification is equivalent in size to 1.5 A levels and aims to provide a coherent introduction to study of the engineering sector. Learners need not necessarily have studied engineering previously, but will have successfully completed a level 2 programme of learning, with GCSEs or vocational qualifications.

What does this qualification cover?

Engineering covers a broad variety of roles and it involves the application of scientific principles and practical knowledge to transform ideas and materials into products and systems safely and support them during their lifetime. This qualification has a focus on a broad range of engineering specialist areas. Learners taking this qualification will study mandatory content covering:

- engineering principles and mathematics
- health and safety, team work and interpreting and creating computer-aided engineering drawings
- design and manufacture of products
- commercial principles and understanding and application of quality systems.

The content of this qualification has been developed in consultation with academics to ensure that it supports progression to higher education. In addition, employers and professional bodies have been involved and consulted in order to confirm that the content is appropriate and consistent with current practice for learners planning to enter employment directly in the engineering sector.

What could this qualification lead to?

Progression from this qualification is either to a larger size qualification at Level 3 (e.g. BTEC National Extended Diploma in Engineering or other related subject (e.g. Computing) or if completed alongside other programmes of study will lead to courses in higher education. The qualification is recognised by higher education providers as contributing to meeting admission requirements for many relevant courses in a variety of areas of the engineering sector, for example:

- BEng (Hons) in Engineering
- BEng (Hons) in Electronics Engineering
- BSc (Hons) in Computer Science
- BSc (Hons) in Mathematics.

This qualification also supports progression to job opportunities in the engineering sector. Jobs that are available in these areas include:

- engineering operative
- manufacturing operative
- semi-skilled operative.

This qualification also supports those following an apprenticeship in engineering who are looking to work and progress in the engineering sector as an engineering operative.

Learners should always check the entry requirements for degree programmes with specific higher education providers.

How does the qualification provide employability skills?

In the BTEC National units there are opportunities during the teaching and learning phase to give learners practice in developing employability skills. Where employability skills are referred to in this specification, we are generally referring to skills in the following three main categories:

- **cognitive and problem-solving skills:** use critical thinking, approach non-routine problems applying expert and creative solutions, use systems and technology
- **intrapersonal skills:** communicating, working collaboratively, negotiating and influencing, self-presentation
- **interpersonal skills:** self-management, adaptability and resilience, self-monitoring and development.

There are also specific requirements in some units for assessment of these skills where relevant. For example, where learners are required to undertake real or simulated activities.

How does the qualification provide transferable knowledge and skills for higher education?

All BTEC Nationals provide transferable knowledge and skills that prepare learners for progression to university. The transferable skills that universities value include:

- the ability to learn independently
- the ability to research actively and methodically
- being able to give presentations and being active group members.

BTEC learners can also benefit from opportunities for deep learning where they are able to make connections among units and select areas of interest for detailed study. BTEC Nationals provide a vocational context in which learners can develop the knowledge and skills required for particular degree courses, including:

- reading technical texts
- effective writing
- analytical and problem-solving skills
- preparation for assessment methods used in degrees.

2 Structure

Qualification structure

Pearson BTEC Level 3 National Foundation Diploma in Engineering

Mandatory units

There are four mandatory units, two internal and two external. Learners must complete and achieve at Near Pass grade or above in all mandatory external units and achieve a Pass or above in all mandatory internal units.

Optional units

Learners must complete at least three optional units.

Pearson BTEC Level 3 National Foundation Diploma in Engineering				
Unit number	Unit title	GLH	Type	How assessed
Mandatory units - learners complete and achieve all units				
1	Engineering Principles	120	Mandatory	External
2	Delivery of Engineering Processes Safely as a Team	60	Mandatory	Internal
3	Engineering Product Design and Manufacture	120	Mandatory and Synoptic	External
4	Applied Commercial and Quality Principles in Engineering	60	Mandatory	Internal
Optional units- learners complete 3 units				
7	Calculus to Solve Engineering Problems	60	Optional	Internal
9	Work Experience in the Engineering Sector	60	Optional	Internal
10	Computer Aided Design in Engineering	60	Optional	Internal
11	Engineering Maintenance and Condition Monitoring Techniques	60	Optional	Internal
12	Pneumatic and Hydraulic Systems	60	Optional	Internal
13	Welding Technology	60	Optional	Internal
15	Electrical Machines	60	Optional	Internal
19	Electronic Devices and Circuits	60	Optional	Internal
21	Electronic Measurement and Testing of Circuits	60	Optional	Internal
22	Electronic Printed Circuit Board Design and Manufacture	60	Optional	Internal
24	Maintenance of Mechanical Systems	60	Optional	Internal
25	Mechanical Behaviour of Metallic Materials	60	Optional	Internal
27	Static Mechanical Principles in Practice	60	Optional	Internal
30	Mechanical Measurement and Inspection Technology	60	Optional	Internal
35	Computer Programming	60	Optional	Internal

Pearson BTEC Level 3 National Foundation Diploma in Engineering				
Unit number	Unit title	GLH	Type	How assessed
36	Programmable Logic Controllers	60	Optional	Internal
41	Manufacturing Secondary Machining Processes	60	Optional	Internal
43	Manufacturing Computer Numerical Control Machining Processes	60	Optional	Internal
44	Fabrication Manufacturing Processes	60	Optional	Internal
45	Additive Manufacturing Processes	60	Optional	Internal
57	Sustainable Transport	60	Optional	Internal

External assessment

This is a summary of the type and availability of external assessment, which is of units making up 44% of the total qualification GLH. See *Section 5* and the units and sample assessment materials for more information.

Unit	Type	Availability
Unit 1: Engineering Principles	<ul style="list-style-type: none"> • Written exam set and marked by Pearson. • Two hours. • 80 marks. 	Jan and May/June First assessment May/June 2017
Unit 3: Engineering Product Design and Manufacture	<ul style="list-style-type: none"> • A task set and marked by Pearson and completed under supervised conditions. • Prior to the supervised assessment, learners will be provided with a case study in order to carry out research in no more than 3 hours in a one week period timetabled by Pearson. • The supervised assessment period is 8 hours and can be arranged over a two-week period timetabled by Pearson. Once the assessment has started it must be completed by the learner within five days. • Written submission. • 60 marks. 	December/January and May/June First assessment May/June 2017

Synoptic assessment

The mandatory synoptic assessment requires learners to apply learning from across the qualification to the completion of a defined vocational task. Within the assessment for *Unit 3: Engineering Product Design and Manufacture*, learners complete product design and manufacturing tasks which draw together underpinning engineering science principles and skills such as engineering drawing and health and safety. Learners complete the task using using knowledge and understanding from their studies of the sector and apply both transferable and specialist knowledge and skills.

In delivering the unit you need to encourage learners to draw on their broader learning so they will be prepared for the assessment.

Employer involvement in assessment and delivery

You are encouraged to give learners opportunities to be involved with employers. See *Section 4* for more information.

3 Units

Understanding your units

The units in this specification set out our expectations of assessment in a way that helps you to prepare your learners for assessment. The units help you to undertake assessment and quality assurance effectively.

Each unit in the specification is set out in a similar way. There are two types of unit format:

- internal units
- external units.

This section explains how the units work. It is important that all teachers, assessors, internal verifiers and other staff responsible for the programme review this section.

Internal units

Section	Explanation
Unit number	The number is in a sequence in the sector. Numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that we always use and it appears on certificates.
Level	All units are at Level 3 on the national framework.
Unit type	This shows if the unit is internal or external only. See structure information in <i>Section 2</i> for full details.
GLH	Units may have a GLH value of 120, 90 or 60 GLH. This indicates the numbers of hours of teaching, directed activity and assessment expected. It also shows the weighting of the unit in the final qualification grade.
Unit in brief	A brief formal statement on the content of the unit that is helpful in understanding its role in the qualification. You can use this in summary documents, brochures etc.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, how learning is structured, and how learning might be applied when progressing to employment or higher education.
Learning aims	These help to define the scope, style and depth of learning of the unit. You can see where learners should be learning standard requirements ('understand') or where they should be actively researching ('investigate'). You can find out more about the verbs we use in learning aims in <i>Appendix 2</i> .
Summary of unit	This new section helps teachers to see at a glance the main content areas against the learning aims and the structure of the assessment. The content areas and structure of assessment are required. The forms of evidence given are suitable to fulfil the requirements.
Content	This section sets out the required teaching content of the unit. Content is compulsory except when shown as 'e.g.'. Learners should be asked to complete summative assessment only after the teaching content for the unit or learning aim(s) has been covered.

Section	Explanation
Assessment criteria	<p>Each learning aim has Pass and Merit criteria. Each assignment has at least one Distinction criterion.</p> <p>A full glossary of terms used is given in <i>Appendix 2</i>. All assessors need to understand our expectations of the terms used.</p> <p>Distinction criteria represent outstanding performance in the unit. Some criteria require learners to draw together learning from across the learning aims.</p>
Essential information for assignments	<p>This shows the maximum number of assignments that may be used for the unit to allow for effective summative assessment, and how the assessment criteria should be used to assess performance.</p>
Further information for teachers and assessors	<p>The section gives you information to support the implementation of assessment. It is important that this is used carefully alongside the assessment criteria.</p>
Resource requirements	<p>Any specific resources that you need to be able to teach and assess are listed in this section. For information on support resources see <i>Section 10</i>.</p>
Essential information for assessment decisions	<p>This information gives guidance for each learning aim or assignment of the expectations for Pass, Merit and Distinction standard. This section contains examples and essential clarification.</p>
Links to other units	<p>This section shows you the main relationship among units. This section can help you to structure your programme and make best use of materials and resources.</p>
Employer involvement	<p>This section gives you information on the units that can be used to give learners involvement with employers. It will help you to identify the kind of involvement that is likely to be successful.</p>

External units

Section	Explanation
Unit number	The number is in a sequence in the sector. Numbers may not be sequential for an individual qualification.
Unit title	This is the formal title that we always use and it appears on certificates.
Level	All units are at Level 3 on the national framework.
Unit type	This shows if the unit is internal or external only. See structure information in <i>Section 2</i> for full details.
GLH	Units may have a GLH value of 120, 90 or 60 GLH. This indicates the numbers of hours of teaching, directed activity and assessment expected. It also shows the weighting of the unit in the final qualification grade.
Unit in brief	A brief formal statement on the content of the unit.
Unit introduction	This is designed with learners in mind. It indicates why the unit is important, how learning is structured, and how learning might be applied when progressing to employment or higher education.
Summary of assessment	This sets out the type of external assessment used and the way in which it is used to assess achievement.
Assessment outcomes	These show the hierarchy of knowledge, understanding, skills and behaviours that are assessed. Includes information on how this hierarchy relates to command terms in sample assessment materials (SAMs).
Essential content	For external units all the content is obligatory, the depth of content is indicated in the assessment outcomes and sample assessment materials (SAMs). The content will be sampled through the external assessment over time, using the variety of questions or tasks shown.
Grade descriptors	We use grading descriptors when making judgements on grade boundaries. You can use them to understand what we expect to see from learners at particular grades.
Key terms typically used in assessment	These definitions will help you analyse requirements and prepare learners for assessment.
Resources	Any specific resources that you need to be able to teach and assess are listed in this section. For information on support resources see <i>Section 10</i> .
Links to other units	This section shows the main relationship among units. This section can help you to structure your programme and make best use of materials and resources.
Employer involvement	This section gives you information on the units that can be used to give learners involvement with employers. It will help you to identify the kind of involvement that is likely to be successful.

Index of units

This section contains all the units developed for this qualification. Please refer to *pages 10–13* to check which units are available in all qualifications in the engineering sector.

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Unit 1: Engineering Principles

Level: **3**

Unit type: **External**

Guided learning hours: **120**

Unit in brief

Learners apply mathematical and physical science principles to solve electrical-, electronic- and mechanical-based engineering problems.

Unit introduction

Modern life depends on engineers to develop, support and control the products and systems that are all around us. For example, cars, heart rate monitors and manufacturing and transport systems. To make a contribution as an engineer you must be able to draw on an important range of principles developed by early engineering scientists, such as Newton, Young, Faraday and Ohm. There is an increasing demand for 'multi-skilled' engineers who can apply principles from several engineering disciplines to develop solutions.

This unit will develop your mathematical and physical scientific knowledge and understanding to enable you to solve problems set in an engineering context. You will explore and apply the algebraic and trigonometric mathematical methods required to solve engineering problems. The mechanical problems you will encounter cover static, dynamic and fluid systems. The electrical and electronic problems you will encounter cover static and direct current (DC) electricity, DC circuit theory and networks, magnetism, and single-phase alternating current theory. You may apply these engineering principles to solve problems involving more than one of these topic areas. This unit is externally assessed. It sits at the heart of the qualification and gives you a foundation to support you in any engineering technician role, an engineering apprenticeship or in higher education.

Summary of assessment

The unit will be assessed through one paper of 80 marks lasting two hours that will be set and marked by Pearson.

Learners will be assessed through a number of short- and long-answer problem-solving questions. Learners will need to explore and relate to the engineering contexts and data presented. Assessment will focus on learners' ability to solve problems that require individual and combined application of mathematical techniques, and electrical, electronic and mechanical principles to solve engineering problems.

The assessment availability is twice a year in January and May/June. The first assessment availability is May/June 2017.

Sample assessment materials will be available to help centres prepare learners for assessment.

Assessment outcomes

AO1 Recall basic engineering principles and mathematical methods and formulae

Command words: calculate, describe, explain, identify, name

Marks: ranges from 1 to 5 marks

AO2 Perform mathematical procedures to solve engineering problems

Command words: calculate, convert, find, solve

Marks: ranges from 1 to 10 marks

AO3 Demonstrate an understanding of electrical, electronic and mechanical principles to solve engineering problems

Command words: find, calculate, describe, draw, explain

Marks: ranges from 1 to 5 marks

AO4 Analyse information and systems to solve engineering problems

Command words: calculate, draw

Marks: ranges from 1 to 5 marks

AO5 Integrate and apply electrical, electronic and mechanical principles to develop an engineering solution

Command words: calculate, draw, explain

Marks: ranges from 1 to 10 marks

Essential content

The essential content is set out under content areas. Learners must cover all specified content before the assessment.

A Algebraic and trigonometric mathematical methods

- Application of appropriate units

A1 Algebraic methods

- Solve, transpose and simplify equations.
- 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).
- Application to problems involving exponential growth and decay.
- Linear equations and straight line graphs:
 - linear equations of the form $y = mx + c$
 - straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line)
 - pair of simultaneous linear equations in two unknowns.
- Factorisation and quadratics:
 - multiply expressions in brackets by a number, symbol or by another expression in a bracket
 - extraction of a common factor $ax + ay$, $a(x + 2) + b(x + 2)$
 - grouping $ax - ay + bx - by$
 - quadratic expressions $a^2 + 2ab + b^2$
 - roots of an equation, including quadratic equations with real roots by factorisation, and by the use of formula.

A2 Trigonometric methods

- Circular measure:
 - radian
 - conversion of degree measure to radian measure and vice versa
 - angular rotations (multiple number (n) of 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
 - application of vectors:
 - calculation of the phasor sum of two alternating currents
 - diagrammatic representation of vectors
 - resolution of forces/velocities.

- Mensuration:
 - standard formulae to solve surface areas and volumes of regular solids
 - volume of a cylinder $V = \pi r^2 h$
 - total surface area of a cylinder $TSA = 2\pi r h + 2\pi r^2$
 - 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 $CSA = \pi r l$

B Static engineering systems

- Application of appropriate units

B1 Static engineering systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems, involving:

- Non-concurrent coplanar forces:
 - representation of forces using space and free body diagrams
 - moments
 - resolution of forces in perpendicular directions $F_x = F \cos \theta$, $F_y = F \sin \theta$
 - vector addition of forces – resultant, equilibrant and line of action
 - conditions for static equilibrium $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$
- Simply supported beams:
 - concentrated loads
 - uniformly distributed loads (UDL).
- Reactions:
 - support reactions
 - pin reaction forces
 - roller reaction forces.

B2 Loaded components

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- direct stress and strain: direct stress $\sigma = \frac{F}{A}$, direct strain $\varepsilon = \frac{\Delta L}{L}$
- shear stress and strain: shear stress $\tau = \frac{F}{A}$, shear strain $\gamma = \frac{a}{b}$
- tensile and shear strength
- elastic constants: Young's Modulus (modulus of elasticity)

$$E = \frac{\sigma}{\varepsilon}; \text{ Modulus of rigidity } G = \frac{\tau}{\gamma}$$

C Dynamic engineering systems

- Application of appropriate units

C1 Dynamic engineering systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- kinetic parameters and principles:
 - displacement (s)
 - velocity – initial velocity (u), final velocity (v)
 - acceleration (a)
 - equations for linear motion with uniform acceleration

$$v = u + at, s = ut + \frac{1}{2} at^2, v^2 = u^2 + 2as, s = \frac{1}{2} (u + v)t$$
- dynamic parameters and principles:
 - force
 - inertia
 - torque (T)
 - mechanical work $W = Fs$, mechanical power (average and instantaneous)
 - mechanical efficiency
 - energy: gravitational potential energy $PE = mgh$, kinetic energy $KE = \frac{1}{2} mv^2$
 - Newton's Laws of Motion
 - principles of conservation of momentum
 - principles of conservation of energy.
- angular parameters:
 - angular velocity (ω)
 - centripetal acceleration $a = \omega^2 r = \frac{v^2}{r}$
 - uniform circular motion power $P = T\omega$
 - rotational kinetic energy $KE = \frac{1}{2} I\omega^2$
- lifting machines, including inclined planes, scissor jacks, pulleys:
 - velocity ratio
 - mechanical advantage
 - effort and load motion
 - friction effects.

D Fluid engineering systems

- Application of appropriate units

D1 Fluid systems

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- submerged surfaces in fluid systems:
 - hydrostatic pressure and hydrostatic thrust on an immersed plane surface $F = \rho g Ax$
 - centre of pressure of a rectangular retaining surface with one edge in the free surface of a liquid
- immersed bodies:
 - Archimedes' principle
 - determination of density using floatation methods
 - relative density

- fluid flow in a gradually tapering pipe:
 - flow rate (volumetric and mass)
 - flow velocities (input and output)
 - input and output pipe diameters
 - incompressible fluid flow (continuity of volumetric flow $A_1v_1 = A_2v_2$ and mass flow $\rho A_1v_1 = \rho A_2v_2$)

E Static and direct current electricity and circuits

- Application of appropriate units

E1 Static and direct current electricity

Recall, perform procedures, demonstrate an understanding of and analyse information and systems, in the context of electrical circuits (networks) and devices, including:

- conductance
- conventional current flow
- charge/electron flow $I = \frac{q}{t}$
- voltage
- Coulomb's law $F = \frac{q_1q_2}{4\pi\epsilon_0r^2}$
- factors affecting resistance, including conductor length, cross sectional area, resistivity, and temperature coefficient of resistance $R = \frac{\rho l}{A}$, $\frac{\Delta R}{R_0} = \alpha\Delta T$
- resistors, including function, fixed, variable, values
- electric field strength, including uniform electric fields $E = \frac{F}{q}$, $E = \frac{v}{d}$
- factors affecting capacitance, including plate spacing, plate area, permittivity $C = \frac{\epsilon A}{d}$
- capacitors – typical capacitance values and construction, including plates, dielectric materials and strength, flux density, permittivity.

E2 Direct current circuit theory

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- Ohm's law $I = \frac{V}{R}$
- Power $P = IV$, $P = I^2R$, $P = \frac{V^2}{R}$
- Efficiency (η) = $\frac{P_{out}}{P_{in}}$
- Kirchhoff voltage and current laws $V = V_1 + V_2 + V_3$ or $\Sigma PD = \Sigma IR$, $I = I_1 + I_2 + I_3$
- Charge, voltage, capacitance and energy stored in capacitors

$$Q = CV, W = \frac{1}{2}CV^2$$

- RC transients (capacitor/resistor), charge and discharge, including exponential growth and decay of voltage and current, and time constant $\tau = RC$
- Diodes, including forward and reverse bias characteristics:
 - forward mode applications, including rectification, clamping, circuit/component protection
 - reverse mode applications, including zener diode for voltage regulation

E3 Direct current networks

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- DC power sources, including cells, batteries, stabilised power supply, photovoltaic cell/array and internal resistance
- at least five resistors in series and parallel combinations

$$R_T = R_1 + R_2 + R_3$$

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

- DC circuits containing resistors and two power sources
- DC power source with at least two capacitors connected (series, parallel, combination).

F Magnetism and electromagnetic induction

- Application of appropriate units

F1 Magnetism

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- magnetic field:
 - flux density $B = \frac{\phi}{A}$
 - magnetomotive force (mmf) and field strength (H), $F_m = NI$, $H = \frac{NI}{l}$
 - permeability $\frac{B}{H} = \mu_0 \mu_r$
 - B/H curves and loops
 - ferromagnetic materials
 - reluctance $S = \frac{F_m}{\phi}$
 - magnetic screening
 - hysteresis
- electromagnetic induction and applications:
 - induced electromotive force (emf)
 - relationship between induced emf, magnetic field strength, number of conductor turns and rate of change of flux
 - relationship between number of turns, magnetic length, permeability, and inductance
 - eddy currents
 - principle of operation of electric motors and generators including efficiency
 - self inductance, including inductance of a coil, energy stored in an inductor, induced emf

$$L = \frac{N\phi}{I}, W = \frac{1}{2} LI^2, E = Blv, E = -N \frac{d\phi}{dt} = -L \frac{dI}{dt}$$

- mutual inductance (principals of transformer operation – step up/down, primary and secondary current and voltage ratios, including efficiency.)

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

- application of Faraday's and Lenz's laws.

G Single-phase alternating current

- Application of appropriate units

G1 Single-phase alternating current theory

Recall, perform procedures, demonstrate an understanding of and analyse information and systems involving:

- waveform characteristics:
 - sinusoidal and non-sinusoidal waveforms
 - amplitude, time period, frequency
 - instantaneous values:
 - peak/peak-to-peak
 - root mean square (RMS):

$$\text{RMS voltage} = \frac{\text{peak voltage}}{\sqrt{2}}$$
 - average values:

$$\text{average value} = \frac{2}{\pi} \times \text{maximum value}$$
 - form factor:

$$\text{form factor} = \frac{\text{RMS value}}{\text{average value}}$$
- AC principles:
 - determination of values using phasor and trigonometric representation of alternating quantities
 - graphical and phasor addition of two sinusoidal voltages
 - reactance and impedance of pure R, L and C components

$$X_C = \frac{1}{2\pi fC}, X_L = 2\pi fL$$

- total impedance of an inductor in series with a resistance $z = \sqrt{X_L^2 + R^2}$
- total impedance of a capacitor in series with a resistance $z = \sqrt{X_C^2 + R^2}$
- rectification, including half wave, full wave.

Grade descriptors

To achieve a grade a learner is expected to demonstrate these attributes across the essential content of the unit. The principle of best fit will apply in awarding grades.

Level 3 Pass

Learners are able to use and apply basic electrical, electronic, mechanical and mathematical principles to solve simple and familiar engineering and mathematical problems directly. They can provide responses showing understanding and analysis of basic and familiar engineering problems. They can interpret and analyse diagrams, graphical information and systems, using their knowledge and understanding to solve basic and familiar problems. They can select and implement appropriate basic procedures to provide solutions for given mathematical and engineering situations. They often use appropriate engineering and mathematical terminology and units.

Level 3 Distinction

Learners are able to use and apply advanced electrical, electronic, mechanical and mathematical principles to solve complex and unfamiliar engineering and mathematical problems directly, indirectly and synoptically. They can provide balanced responses showing developed understanding and evaluation of complex familiar and unfamiliar engineering problems. They can interpret and evaluate diagrams, graphical information and systems, using their knowledge and understanding to solve complex familiar and unfamiliar problems. They can select and implement appropriate advanced procedures to provide justified and optimised solutions for given engineering and mathematical situations. They use appropriate and technically accurate engineering and mathematical terminology consistently. Learners can propose solutions to problems, drawing on their knowledge and understanding of electrical, electronic, mechanical and mathematical principles.

Key terms typically used in assessment

The following table shows the key terms that will be used consistently by Pearson in our assessments to ensure students are rewarded for demonstrating the necessary skills.

Please note: the list below will not necessarily be used in every paper/session and is provided for guidance only.

Command or term	Definition
Calculate	Learners judge the number or amount of something by using the information they already have, and add, subtract, multiply, or divide numbers. For example, 'Calculate the reaction forces...'
Convert	Learners will change the form of a measurement to different units without a change of size or amount. For example, 'Convert degrees into radians...'
Draw	Learners make a graphic representation of data by hand (as in a diagram). For example, 'Draw a diagram to represent...'
Describe	Learners give a clear, objective account in their own words showing recall, and in some cases application, of the relevant features and information about a subject. For example, 'Describe mechanical advantage...'

Command or term	Definition
Explain	Learners make something clear or easy to understand by describing or giving information about it. For example, 'Explain one factor affecting...'
Find	Learners discover the facts or truth about something. For example, 'Find the coordinates where...'
Identify	Provide or select an answer from a number of alternatives. For example, 'Identify the unit of measure for the energy loss and identify the definition of...'
Label	Learners affix a label to; mark with a label. For example, 'Label the diagram to show...'
Name	Give the correct term for something.
Solve	Learners find the answer or explanation to a problem. For example, 'Solve the equation to...'
State	Learners declare definitely or specifically. For example, 'State all three conditions for...'

Links to other units

This unit would relate to the teaching of the following and other units:

- Unit 2: Delivery of Engineering Processes Safety as a Team.
- Unit 3: Engineering Product Design and Manufacture
- Unit 4: Applied Commercial and Quality Principles in Engineering.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 2: Delivery of Engineering Processes Safely as a Team

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore how processes are undertaken by teams to create engineered products or to deliver engineering services safely.

Unit introduction

The use of engineering processes is integral to the manufacture of engineered products and the delivery of engineering services. Thousands of engineering processes are used in the manufacture and service of a complex product, such as an aeroplane. To ensure that these engineering processes can be planned and carried out safely and effectively, engineers must be able to work together to get the job done. It is for this reason that so many engineering companies focus time and effort on understanding engineering processes and developing teamwork.

In this unit, you will examine common engineering processes, including health and safety legislation, regulations that apply to these processes and how individual and team performance can be affected by human factors. You will learn the principles of another important process, engineering drawing, and develop two-dimensional (2D) computer-aided drawing skills while producing orthographic projections and circuit diagrams. Finally, you will work as a team member and team leader to apply a range of practical engineering processes to manufacture a batch of an engineered product or to safely deliver a batch of an engineering service. To complete the assessment task within this unit, you will need to draw on your learning from across your programme.

It is important that engineers understand how engineering processes are used to safely transform ideas and materials into products and services, and how critical it is to be able to work as a valuable member of an effective team or as a team leader. This unit will enable you to apply the knowledge and understanding you gained in *Unit 1: Engineering Principles*. The unit will help to prepare you for an engineering apprenticeship, a higher education engineering degree or a technician-level role in a wide range of specialist engineering areas.

Learning aims

In this unit you will:

- A** Examine common engineering processes to create products or deliver services safely and effectively as a team
- B** Develop two-dimensional computer-aided drawings that can be used in engineering processes
- C** Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine common engineering processes to create products or deliver services safely and effectively as a team	<p>A1 Common engineering processes</p> <p>A2 Health and safety requirements</p> <p>A3 Human factors affecting the performance of engineering processes</p>	A report, prepared as an individual, detailing engineering processes and the impact that human factors can have on their performance, using a case study based on a given engineered product/products or a given engineering service/services.
B Develop two-dimensional computer-aided drawings that can be used in engineering processes	<p>B1 Principles of engineering drawing</p> <p>B2 2D computer-aided drawing</p>	Practical activities to be undertaken as an individual to produce 2D computer-aided drawings. The drawings should include an orthographic projection and an electric circuit diagram. The evidence will include the drawings, observation records/witness statements and annotated screenshots.
C Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team	<p>C1 Principles of effective teams</p> <p>C2 Team set-up and organisation</p> <p>C3 Health and safety risk assessment</p> <p>C4 Preparation activities for batch manufacture or batch service delivery</p> <p>C5 Delivery of manufacturing or service engineering processes</p>	Complete practical engineering processes as a leader and as a member of a team. The evidence will include records of team meetings (minutes), activity logs, a risk assessment, set-up planning notes, quality control charts/annotated drawings, modified production plans, annotated photographs of the processes and observation records/witness statements.

Content

Learning aim A: Examine common engineering processes to create products or deliver services safely and effectively as a team

A1 Common engineering processes

- Transforming ideas and materials into products or services, including:
 - preparation processes undertaken before manufacture or service delivery – use of information sources and the creation of technical specifications, engineering drawings, work plans and quality control documentation with due regard to the scale of production (one-off, small batch, large batch, mass or continuous)
 - standards relevant to the specialist area of study – guidelines/rules to ensure conformity in processes or outputs, e.g. BS 8888, reference charts (limits and fits, tapping drills, bend allowances), procedure specifications.
- A product and a service are closely aligned concepts, define:
 - a product as a tangible and discernible item, e.g. a car
 - a service as an intangible benefit, either in its own right or as a significant element of a tangible product, e.g. a car service.
- Common processes used to create engineered products, including:
 - fitting, e.g. at a bench using manual tools (drilling, cutting, filing)
 - machining, e.g. turning, milling, grinding
 - fabrication, e.g. welding, sheet metal work (bending, stamping, punching)
 - electrical, e.g. installation of looms, use of connectors/cables
 - forming, e.g. casting, forging, moulding.
- Common processes used in engineering services, including:
 - disassembly, e.g. use of general tools and special tools to strip or remove
 - inspection, e.g. checking for faults/correct operation, testing
 - systems servicing, e.g. capture of fluid, depressurisation
 - installation/replacement, e.g. rigging, assembly, refitting.

A2 Health and safety requirements

The general contents of legislation and regulations or other relevant international equivalents and how they are satisfied by safe systems of work/procedures, including:

- Current Health and Safety at Work legislation – duties of employers, employees, the Health and Safety Executive (HSE) and others, general prohibitions
- Current Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) – duties of employers, the self-employed and people in control of work premises (the Responsible Person) to report certain serious workplace accidents, occupational diseases and specified dangerous occurrences
- Current Personal Protective Equipment (PPE) at Work Regulations – appropriateness if risk cannot be controlled in any other way, types of PPE, assessing suitable PPE given the hazard, supply, instructions/training, correct use, maintenance and storage
- Current Control of Substances Hazardous to Health Regulations (COSHH) – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Current Manual Handling Operations Regulations (MHOR) – avoiding the need for manual handling, types of hazard, assessing risk of injury when manual handling is required, controlling and reducing the risk of injury, training in the use of techniques/mechanical aids.

A3 Human factors affecting the performance of engineering processes

- Understanding that human factors affect the productivity of processes, including conformance to quality standards, reliability and the safety of individuals.
- Understanding that human factors affect the performance of individuals and teams, including:
 - professionalism – adherence to codes of conduct, acting with due care, skill and diligence by recognising appropriate behaviours and possible limitations, preventing avoidable dangers/adverse impact on the environment, enhancing operational competence
 - ethical principles – rigour, honesty, integrity, respect, responsibility
 - behaviours – values, attitude, persuasion, coercion, rapport, authority
 - limitations – stress, time pressure, fatigue, memory, capability, motivation, knowledge, experience, health, inhibitors, e.g. alcohol and drugs.

Learning aim B: Develop two-dimensional computer-aided drawings that can be used in engineering processes**B1 Principles of engineering drawing**

- Attributes of orthographic projections, including:
 - geometry – shape of the component represented as different views, how the component is viewed from various angles, visibility of component features
 - dimensions – size of the component in defined units
 - tolerances – allowable variations for defined dimensions
 - material – what the component is to be made from
 - surface texture – surface quality required, e.g. roughness, flatness
 - scale – relative to actual dimensions.
- Drawing conventions or other relevant international equivalents, including:
 - standards including BS 8888 and BS 60617 or other relevant international equivalents
 - title block/layout – drawing number(s), projection symbols, scale, units, general tolerances, name of author, date, border, parts referencing
 - views – elevation, plan, end, section, hatching style, auxiliary
 - line types – centre, construction, outline, hidden, leader, dimension
 - common features, e.g. screw threads, springs, splines, repeated items, holes, chamfers, radii
 - circuit diagram symbols and components, e.g. cell/battery, switch, resistor, diode, capacitor, transistor, integrated circuit, light-emitting diode (LED), motor, buzzer
 - lettering – titles, notes, annotation
 - abbreviations – A/F, CHAM, DIA, R, PCD, M.

B2 2D computer-aided drawing

Using a computer-aided design (CAD) system to produce engineering drawings and circuit diagrams, including:

- coordinates – absolute, relative, polar
- drawing template – border, title block with all necessary information
- layers – names, line types, colours, visibility
- commands – line, circle, arc, polygon, chamfer, fillet, grid, snap, copy, rotate, erase, stretch, trim, scale, dimensioning, text, pan, zoom-in, zoom-out, insertion and editing commands to produce and erase circuit components and connections
- cross-hatching – simple and complex areas, predefined hatch patterns, application to cross-sectioning.

Learning aim C: Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team

C1 Principles of effective teams

- Good communication – verbal, written (e.g. electronic documents and data, activity logs, meeting minutes), effective listening, respect for others' opinions, negotiation, assertiveness and non-verbal actions, e.g. smiling.
- Planning – thinking ahead, organisation, consideration of alternatives.
- Motivation – shared goals, collaboration, reaching agreements, adapting behaviour, fairness and consideration, opportunities to take responsibility, constructive feedback.
- Working with others – team player, flexibility/adaptability, social skills, supporting others.
- Working environment – conducive to successful outcomes, safe, supportive, challenging, opportunities to show initiative and leadership.

C2 Team set-up and organisation

- A team is defined as containing three or more individual members who have a shared common objective to complete.
- Strengths and limitations of team members – perceived competencies and constructive peer feedback.
- Allocation of responsibilities – roles, activities.
- Timescales – planning the activities.
- Objectives – team targets.

C3 Health and safety risk assessment

Risk assessment in an engineering workshop and for specific engineering processes, following guidance from the HSE (or other relevant international equivalents), including:

- identification of hazards – bad housekeeping, poor lighting, lack of grip/uneven surfaces/heights, lifting and handling operations, hand tools, machines, substances, heat/flammability
- assessing risk by determining how hazards can cause injury – contact, being struck, lifting and handling injury, fall, slip, trip, trap, exposure
- choosing and using appropriate control measures and precautions to reduce risk – good work area design, substitution, safe means of access and egress, safe system of work (permits to work), periodic inspection, testing and maintenance, physical barriers (guarding), PPE, supervision and training, good housekeeping, cleaning regime
- recording all findings – standard HSE (five steps) pro forma
- reviewing the risk assessment after new equipment/work activities have been undertaken, at regular intervals.

C4 Preparation activities for batch manufacture or batch service delivery

- A batch is defined as a quantity of three or more of a product or service delivered together.
- Understanding the requirements of production plans, specifications, engineering drawings and other technical documentation, including:
 - operations – sequence of production
 - health and safety factors – product or service based
 - processes – disassembly, mechanical, electrical, assembly, testing
 - materials, parts and components – to be disassembled, worked on, processed, joined, assembled and checked
 - equipment – marking out, hand tools, machinery, measuring
 - quality checks – critical production control points, how quality will be checked and inspected.

C5 Delivery of manufacturing or service engineering processes

- For engineered products or engineering services.
- Examples of engineered products, e.g. screwdriver, toolmakers' clamp, fabricated box/enclosure, outside calipers, ball joint splitter, clamp stand, assembling looms.
- Selecting, setting up and using engineering equipment to manufacture engineered products, including:
 - marking out processes, e.g. using a scribe, rule/tape, punch, square, vernier height gauge, marking out medium
 - manual processes, e.g. using shears, punch, guillotine, bender, saw, tap, die, file
 - machining processes, e.g. using a drill, lathe, milling machine
 - assembly processes, e.g. using adhesive, mechanical fasteners, cables/connectors
 - quantity production, e.g. using form tools, template, jig, mould, fixture, stops
 - measuring processes, e.g. using a micrometer, vernier calipers, comparators.
- Examples of engineering services, e.g. dismantling/assembly of alternators, including replacing worn parts and testing, removing and replacing fluid plumbing and checking for leaks, stripping out a variety of hardware and reinstalling/testing, assembly of pipework, including the connection of valves and operational checks, assembly and testing of electrical switch panels.
- Selecting, setting up and using engineering equipment to deliver engineering services, including:
 - disassembly/removal/strip processes, e.g. using a screwdriver, wrench, spanner, sockets, pliers/grips, keys
 - manual processes, e.g. using snips, cutters, knives, punch, saw, file, hammer
 - assembly processes, e.g. using a soldering iron, mechanical fasteners, cables/connectors, crimping tools, pneumatic tools, clamps
 - inspection/testing processes, e.g. using a multimeter, flow meter, torque meter, pressure sensor/gauge.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine common engineering processes to create products or deliver services safely and effectively as a team		A.D1 Evaluate, using high-quality written language, the effectiveness of using different engineering processes to manufacture a product or to deliver a service and how human factors, as an individual and as a team, affect the performance of engineering processes.
A.P1 Explain how three engineering processes are used safely when manufacturing a given product or when delivering a given service. A.P2 Explain how human factors, as an individual or as a team, affect the performance of engineering processes.	A.M1 Analyse why three engineering processes are used to manufacture a product or to deliver a service and how human factors, as an individual and as a team, affect the performance of engineering processes.	
Learning aim B: Develop two-dimensional computer-aided drawings that can be used in engineering processes		B.D2 Refine, using layers, an accurate orthographic projection of a component containing at least three different common feature types and a circuit diagram containing at least six different component types to an international standard.
B.P3 Create an orthographic projection of a given component containing at least three different feature types. B.P4 Create a diagram of a given electronic circuit containing at least six different component types.	B.M2 Produce, using layers, an accurate orthographic projection of a component containing at least three different feature types and a circuit diagram containing at least six different component types that mostly meet an international standard.	
Learning aim C: Carry out engineering processes safely to manufacture a product or to deliver a service effectively as a team		C.D3 Consistently manage own contributions effectively using feedback from peers, as a team member and as a team leader, to set up, organise and manufacture a product or deliver a service safely, demonstrating forward thinking, adaptability or initiative.
C.P5 Manage own contributions to set up and organise a team in order to manufacture a product or deliver a service. C.P6 Produce, as an individual team member, a risk assessment of at least one engineering process. C.P7 Set up, as an individual team member, at least one process safely by interpreting technical documentation. C.P8 Manage own contributions safely, as a team member and as a team leader, to manufacture a batch of an engineered product or to deliver a batch of an engineering service.	C.M3 Manage own contributions safely and effectively using feedback from peers, as a team member and as a team leader, to manufacture a product or to deliver a service.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.P7, C.P8, C.M3, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of technical documentation (such as engineering drawings, production plans, specifications, health and safety regulations), components and circuits
- suitable CAD workstations and output devices, e.g. printers and plotters, and 2D CAD software that is capable of professional 2D drawings and their output, e.g. AutoCAD 2D, AutoCAD Lt, TurboCAD Deluxe, DraftSight
- standard engineering workshop equipment and resources (as specified in the learning aims and unit content section), so learners can carry out common engineering processes to manufacture an engineered product batch or deliver an engineering service as a member of a team.

Essential information for assessment decisions

Learning aim A

The processes to be considered for learning aim A do not have to be the same as those used for learning aim C.

For distinction standard, learners will produce evidence that evaluates the relative merits of using different common engineering processes to manufacture a given product or deliver a given service, by comparing and contrasting the advantages and limitations of the chosen processes and of using other possible processes. Learners will provide detailed and justified reasons as to which processes are most effective, by referring to the specific requirements of the given product or service, for example by considering why a product is cast rather than machined, or whether to test or disassemble at a given interval.

Learners will also produce evidence that shows they can evaluate the impact that a range of human factors, as an individual and as a team, can have on the performance of engineering processes, for example, how coercion by someone in authority could lead to an individual or team introducing unnecessary hazards and risks into the engineering processes.

Overall, the evidence will be easy to read by a third party, who may or may not be an engineer, and will be easily understood. 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, learners will produce evidence that shows they can give detailed reasons as to why three common engineering processes have been chosen to manufacture a given product or to deliver a given service. The analysis will be consistent across all the processes and will include a contextual commentary. For example, for each process it will refer to scale of manufacture, the achievement of accuracy in comparison to a standard, and specific health and safety requirements.

Learners will also produce contextual evidence that shows they can analyse how human factors, as an individual and as a team, can impact on the performance of the three common engineering processes, for example by anticipating and preventing common errors, avoidable dangers or adverse impacts on the environment.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will produce evidence that shows they understand how three common engineering processes are used to manufacture a product or deliver a service. The evidence will be factually accurate and will include clear references to health and safety legislation and regulations, for example how drilling, turning and milling are used to produce a given product/products, or how to dismantle and replace worn parts and test an item using safe working practices and personal protective equipment, including why and how to report a dangerous occurrence during a process.

Learners will also produce evidence that shows they recognise the impact that human factors, either as an individual or as a team, can have on the three common engineering processes, for example the productivity of the processes being affected by an individual's attitude or capability, or safety being affected by fatigue.

Overall, the explanations may be basic in parts and may have some inaccuracies relating to engineering terminology.

Learning aim B

The orthographic drawings must be created on a 2D CAD package and not on a 3D CAD package. The component and electrical circuit to be drawn for learning aim B do not have to be used for learning aims A or C. The drawing should be created from an actual engineered component that must contain at least three different types of common feature. Learners will create the drawings using the knowledge and understanding gained in *Unit 1: Engineering Principles*. For example, taking measures from and performing calculations using the physical component, which could include geometry/vectors, basic arithmetic, trigonometry, and surface area and volume.

For distinction standard, learners will show in their evidence that they used a full range of CAD commands when generating the drawings and prepared and used additional layers as required for the drawing template, dimensioning and annotation.

Overall, all details in the 2D CAD orthographic projection and the electrical circuit diagram must be produced to typically represent the standards found in BS 8888 and BS 60617 (or other relevant international equivalents), with no omissions or errors evident.

For merit standard, learners will show in their evidence that they used a layer for a drawing template with a full title block, border and appropriate text.

Overall, all details in the 2D CAD orthographic projection and the electrical circuit diagram must be produced to typically represent the standards found in BS 8888 and BS 60617 (or other relevant international equivalents), although there may be some minor errors evident, such as the lack of a visible gap between some features of the component and extension lines, or some text that is incorrectly orientated.

For pass standard, learners will produce elevations that are technically correct but there may be some errors, such as a repeated dimension or inaccurate annotation.

Overall, all details in the 2D CAD orthographic projection drawing and the electric circuit diagram must be suitable for a competent third party to manufacture the component or the electric circuit from the drawings.

Learning aim C

Learners will work as a team to deliver an engineering service or to manufacture a product. They will use the knowledge and understanding gained in *Unit 1: Engineering Principles* to undertake and manage a practical service or manufacturing task. During assessment, a team should manufacture a batch of an engineered product or deliver a batch of an engineering service, not both. The choice is likely to be dependent on the sector context and/or the resources available. All planning and manufacturing or service activities should take no more than 15 hours in total. A team should consist of three or four learners and it is expected that the role of team leader will be undertaken by all team members (in rotation) after the initial planning activities. The number of items in a batch, and the number of processes in a product or service, should be between three and six.

Teams should be given a range of technical documentation (such as engineering drawings, production plans and specifications) prior to the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. Materials can be prepared and engineering equipment can be laid out prior to team activities, but each learner must set up and undertake at least one engineering process.

For distinction standard, learners will consistently demonstrate at least one of the following traits during the planning and manufacturing or service activities: forward thinking, adaptability or initiative. For example, learners may respond to opportunities as they arise by convincing the team to adopt a more efficient approach to the manufacturing or service activities, or a different approach if a lack of equipment or resources demands it, or they may adapt to circumstances quickly by providing feedback to team members or by coaching others who are struggling with an activity or process. Learners may also prove their capability to adapt a process and/or machines to manufacture quantities of a product, for example by setting stops or by using simple techniques to process components at the same time. Similar approaches could be used in the delivery of a batch of an engineering service.

Learners will show their ability to objectively review team targets at suitable points and reach agreements with other team members as to an appropriate way forward given current progress.

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 demonstrate an active role in making decisions concerning the allocation of roles and responsibilities, time planning and setting team targets, for example by explicitly taking into account the preferences and perceived strengths of team members.

Learners will produce a risk assessment, which will be laid out on an appropriate industry-standard template and will include detailed attention to all five steps, for example clear identification of all significant hazards, who might be harmed and how, current precautions in place, further control measures needed and a suitable time period until review.

Learners will interpret technical documentation to set up safely and effectively at least one engineering process, for example, so that others in the team could also carry out the process with minimal explanation required.

During the delivery of manufacturing or service processes, learners will show that they can work effectively as a team member and as a team leader to make effective progress towards team targets. For example, they will modify their approach based on feedback from peers and will generate a progress log to allow team members to quickly review progress.

Overall, the evidence will be clear, but some parts of it may be presented in an inconsistent fashion, making it more difficult for a third party to understand.

For pass standard, learners will manage their contribution to making decisions concerning the allocation of roles and responsibilities, time planning and setting team targets. These activities will be completed as a minimum to set up and organise the team to manufacture a batch of an engineered product or to deliver a batch of an engineered service.

It will be essential to ensure that each team member has clear responsibilities and that everyone makes a contribution to the end result during the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. All individual team members must be clear about who is responsible and accountable for each aspect of the work, and team targets should be set and reviewed. To facilitate this, each team must carry out a series of meetings both prior to and during the manufacture of a batch of an engineered product or the delivery of a batch of an engineering service. Each member of the team must produce their own evidence against the assessment criteria, as evidence cannot be shared.

Learners will produce their own risk assessment to show how health and safety is managed in the engineering workplace, for at least one engineering process to be used when manufacturing the engineered product or when delivering the engineering service. The risk assessment should consider the most significant hazards with details of suitable control measures and be laid out on an appropriate industry-standard template. It will be appropriate, but may lack detail. For example, it may focus on the more obvious hazards and control measures, including those already in place.

Learners will also interpret technical documentation, including a production plan and an engineering drawing given to them, to set up safely at least one engineering process, for example, so that they can carry out the process in a consistent manner.

During the delivery of manufacturing or service processes, learners will show that they can act independently as a team member and as a team leader to make progress towards team targets, although learners may demonstrate some reluctance to adapt to changing circumstances. The products or services delivered by the team do not have to be accurate and do not need to be tested for functionality, but teams must keep quality records. For example, the dimensions of a hole would be checked for conformance against the technical documentation and notes would be made on the outcome of the quality check. Also, teams do not need to rework any non-conforming product or service outcomes.

Overall, the evidence will be logically structured but may be imprecise and basic in some parts, meaning that only a third party with technical knowledge can understand aspects of it.

Links to other units

In the Certificate (180 GLH) qualification this unit should be completed towards the end of the programme. In order to complete the synoptic assessment task in this unit, learners should select and apply relevant knowledge and skills from other areas of the mandatory content. Learners should build on their knowledge of engineering approaches and their applications from *Unit 1: Engineering Principles*.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 3: Engineering Product Design and Manufacture

Level: **3**

Unit type: **External**

Guided learning hours: **120**

Unit in brief

Learners will explore engineering product design and manufacturing processes and will complete activities that consider function, sustainability, materials, form and other factors.

Unit introduction

Engineering products are part of our daily lives, from aircraft to the smallest electronic circuits found in medical devices. Engineering products are designed as a result of the identification of a need or opportunity, and then engineers using creative skills and technical knowledge to devise and deliver a new design or improvements to an existing design. For example, advances in the development of fuels led to the first internal combustion engine, and engineers have been improving its design ever since.

In this unit, you will examine what triggers changes in the design of engineering products and the typical challenges that engineers face, such as designing out safety risks. You will learn how material properties and manufacturing processes impact on the design of an engineering product. Finally, you will use an iterative process to develop a design for an engineering product by interpreting a brief, producing initial ideas and then communicating and justifying your suggested solution. You will draw on and apply knowledge and understanding from *Unit 1: Engineering Principles* and *Unit 2: Delivery of Engineering Processes Safely as a Team*, for example by using calculations to demonstrate a reduction in mass, by sketching using orthographic projection drawing methods or by justifying an engineering process as its use reduces the carbon footprint of a product. To complete the assessment task within this unit, you will need to draw on your learning from across your programme.

It is important that engineers use creative and technical knowledge, understanding and skills to transform ideas into viable products, and that they understand the critical importance of this activity in ensuring that products are both safe and effective. This unit will help prepare you for an engineering apprenticeship, engineering courses in higher education or for technician-level roles in a variety of engineering sectors.

Summary of assessment

This unit is assessed by a set task of 60 marks provided by Pearson and completed under supervised conditions. Part A is given to learners one week before Part B is scheduled. Learners are advised to spend no more than 3 hours on Part A. Learners will be given a case study and produce independent research, no design work should take place at this time, the perimeters of the design are contained in part B.

The supervised assessment period is eight hours and can be arranged over a number of sessions within a two-week assessment period timetabled by Pearson, once the assessment has started the learner must complete within five days. During the supervised assessment period, learners will complete a task that will require them to follow a standard development process of interpreting a brief, scoping initial design ideas, preparing a design proposal and evaluating their proposal.

The assessment availability is December/January and May/June each year. The first assessment availability is May/June 2017.

Sample assessment materials will be available to help centres prepare learners for assessment.

Assessment outcomes

AO1 Demonstrate knowledge and understanding of engineering products and design

AO2 Apply knowledge and understanding of engineering methodologies, processes, features and procedures to iterative design

AO3 Analyse data and information and make connections between engineering concepts, processes, features, procedures, materials, standards and regulatory requirements

AO4 Evaluate engineering product design ideas, manufacturing processes and other design choices

AO5 Be able to develop and communicate reasoned design solutions with appropriate justification

Essential content

The essential content is set out under content areas. Learners must cover all specified content before the assessment.

A Design triggers, challenges, constraints and opportunities, and materials and processes

A1 Design triggers

The triggers that stimulate engineering design activity, including:

- market pull/technology push (product and process)
- demand
- profitability
- innovation
- market research
- product/process performance issues
- sustainability (carbon footprint)
- designing out risk.

A2 Design challenges

Commercial-, regulatory- or public policy-based trends that challenge current technology or design, including:

- reduction of energy wasted during design of an engineered product
- reduction of energy wasted during operation of an engineered product
- reduction of physical dimensions
- reduction of product mass
- increase in component efficiency
- energy recovery features
- reduced product life cycle costs
- integration of different power sources for vehicles
- reduced use of resources in high-value manufacturing
- sustainability issues throughout the product lifecycle (raw materials, manufacture, packaging and distribution, use and reuse, end of life)
- designing out risk (for individual employees and customers).

A3 Equipment level and system level constraints and opportunities

Factors that place limitations and offer opportunities at equipment level on the design of engineering products, including:

- reasons for selecting different solutions for equipment interfaces (mechanical, electrical, hydraulic, software)
- systems integration compromises (cooling, location for optimum equipment performance, bonding, centre of gravity, electrical and electronic compatibility)
- equipment product design specification (PDS) (shortcomings absorbed at system level, electromagnetic compatibility (EMC), mass, cooling)
- cost effective manufacture (capital outlay, use of tooling, set up cost).

A4 Material properties

Properties, modes of failure, protection and lubrication of engineering materials and components that impact upon their selection when designing an engineering product, including:

- mechanical properties
- physical properties
- thermal properties
- electrical and magnetic properties

- behaviour of advanced materials (bio materials, smart alloys, nanoengineered materials)
- modes of failure
- surface treatments and coating
- lubrication (purposes, regimes).

A5 Mechanical power transmission

Characteristics of an engineering system that makes use of forces and movement that impacts on mechanical power transmission component selection when designing an engineering product, including:

- linkages (types, mechanical advantage, examples from nature)
- mechanical motion (linear, rotary, reciprocating, oscillating)
- power sources (mechanical, electrical, energy from nature)
- control of power transmission (sensors, actuators, servomotors).

A6 Manufacturing processes

Characteristics and effects of manufacturing processes that impact on the selection of engineering materials and components when designing an engineering product, including:

- processes for metals (additive, moulding, machining, forming, casting, powder metallurgy, joining, assembly)
- processes for polymers (additive, casting, moulding, extrusion, thermoforming)
- processes for ceramics (additive, casting, forming)
- processes for composites (layup, moulding, automated tow placement)
- effects of processing (recrystallisation, grain structure, alloying elements, material combinations, process parameters)
- scales of manufacture (one-off, small batch, large batch, mass, continuous).

B Interpreting a brief into operational requirements and analysing existing products

B1 Design for a customer

Meeting customer needs during engineering design activity, including:

- types of customer (internal, external)
- product and service requirements (performance specifications, compliance to operating standards, manufacturing quantities, reliability/product support, product life cycle, usability, anthropometrics)
- product design specification/criteria (cost, quantity, maintenance, finish, materials, weight, aesthetics, product life cycle, sustainability, carbon footprint, reliability, safety, testing, ergonomics, usability, competition, market, manufacturing facility, manufacturing constraints, manufacturing processes)
- commercial protection (patents, registration, copyright, trademarks).

B2 Regulatory constraints and opportunities

Regulatory factors that place limitations and opportunities on the design of engineering products, including:

- legislation, standards, codes of practice, national and international certification requirements
- environmental constraints (sustainability, carbon footprint, product life cycle)
- health and safety, security (product and process).

B3 Market analysis

Engineering goals in terms of marketing when designing an engineering product, including:

- unique selling point (USP)
- benefits of the design
- obsolescence.

B4 Performance analysis

Engineering goals in terms of performance when designing an engineering product, including:

- product form
- product functionality
- technical considerations
- choice of materials and components
- environmental sustainability (impact, carbon footprint)
- interactions with other areas/components
- likelihood of failure or wear.

B5 Manufacturing analysis

Engineering goals in terms of manufacturing when designing an engineering product, including:

- processes for manufacturing/assembly
- manufacturing requirements
- quality indicators
- environmental sustainability (impact, carbon footprint)
- design for manufacture.

C Using an iterative process to design ideas and develop a modified product proposal**C1 Design proposals**

Initial and developed propositions to improve an engineering product, including:

- technical design criteria
- idea generation (context, creativity, range)
- initial design ideas (fitness for purpose, refinements, recognition of constraints)
- developed design idea (aesthetics, ergonomics, sizes, mechanical and electronic principles, material requirements, manufacturing processes, assembly arrangements, cost estimations, factor of safety, selection procedures for bought out components)
- use of information sources.

C2 Communicating designs

Communication of an initial and a developed proposition to improve an engineering product, including:

- freehand sketching and diagrams (2D and 3D, illustrations, technical)
- graphical techniques (charts, keys, shading, animation, symbols, conventions)
- written skills (annotation, technical language, interpreting results)
- documentation (detail and assembly orthographic projections, specifications, parts list, materials list, production plan, circuit/block diagrams, flowchart, design log).

C3 Iterative development process

Using an iterative process to improve an engineering product, including:

- refining a task or process (analysing, adapting, enhancing)
- cyclic process (logical non-linear approach, focus on product design specification/criteria).

D Technical justification and validation of the design solution**D1 Statistical methods**

Statistical techniques as applied to engineering problems, including:

- statistical measurement (discrete/continuous, mean, median, mode, variance)
- data handling:
 - graphical representation (bar chart, pie chart, frequency table, histogram, cumulative frequency diagram or graph)
 - frequency distributions (normal, skewed, standard deviation).

D2 Validating designs

Rationalise choices made when generating a developed proposition to improve an engineering product, including:

- objective referencing against product design specification/criteria
- objective referencing against weighted matrix
- indirect benefits and opportunities
- balancing benefits and opportunities with constraints (cost-benefit analysis, environmental benefits, health and safety risks, product life cycle considerations)
- design for manufacturing
- further modifications (technology-led adaptations).

Grade descriptors

To achieve a grade a learner is expected to demonstrate these attributes across the essential content of the unit. The principle of best fit will apply in awarding grades.

Level 3 Pass

Learners demonstrate knowledge and understanding of iterative design methodologies, processes, features and procedures and their application to engineering products. They can interpret a design brief to generate ideas, and will deploy skills and selected techniques to develop modified products in context. Learners demonstrate research and analytical skills in order to create a product design specification to meet the requirements of a brief. They make recommendations and proposals relevant to familiar and unfamiliar situations, with consideration of design sustainability and safety issues. Learners will make evaluative judgements in relation to their design proposal and be able to provide technical justifications in the validation of their design solution.

Level 3 Distinction

Learners demonstrate thorough knowledge and understanding of iterative design methodologies, processes, features and procedures and can apply this understanding to engineering products in context. They can interpret a design brief to generate complex design ideas, and will deploy a range of skills and selected techniques to develop modified products in context and with justification. They demonstrate comprehensive research and analysis skills in order to generate a product design specification that fully and effectively meets the requirements of the brief. They present justified recommendations and proposals relevant to familiar and unfamiliar situations, with consideration of design sustainability and safety issues. Learners are able to select appropriate techniques and processes to design ideas and will justify applications in arriving at creative, feasible and optimised solutions. Learners will make robust, evaluative judgements in relation to their design proposal and be able to provide detailed technical justifications in the validation of their design solution.

Key terms typically used in assessment

The following table shows the key terms that will be used consistently by Pearson in our assessments to ensure students are rewarded for demonstrating the necessary skills.

Please note: the list below will not necessarily be used in every paper/session and is provided for guidance only.

Command or term	Definition
Client brief	Outlines the client's expectations and requirements for the product.
Design	A drawing and/or specification to communicate the form, function and/or operational workings of a product prior to it being made or maintained.
Manufacture	To make a product for commercial gain.
Project log	A document to record the progress made, key activities and decisions taken during the development of a project.

Links to other units

The assessment for this unit should draw on knowledge, understanding and skills developed from:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safety as a Team
- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 5: A Specialist Engineering Project
- Unit 6: Microcontroller Systems for Engineers
- Unit 7: Calculus to Solve Engineering Problems
- Unit 32: Computer System Principles and Practice
- Unit 39: Modern Manufacturing Systems
- Unit 48: Aircraft Flight Principles and Practice.

Employer involvement

Centres may involve employers in the delivery of this unit if there are local opportunities. There is no specific guidance related to this unit.

Unit 4: Applied Commercial and Quality Principles in Engineering

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore commercial engineering, for example key business activities, cost control, quality systems and value management, which is used by engineering organisations to create value.

Unit introduction

Engineering organisations use a wide range of systems and methods to ensure that they are competitive. For example, organisations can develop a competitive advantage by increasing the quality of their products, innovating with new product designs or reducing the cost of their operations. Well-known brands that have successfully produced a competitive advantage in this way include Dyson, Rolls-Royce and Škoda.

In this unit, you will explore how key business activities and trade considerations influence engineering organisations and are used to create a competitive advantage. You will understand why organisations need to control costs and how they make decisions, applying an activity-based costing methodology. You will also understand what is meant by quality and why it means different things to different people; you will investigate quality systems, including quality assurance and control. Finally, you will explore value management as a process to create value in an organisation.

The quality systems and value management principles and processes provide a foundation for business process improvement techniques, such as Lean and Six Sigma, which many engineering organisations follow to ensure continuous improvement. It has not been possible to include these methodologies as part of this unit; however, should you encounter them in the workplace then this unit provides a basis for understanding and applying them.

As an engineer, it is important that you understand some of the commercial and competitive considerations which ensure that engineering organisations thrive. You will need to apply these principles to technical engineering projects to ensure that they add value to the organisation and are profitable. This unit will help to prepare you for an engineering apprenticeship, higher education and technician-level engineering roles.

Learning aims

In this unit you will:

- A** Examine business functions and trade considerations that help engineering organisations thrive
- B** Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable
- C** Explore how engineering organisations use quality systems and value management to create value.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine business functions and trade considerations that help engineering organisations thrive	A1 Business functions and key activities A2 Trade considerations A3 Competitive advantage	A written report that evaluates how key business activities and trade considerations influence a local engineering organisation and can create competitive advantage.
B Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable	B1 Reasons for cost control and types of costs B2 Activity-based costing method	A research and problem-solving project to explore the costs associated with engineering activities and the completion of an activity-based cost model for a product or service.
C Explore how engineering organisations use quality systems and value management to create value	C1 Quality systems C2 The principles and processes of value management	A research activity to explore quality systems and value management processes. In addition, an applied value analysis exercise to determine if further value can be created from an engineering product or service.

Content

Learning aim A: Examine business functions and trade considerations that help engineering organisations thrive

A1 Business functions and key activities

Functions within an engineering organisation, including human resources (HR), finance, sales, marketing, operations, research and development, and purchasing.

Key activities of business functions, to include:

- manufacturing of products and delivering services, e.g. forming, fabrication, removal of material, addition of material, assembly processes, quality control
- supply chain management, e.g. outsourcing decisions, supplier appraisal
- marketing and sales, e.g. brand awareness, market research, sales, customer feedback
- customer relations, e.g. meeting expectations, being proactive
- resource management, e.g. sources of funding, resource allocation, stock control
- staff recruitment, e.g. internal and external recruitment, apprenticeships
- staff management, e.g. appraisals, support and training (continuing professional development)
- financial, e.g. financial statements (profit and loss, break-even).

A2 Trade considerations

Tendering and contracting, or other relevant international equivalents, including:

- terms, both expressed and implied, e.g. breach of contract, force majeure
- warranties and conditions, e.g. indemnities, guarantees, insurance
- consequences of non-performance, e.g. rejection of goods/services, financial penalty clauses
- documentation, e.g. drawings, estimates, quotations, specifications.

Definition and purpose of intellectual property rights, including patents, registered designs and trademarks.

A3 Competitive advantage

Competitive advantage is the term used to describe what an organisation does that allows it to outperform competitors. It can be created by all functions and/or any combination of activity and trade consideration:

- by innovating
- using new technology
- protecting intellectual property
- managing costs.

Learning aim B: Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable

B1 Reasons for cost control and types of costs

- Reasons for cost control:
 - identifying hidden costs and managing all costs
 - informed decision making, e.g. investment, withdrawal, make or buy
 - improving competitiveness.
- Types of costs, including:
 - direct costs, e.g. raw materials, work in progress (WIP), direct labour costs
 - indirect costs, e.g. energy, insurance, wages, consumables
 - variable costs, e.g. raw materials, consumables
 - semi-variable costs, e.g. overtime costs, commission, maintenance
 - fixed costs, e.g. overheads, rent, machinery costs, depreciation, insurance
 - general/administration costs, e.g. human resources (HR), finance and information technology.

B2 Activity-based costing method

Stages of implementing activity-based costing:

- identifying activities, including the processes and activities required to produce an output
- assigning resource costs to activities, including direct costs, indirect costs and general/administration costs
- identifying outputs, including products, services or customers
- assigning activity costs to outputs, including using activity drivers to assign costs to outputs (cost objects)
- activity cost pools, including material handling, set-up costs, and procurement
- application of activity-based costing to determine profitability.

Learning aim C: Explore how engineering organisations use quality systems and value management to create value**C1 Quality systems**

- Quality standards and accreditation include international quality standards that can be applied for voluntarily by engineering organisations, allowing them to show that they have quality management systems in place. Quality standards associated with engineering activities include:
 - the International Organization for Standardization (ISO) 9000 series, a quality assurance system for the manufacturing and service industries, including:
 - ISO 9000 – knowledge of the 20 requirements for a quality management system
 - ISO 9001 – a planning tool for quality, and to support continual improvement
 - the ISO 14000 series, an environmental management system, including:
 - ISO 14001 – a method of reducing waste
 - ISO 14006 – to improve product quality in an environmentally positive way
 - ISO 14040 series – for life-cycle assessments.
- Quality assurance:
 - definition – planned activities to ensure that the quality requirements of a product or service are met
 - quality assurance as a company-wide philosophy
 - total quality management (TQM) – PDCA cycle (plan, do, check, act).
- Purposes of implementing a quality system, including:
 - benchmarking against other organisations
 - ensuring consistency of processes
 - ensuring conformity of the product or service to a standard
 - reducing unnecessary waste, e.g. inventory, over processing and over production
 - improving the effectiveness of the engineering organisation
 - gaining a competitive advantage
 - achieving customer satisfaction
 - ensuring that a product or service is fit for purpose.
- Quality control:
 - definition – the testing and monitoring of activities that are used to check the quality of a product or service outcome
 - inspection, sampling and testing
 - condition monitoring, e.g. vibration or thermal analysis
 - planned maintenance
 - applying a 'right first time' philosophy.

C2 The principles and processes of value management

- Principles of value management:
 - definitions of cost, value, value added and non-value added activities
 - concepts of function, process and product
 - reasons for poor value, e.g. lack of innovation, poor communication.
- Phases in the process of carrying out a value analysis exercise on a product or service:
 - information phase, e.g. identification of key issues, identification of added and non-value added processes, and cost overviews
 - analysis phase, e.g. functional analysis, which existing processing methods are used, identifying features or parts which are unnecessary
 - creative phase, e.g. generating alternatives for better value solutions, problem-solving tools and methods, developing a least-cost solution
 - evaluation phase, e.g. assessing and prioritising ideas
 - development and reporting phase, e.g. refining ideas and developing action plans.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine business functions and trade considerations that help engineering organisations thrive		A.D1 Evaluate, using language that is technically correct and of a high standard, how key business activities and trade considerations combine to influence an engineering organisation, which can create a competitive advantage.
A.P1 Explain how key business activities influence an engineering organisation. A.P2 Explain how trade considerations influence an engineering organisation.	A.M1 Analyse how key business activities and trade considerations influence an engineering organisation, which can create a competitive advantage.	
Learning aim B: Explore activity-based costing as a method to control costs and to determine if an engineering product or service is profitable		B.D2 Produce an accurate and refined activity-based costing model, during the process, for a product or service to determine the major cost areas that could impact on profitability, explaining the reasons for cost controls.
B.P3 Explain why an engineering organisation controls costs. B.P4 Produce an activity-based cost model for an engineering product or service.	B.M2 Produce accurately an activity-based cost model for an engineering product or service, explaining the reasons for cost controls.	
Learning aim C: Explore how engineering organisations use quality systems and value management to create value		C.D3 Evaluate the outcome of a value management exercise for a given engineering activity and make recommendations which include the use of quality systems to implement efficiencies in the engineering activity.
C.P5 Explain the purposes of different quality management systems and value management used by engineering organisations. C.P6 Complete a value analysis exercise on a given engineering process.	C.M3 Analyse the purpose of different quality management systems and value management used by engineering organisations. C.M4 Complete accurately a value analysis exercise on a given engineering process.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- case studies outlining the operations of engineering organisations
- financial statements for engineering activities
- products or services to analyse, including details of the processes used to achieve the outcomes.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and thorough evaluation of how key business activities and trading considerations combine to influence an organisation. The evaluation will explore, for example, the joint decision of finance, purchasing and operations functions within the organisation to outsource an activity or service, the consideration of whether the organisation has the resources to undertake the activity in-house, and, if suitable suppliers are available, whether they would be able to meet the expectations of the organisation, and agree suitable trading terms. Learners will evaluate whether the use of outsourcing would give the organisation a competitive advantage, for example by lowering costs.

Overall, the evaluation will use correct technical terms, be easy to read and be logically structured. It will be written in a way that is easy to understand for a third party who may or may not be an engineer.

For merit standard, learners will provide a thorough analysis of business activities and trading considerations, using examples to demonstrate that a range of factors impact on the organisation. For example, learners will explain how decisions regarding staff recruitment made by the HR function will impact on financial cash flow. Also, learners will explain the purpose of intellectual rights and how the protection of such rights can be used by engineering organisations to develop a competitive advantage, for example by protecting a brand name through the use of trademarks.

Overall, the analysis will be logically structured and use correct technical terms.

For pass standard, learners will explain how key business activities influence an engineering organisation. For example, learners will explain that the finance function produces a range of financial statements, such as profit and loss reports, to determine the financial viability of the organisation.

Learners will also explain how tendering, contracting and other trade related considerations influence a business organisation. For example, learners will identify and explain the main terms used in contracts or the types of documents used for contracts and tenders, and how these are used by the organisation. For intellectual rights, learners will explain how each of the intellectual rights is used, and how this could benefit the organisation.

Overall, the evidence will be logically structured, and make appropriate use of technical terms. Some explanations may have minor technical inaccuracies, such as using the term 'warranties' when 'guarantees' is more appropriate.

Learning aim B

For distinction standard, learners will provide an accurate activity-based cost model for a given engineering product or service that is refined during the process, to include all of the activities required to produce the final output. Learners will record all costs, assigning them to the correct cost type, and use the model to identify any hidden costs, for example maintenance of equipment or staff training.

Learners' evidence will explain why costs are controlled and will evaluate how the cost model can be used to improve the profitability of an engineering product or service. The evidence will explain how costs are categorised, and give specific examples from an engineering activity for each cost category. For example, raw materials can be apportioned directly to an engineering activity; however, these costs are also variable since they are dependent on the amount of product being manufactured.

The cost model will be used to identify cost areas that have the greatest impact on the profitability of the product or service. For example, learners may identify that the biggest cost area is energy consumption but that there is scope to reduce it.

Overall, the cost model will be clearly presented, thorough and accurate. There will be no arithmetic and/or follow-through errors and all costs will be identified and assigned appropriately. The evidence will contain the correct technical terms, be easy to read and be logically structured.

For merit standard, learners will produce an accurate activity-based cost model for a given engineering product or service. The model will include all of the engineering activities that contribute to the output and will assign the majority of these correctly to appropriate cost types. Learners will explain the reasons for producing an activity-based cost model, for example as part of an investment decision-making process to evaluate how costs could be reduced.

Overall, the activity-based cost model and evidence will be clearly presented, and use correct technical terminology throughout. The model may contain some minor arithmetic and/or follow-through errors.

For pass standard, learners will explain why it is important for an engineering organisation to analyse and control costs. For example, learners will explain that cost control information can be used for decision-making purposes, including make or buy decisions for a new engineering-based product or service.

An activity-based cost model will be produced for a given product or service. The model may contain some errors, such as assigning a couple of costs inappropriately and/or omitting some activities that contribute to the output.

Overall, learners must be able to demonstrate the correct use of method when applying activity-based costing and use the correct units. The cost model and evidence should be logically structured, although basic in parts, and it may contain minor arithmetic and/or follow-through errors.

Learning aim C

For distinction standard, learners will use evidence to evaluate the outcomes of a value analysis exercise and consider the results alongside the use of quality management systems. They will identify and explain, using evidence, how efficiencies can be made for a given engineering product or service. Learners will evaluate how quality management tools, such as the ISO 9000 and ISO 14000 groups of international standards can improve a given engineering activity. For example, learners may include how the problem will be defined and the data collected during the planning stage, a solution will be developed during the implementation stage, comparisons to the original process will be considered during the checking stage, and recommendations should be made in the acting stage. Learners will use the findings of this activity, in conjunction with the outcomes of a value analysis activity, to evaluate methods of implementing efficiencies for an engineering activity. They will identify where there is scope to improve quality or where meeting aspects of the ISO 9000/14000 standards will bring an improvement to the product or service.

Learners will complete a value analysis exercise for the same product or service and present their results covering the appropriate phases of the process. An example would be a simple engineered product where the cost of the product is the amount paid to manufacture it, its value is how much it is worth, value added activities include machining and processing, and non-value added activities such as transportation or inspection and testing are also included. Learners will include a functional analysis of the processes involved in producing the outcome, for example considering if different materials which offer better value could be used, with the results being used to generate alternatives which would offer better value solutions. They will use their analysis to identify

where waste, such as excessive manufacturing techniques, occurs during the activity, and identify improvements that could be made to the process to improve efficiency and develop a lower-cost alternative solution.

Finally, learners will evaluate their findings from the quality management activity and the value analysis task to identify which areas can increase the profitability and efficiency of the process being investigated. They will suggest methods to improve the activity, and prioritise those aspects that will offer the greatest benefit to the organisation.

Overall, the evidence will be logically structured and clearly presented. The evaluation will be written using accurate technical language.

For merit standard, learners will analyse the quality management and value analysis tools that an engineering organisation uses to improve efficiency and gain a competitive advantage. For example, learners will analyse the potential benefits of implementing a quality system for an activity and how this would relate to the quality assurance and control checks that are already applied to the process. Learners will evaluate what may be achieved by gaining ISO 9001 accreditation and continue to analyse the reasons why value management methods, such as value analysis, are applied to the same engineering activities.

Learners will complete an accurate value analysis exercise for a given engineered product or service. The major value added and non-value added activities will be identified, with cost assumptions for each being made. Learners will produce ideas to improve the value of the processes, for example by suggesting the use of standardised components or removing some non-value added features of the product or service.

Overall, the value analysis and associated report will be clearly presented and use correct technical language throughout. The value analysis will be accurate, but may omit some minor aspects of the engineering activity.

For pass standard, learners will explain how an engineering organisation can use quality and value management systems to create a competitive advantage. For example, learners will explain that quality assurance and quality control are used to improve the outcomes of the product or service, and will give the organisation a competitive advantage, as the product or service being provided will then have greater value. Learners will make reference to relevant ISO standards, such as the ISO 9000 group, which offer engineering organisations the potential to improve quality. Further, they will explain that improving the efficiency of the activity will also improve the competitiveness of the organisation by increasing the value of the outcome compared to the initial cost.

Learners will complete a value analysis exercise for a given engineered product or service. Most of the key stages of the process will be identified, with costs associated to each activity. There may be some errors, and some non-value added activities may be missed, but overall the analysis will result in the identification of opportunities for a better value solution.

Links to other units

This mandatory unit is linked to many of the other units in the qualification and in particular to mandatory *Unit 5: A Specialist Engineering Project*.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with commercial and quality systems expertise
- contribution of ideas to unit assignment/project materials.

Unit 7: Calculus to Solve Engineering Problems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners use differential (rates of change) and integral (summing) calculus to solve engineering problems and develop a mathematical model of a local and relevant system.

Unit introduction

Many of the products, components and systems that we use have been subject to a rigorous design process that will have involved the use of calculations including mathematical calculus. During the design stage, it is important to be able to predict how a product will perform in service, for example the handling characteristics of a car or the power output from an electrical power supply. Also, investing time and resources in setting up manufacturing machinery and supply chains is very expensive – working with formulae and numbers on paper or using a computer involves a lot less cost and allows engineers to determine optimal (or near-optimal) solutions.

In this unit, you will investigate how to apply differential and integral calculus methods to solve engineering problems. You will learn about the rules and procedures of calculus mathematics to obtain solutions to a variety of engineering problems. You will solve a complex problem from your specialist area of study and perhaps from a local organisation by breaking it down into a series of linked manageable steps. Each step will be solved using calculus methods learned through investigation and practice. These mathematical skills are transferable and will be used to support your study of other topics in the BTEC Nationals engineering programme, for example in mechanical principles and electrical systems.

As an engineer you need to understand and develop the skills required to solve problems using calculus and other mathematical procedures. This unit will prepare you well for progressing to higher education to study for an engineering degree or a Higher National Diploma (HND). It will also help prepare you for an apprenticeship or for employment in a range of engineering disciplines as a technician, and will help you work with professional engineers as part of a team working on cutting-edge products and systems.

Learning aims

In this unit you will:

- A** Examine how differential calculus can be used to solve engineering problems
- B** Examine how integral calculus can be used to solve engineering problems
- C** Investigate the application of calculus to solve a defined specialist engineering problem.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how differential calculus can be used to solve engineering problems	A1 Functions, rate of change, gradient A2 Methods of differentiation A3 Numerical value of a derivative A4 Second derivative and turning points	A report containing the results of learners' analysis and calculation, carried out under controlled conditions.
B Examine how integral calculus can be used to solve engineering problems	B1 Integration as the reverse/inverse of differentiation B2 Integration as a summing tool B3 Numerical integration	A report containing the results of learners' analysis and calculation, carried out under controlled conditions.
C Investigate the application of calculus to solve a defined specialist engineering problem	C1 Thinking methods C2 Mathematical modelling of engineering problems C3 Problem specification and proposed solution C4 Solution implementation	A report containing the results of learners' analysis, planning and calculation, carried out under controlled conditions.

Content

Learning aim A: Examine how differential calculus can be used to solve engineering problems

A1 Functions, rate of change, gradient

- Function notation, e.g. $y = f(x)$, $s = f(t)$, $Q = f(t)$
- Types of functions: polynomial, trigonometric (sine, cosine), logarithmic and exponential.
- Routine functions are differentiated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
 - polynomial, e.g. $s = 5t^2 - 3t + 4$
 - trigonometric (sine, cosine), e.g. $y = \sin^2 4x$
 - logarithmic, e.g. $v = 8 \log_e(5x)$
 - exponential, e.g. $y = 2e^{(3x+5)}$
- Non-routine functions are differentiated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
 - polynomial, e.g. $I = \frac{z+3}{5-4z}$
 - trigonometric (sine, cosine), e.g. $v = (\sin 2t \cos 3t)$
 - logarithmic, e.g. $y = 5x^2 \log_e(3x)$
 - exponential, e.g. $v = 5e^{3t}(2t^2 - 3)$
- Expanding or simplifying polynomial functions.
- Rate of change of a function.
- Graphical representation of a function.
- Gradient of a function – graphically by tangent.
- Time-based functions, e.g. velocity, charge rate, energy transfer.

A2 Methods of differentiation

- Gradient of a function.
- Small change in a quantity.
- Differentiation from first principles to produce the limiting value (derivative) of a simple power function, e.g. $y = 2x^2$
- Leibniz notation $\left(\frac{dy}{dx}\right)$ or representing the derivative of a function.
- Engineering notation for the derivative, e.g. $\left(\frac{ds}{dt}\right)$, $\left(\frac{dQ}{dt}\right)$
- Independent variable and the coding method 'with respect to' (w.r.t.).
- Differentiation by standard results ($y = ax^n$, where $\frac{dy}{dx} = nax^{(n-1)}$)
- The derivatives of algebraic (power), trigonometric (sine, cosine), logarithmic and exponential functions (ax^n , $\sin ax$, $\cos ax$, $\log_e(ax)$, e^{ax})
- Product and quotient rules: $\frac{dy}{dx} = v \frac{du}{dx} + u \frac{dv}{dx}$, $\frac{dy}{dx} = \frac{\left(v \frac{du}{dx} - u \frac{dv}{dx}\right)}{v^2}$
- Function of a function (chain rule) method.
- Substitution method.

A3 Numerical value of a derivative

- Substitution of numerical values into the expression for the derivative.
- Instantaneous gradient at a point on a curve.
- Positive, negative and zero values for gradients.
- Gradient values obtained analytically and graphically.
- Engineering examples of rates of change, e.g. velocity/acceleration of a moving object, rate of charge/discharge of a capacitor, heat flow, radioactive decay, cutting tool life, charge/discharge rate for an air receiver, hydraulic flow rates.

A4 Second derivative and turning points

- Leibniz notation for the second derivative $\left(\frac{d^2y}{dx^2}\right)$
- Second derivative of algebraic (polynomial) and trigonometric (sine, cosine) functions.
- Turning points on a function.
- Graphical representation of an algebraic function with two turning points, e.g. $y = x^3 - 5x^2 + 2x + 6$
- Maximum (max) and minimum (min) turning points, inflection point.
- Second derivative test for max/min points on a function.
- Numerical value of the dependent variable at the max/min points of a function.
- Engineering applications, e.g. maximising the volume of a container for a given surface area, minimising the cost of mass-producing components on a machine tool, resistance matching in electrical power circuits to achieve maximum power transfer.

Learning aim B: Examine how integral calculus can be used to solve engineering problems**B1 Integration as the reverse/inverse of differentiation**

- Symbolic representation $\int(\)dx$
- Algebraic expressions and the constant of integration.
- Types of functions: polynomial, trigonometric (sine, cosine), reciprocal and exponential.
- Routine functions are integrated in one step without the need for manipulation, using standard calculus methods and/or are not applied to an engineering context, including:
 - polynomial, e.g. $\int(x^2 - 3x + 4)dx$
 - trigonometric (sine, cosine), e.g. $\int(\sin 5\theta - 3\cos 4\theta)d\theta$
 - reciprocal, e.g. $\int\left(\frac{3}{x}\right)dx$
 - exponential, e.g. $\int(e^{3t})dt$
- Non-routine functions are integrated in more than one step requiring manipulation, using standard calculus methods and/or may be applied to an engineering context, including:
 - polynomial, e.g. $\int x^2(x^3 + 5)^2 dx$
 - trigonometric (sine, cosine), e.g. $\int\left(\frac{\cos \theta}{1 - \sin \theta}\right)d\theta$
 - exponential, e.g. $\int e^t \cos t dt$
- Integration of common functions by standard results – ax^n , $\sin ax$, $\cos ax$, $\frac{1}{x}$, e^{ax}
- Indefinite integrals, constant of integration, initial conditions.
- Definite integrals – limits and square bracket notation.
- Integration by substitution.
- Integration by parts.

B2 Integration as a summing tool

- Area under a curve from first principles – strip theory (approximate area of the elemental strip = $y\delta x$).
- Area under a curve as a summation between the upper and lower limits applied to the function.
- Mean value and root mean square (RMS) value of periodic functions.
- Engineering applications, e.g. work done by force producing displacement of an object, distance travelled by a vehicle, mean and RMS values of waveforms in electrical circuits.

B3 Numerical integration

- Trapezoidal rule, mid-ordinate rule, Simpson's rule – comparison of methods in terms of their complexity and accuracy.
- Area under a curve obtained by integrating its function – comparison with the value obtained using Simpson's method.
- Numerical integration using a spreadsheet.
- Engineering applications, e.g. determination of mechanical, electrical and thermal energy.

Learning aim C: Investigate the application of calculus to solve a defined specialist engineering problem**C1 Thinking methods**

- Reductionism – considering a complex problem as the sum of its elements/parts or breaking a problem down into its parts.
- Synectics – creativity in mathematics, idea generating methods.
- Logical thinking – coherent and logical approach to solving a problem, e.g. Polya's problem-solving method.

C2 Mathematical modelling of engineering problems

- Analytical methods.
- Numerical methods.
- 'What if' repetitive calculation, 'Goal Seek'.
- Benefits of using mathematical modelling, e.g. design viability, structural integrity of a product, accurate prediction of how a new product will perform in service, cost benefit of accurate simulation, e.g. in the design of aircraft.
- Engineering applications, e.g. mechanical design, stress analysis, performance calculation for an electronic or fluid-powered hydraulic circuit.

C3 Problem specification and proposed solution

- Application of thinking methods to understand a given engineering problem.
- The use of mathematical modelling to devise a method to solve the given engineering problem.

C4 Solution implementation

- The use of calculus and other appropriate mathematical methods to solve the given engineering problem.
- Reflection on the problem-solving process and the solution obtained, making refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how differential calculus can be used to solve engineering problems		A.D1 Evaluate, using technically correct language and a logical structure, the correct graphical and analytical differential calculus solutions for each type of given routine and non-routine function, explaining how the variables could be optimised in at least two functions.
A.P1 Find the first and second derivatives for each type of given routine function. A.P2 Find, graphically and analytically, at least two gradients for each type of given routine function. A.P3 Find the turning points for given routine polynomial and trigonometric functions.	A.M1 Find accurately the graphical and analytical differential calculus solutions and, where appropriate, turning points for each type of given routine and non-routine function and compare the results.	
Learning aim B: Examine how integral calculus can be used to solve engineering problems		B.D2 Evaluate, using technically correct language and a logical structure, the correct integral calculus and numerical integration solutions for each type of given routine and non-routine functions, including at least two set in an engineering context.
B.P4 Find the indefinite integral for each type of given routine function. B.P5 Find the numerical value of the definite integral for each type of given routine function. B.P6 Find, using numerical integration and integral calculus, the area under curves for each type of given routine definitive function.	B.M2 Find accurately the integral calculus and numerical integration solutions for each type of given routine and non-routine function, and find the properties of periodic functions.	
Learning aim C: Investigate the application of calculus to solve a defined specialist engineering problem		C.D3 Critically analyse, using technically correct language and a logical structure, a complex engineering problem, synthesising and applying calculus and a mathematical model to generate an accurate solution.
C.P7 Define a given engineering problem and present a proposal to solve it. C.P8 Solve, using calculus methods and a mathematical model, a given engineering problem.	C.M3 Analyse an engineering problem, explaining the reasons for each element of the proposed solution. C.M4 Solve accurately, using calculus methods and a mathematical model, a given engineering problem.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.P5, B.P6, B.M2, B.D2)

Learning aim: C (C.P7, C.P8, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to maths support websites, spreadsheet software, e.g. www.mathcentre.ac.uk/students/topics

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will demonstrate mastery in the application of differential calculus methods to the solution of given problems using mathematical functions. Learners will correctly and efficiently manipulate six routine and six non-routine functions.

A reasoned and balanced evaluation (argument) will be presented when considering how variables can be optimised for at least two non-routine functions related to an engineering context, for example determining the dimensions of a container with a given volume so that its surface area is minimised, thereby minimising the material cost and environmental impact of the container.

Overall, the evidence will be logically structured and will be easy to understand by a third party with a mathematical background, who may or may not be an engineer. For example, learners will use mathematical terminology correctly and use relevant units when working with functions set in engineering contexts. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Learners will work to a specified numerical precision (as determined by the assessor), through the use of appropriate significant figures or decimal places.

For merit standard, learners will apply the correct skills and methods when producing the derivatives of functions and evaluating their gradients. Learners will correctly manipulate six routine and six non-routine functions (four polynomial, four trigonometric, two logarithmic and two exponential). Learners will compare the results, obtained graphically and analytically, for the two gradients being investigated, for example, there will be discussion about the numerical accuracy of the two methods.

Overall, learners' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. A limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For pass standard, learners will apply the correct skills and methods when differentiating at least six given routine mathematical functions. Learners will correctly manipulate at least two polynomial, two trigonometric, one logarithmic and one exponential functions. Some functions will be sufficiently complex to enable learners to select and apply the correct method (product, quotient, function of a function and substitution) when producing first and second derivatives.

Learners will demonstrate that they can find, graphically and analytically, at least two gradients for each type of function. For the polynomial and trigonometric functions, learners will calculate the turning points in the context of rates of change.

Overall, learners must be able to demonstrate the correct use of a method when differentiating functions and use the correct units. Minor arithmetic and scaling errors are acceptable. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'. Graphical presentation of functions and determination of their gradients can be done using a spreadsheet, provided that formulae are visible (printed out).

Learning aim B

For distinction standard, learners will demonstrate mastery in the application of integral calculus methods to solve given problems using mathematical functions. Learners will correctly and efficiently manipulate eight routine and three non-routine functions.

Learners must present reasoned arguments when evaluating the use of analytical and numerical integration methods on at least two non-routine functions, for example finding work done by expressing parameters as a definite integral and then repeating the operation using Simpson's rule.

Overall, the evidence will be logically structured, easy to understand by a third party with a mathematical background, who may or may not be an engineer, and will use correct mathematical terminology. Small and large numerical values will be correctly presented in an appropriate format, i.e. standard form or engineering notation. Learners will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

For merit standard, learners will apply the correct skills and methods when producing the integrals of functions and determining the properties of periodic functions. Learners will correctly manipulate eight routine and three non-routine definitive functions – at least eleven functions in total, including a polynomial, a trigonometric and an exponential non-routine function.

Numerical integration will have been accurately completed for four definitive routine functions.

Overall, learners' numerical work will be accurate, using an appropriate degree of precision as specified by the assessor in significant figures or decimal places, and relevant units will be used for all functions. A limited number of arithmetic follow-through errors are acceptable for non-routine functions.

For pass standard, learners will apply the correct skills and methods when integrating at least eight given routine mathematical functions. Learners will correctly manipulate at least two routine functions for each of the different function types (polynomial, trigonometric, reciprocal and exponential). At least one of each type will be an indefinite integral and one of each type will be a definitive integral. In total, at least eight different routine functions will be solved, and some will be sufficiently complex to enable the learner to select and apply the correct method (substitution and by parts) when producing indefinite and definite integrals.

Numerical integration will be completed on the four definitive integrals and they can be manipulated using a spreadsheet, provided that formulae are visible (printed out). There will also be evidence of simple checks being undertaken to determine if numerical answers are 'reasonable' 'reasonable'.

Overall, learners must be able to demonstrate the correct use of method and units when integrating functions analytically and by a numerical method. Minor arithmetic and scaling errors are acceptable.

Learning aim C

For distinction standard, learners will demonstrate mastery in the application of calculus methods to solve a complex engineering problem. The identified problem must be sufficiently complex to allow learners to apply thinking methods, mathematical modelling and both differential and integral calculus methods to the solution of the problem. Learners must show that they are able to break a complex problem down into a series of manageable steps through the application of reductionism and logical thinking.

Learners will produce a full specification for the problem, based on gathered and given information and use this to produce a proposal; there must be evidence that this has been done before they embark on the mathematical manipulations. Evidence for this could be supported by an assessor observation record.

Overall, the evidence will be straightforward to understand by a third party with a mathematical background, who may or may not be an engineer, and there will be correct use of mathematical terminology and the application of relevant units. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation. Learners will work to a specified numerical precision (as determined by the assessor) through the use of appropriate significant figures or decimal places.

Mathematical methods will be applied efficiently to the solution of the problem, for example by using a logical approach to the solution and/or efficient use of a spreadsheet for numerical analysis.

For merit standard, learners will produce a reasoned analysis of a complex engineering problem, breaking it down into planned stages to obtain a solution. The method will apply differential and integral calculus appropriately at each stage, and the resulting solution will be of an acceptable degree of accuracy (as determined by the assessor).

Overall, the evidence will be logically structured, technically accurate and easy to understand. The planned method may contain some simplification and approximations to allow a solution to be calculated. Rules of differentiation and integration should be selected and applied correctly, for example by using a substitution method to integrate terms rather than by expansion.

For pass standard, learners will present the solution of a given complex engineering problem. The solution may not be complete, and there may be some inaccuracies or omissions, but there should be evidence of some proficiency in the use of differential and integral calculus. For example, learners solving a dynamics problem based on the acceleration and energy transfers of a moving vehicle would be expected to determine the maximum accelerating force and work done to get the vehicle up to a given velocity.

Overall, the report should be logically structured and contain a commentary on each stage of the solution. Rules of differentiation and integration should be applied correctly. It may contain some minor arithmetic errors, for example the value of a definite integral may be incorrect, although the indefinite integral has been correctly deduced, and the method chosen may not be optimal, for example expanding a function such as to integrate rather than using a substitution method. Minor 'carry-through' errors are acceptable and there will be an appreciation of the correct use of units, but there may be errors in their application.

Links to other units

This mandatory unit is linked to many of the other units in the qualification, in particular mandatory *Unit 1: Engineering Principles*, as well as a number of optional units including:

- Unit 15: Electrical Machines
- Unit 17: Power and Energy Electronics
- Unit 21: Analogue Electronic Circuits
- Unit 27: Static Mechanical Principles in Practice
- Unit 28: Dynamic Mechanical Principles in Practice
- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 31: Thermodynamic Principles and Practice
- Unit 48: Aircraft Flight Principles and Practice.

Employer involvement

This unit would benefit from employer involvement in the form of:

- technical workshops involving staff from local organisations with expertise in applying calculus to solve engineering problems
- contribution of ideas to unit assignment/project materials.

Unit 9: Work Experience in the Engineering Sector

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the benefits of work experience. They carry out and reflect on a period of work experience, and plan for their personal and professional development.

Unit introduction

If you are thinking about a career in engineering, you should do some work experience to make you aware of the kinds of tasks and activities you may be required to do. It will help you reflect on and develop your attributes and skills required for work in the sector and will also help to extend your knowledge and understanding of the roles and responsibilities of engineering professionals.

In this unit, you will learn about the benefits of work experience in engineering. You will examine how work experience can help you to develop personal and professional skills such as communication and teamwork and help you to understand more about the expectations of different professional roles. You will develop a plan to support your learning in placement and you will monitor your progress through a reflective journal. This is a very practical unit, which will support your work experience placement in engineering and provide a foundation for you to develop, apply and reflect on knowledge and skills in a realistic situation.

A work experience placement will help you prepare for further study in a variety of higher education programmes. It is an important factor in progression to higher education, and is a component of many degree courses accredited by the Engineering Council.

Learning aims

In this unit you will:

- A** Examine the benefits of work experience in engineering for own learning and development
- B** Develop a work experience plan to support own learning and development
- C** Carry out work experience tasks to meet set objectives
- D** Reflect on how work experience influences own personal and professional development.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the benefits of work experience in engineering for own learning and development	A1 Developing skills and attributes A2 Clarifying expectations for employment in engineering A3 Exploring career options	A report evaluating the benefits of work experience in the engineering sector and the importance of preparing for placement. The report must include a plan to meet personal and professional goals.
B Develop a work experience plan to support own learning and development	B1 Preparation for work experience B2 Setting goals and learning objectives	
C Carry out work experience tasks to meet set objectives	C1 Work experience tasks C2 Work shadowing and observation	Observation of learners on work placements in the engineering sector carrying out tasks and activities and interacting with customers and staff, evidenced by observation report signed by assessor. Reflective log evaluating own development on work placement.
D Reflect on how work experience influences own personal and professional development	D1 Reviewing personal and professional development D2 Using feedback and action planning	

Content

Learning aim A: Examine the benefits of work experience in engineering for own learning and development

A1 Developing skills and attributes

- Reflecting on own skills and attributes and areas for development.
- Developing professionalism.
- Communication and interpersonal skills.
- Organisational skills, e.g. time management, prioritising tasks.
- Technical skills and their application in the workplace.
- Ability to link theory with practice.
- Teamwork skills.
- Confidence and personal responsibility.

A2 Clarifying expectations for employment in engineering

- Understanding the rights and responsibilities of engineers.
- Respecting diversity, equality and dignity in the workplace.
- Respecting confidentiality.
- Understanding health, safety and security regulations.
- Preparation for employment in the sector.

A3 Exploring career options

- Working in different engineering sectors, e.g. aerospace, manufacturing, electrical/electronic.
- Sources of information about careers and career pathways in engineering.
- Professional engineering bodies and types of membership, e.g. Engineering Technician (Eng Tech), Incorporated Engineer (IEng).
- Using work experience to inform career choices, confirm ideas or consider alternative options.

Learning aim B: Develop a work experience plan to support own learning and development

B1 Preparation for work experience

- Expectations for learners on work experience, e.g. dress, behaviour.
- Responsibilities and limitations for learners on work experience, e.g. restrictions due to experience or training requirements to carry out tasks.
- Researching specific work experience placements, e.g. organisation, job roles.
- Role of placement supervisors/mentors.

B2 Setting goals and learning objectives

- Reflecting on current knowledge and skills.
- Identifying own strengths and areas for development.
- Identifying established standards and values required for engineering professionals, e.g. entry requirements for membership of professional bodies such as the Institution of Mechanical Engineers (IMechE), Institution of Engineering and Technology (IET).
- Identifying SMART (specific, measurable, achievable, realistic and time-related) targets for own work experience.
- Setting personal development goals, e.g. developing communication skills, confidence.
- Setting professional development goals, e.g. developing competence, technical ability.

Learning aim C: Carry out work experience tasks to meet set objectives

C1 Work experience tasks

- Assisting and participating in engineering tasks, e.g. preparing the workplace to carry out given tasks.
- Assisting and participating in non-engineering tasks, e.g. attending meetings, general office tasks.
- Participating as part of a team.
- Understanding the importance of supervision of work activities.
- Using work experience reflective journals to link theory with practice, reflecting on how work experience placement influences own professional development.

C2 Work shadowing and observation

- Work shadowing different professionals to appreciate the range of engineering functions.
- Observing specific procedures to gain new knowledge and skills.
- Working relationships and agreed ways of working in engineering, developing trust, mutual respect, mindfulness, open communication and welcoming diversity.
- Reflecting on work practice and procedures used within the setting.

Learning aim D: Reflect on how work experience influences own personal and professional development

D1 Reviewing personal and professional development

- Understanding that reflective practice is an ongoing activity.
- Theories and frameworks for reflective practice.
- Reviewing work experience reflective journal.
- Evaluating own performance.
- Reflecting on personal and professional development.

D2 Using feedback and action planning

- The importance of continuing professional development (CPD).
- Identifying areas of positive and constructive feedback.
- Highlighting areas for improvement.
- Creating an action plan for personal and professional development.
- Identifying career goals.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the benefits of work experience in engineering for own learning and development		AB.D1 Justify the benefits of preparation in supporting own understanding of the expectations of work experience.
A.P1 Explain how work experience can support the development of own professional skills and personal attributes for work in engineering.	A.M1 Analyse how work experience can provide support in gaining a realistic understanding of the engineering sector.	
A.P2 Discuss ways in which work experience can inform own career choices and help prepare for employment in engineering.		
Learning aim B: Develop a work experience plan to support own learning and development		
B.P3 Explain own responsibilities and limitations on work experience in engineering.	B.M2 Assess the importance of own work experience plan to support own learning and development.	C.D2 Demonstrate work-related skills proficiently, taking the initiative to carry out activities according to own responsibilities and setting's procedures, selecting appropriate skills and techniques for different situations. D.D3 Justify how planning for and reflecting on skills developed during own work experience placement have informed future plans for personal and professional development.
B.P4 Explain how to meet own specific personal and professional development goals while on work placement.		
Learning aim C: Carry out work experience tasks to meet set objectives		
C.P5 Demonstrate work-related skills to meet set objectives for work experience tasks.	C.M3 Demonstrate work-related skills with confidence and proficiency to meet objectives in different situations.	
C.P6 Discuss ways in which work shadowing and observation can support development of own skills while on work placement.		
Learning aim D: Reflect on how work experience influences own personal and professional development		
D.P7 Review own strengths and areas for development in response to feedback on work experience placement.	D.M4 Assess how self-reflection can contribute to personal and professional development in a work experience placement.	
D.P8 Produce a personal development plan which identifies improvements to personal and professional skills for the future.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, A.P2, B.P3, B.P4, A.M1, B.M2, AB.D1)

Learning aims: C and D (C.P5, C.P6, D.P7, D.P8, C.M3, D.M4, C.D2, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to a ten working-day equivalent work experience placement in an engineering setting.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will reach valid judgements about the benefits of preparation for work experience placements. Learners must use research to justify the validity of proposals about the expectations of work experience and articulate their views concisely to justify conclusions. They must draw on and show knowledge to make suitable justifications and recommendations for their planned placement.

For merit standard, learners will make reasoned analytical judgements involving comparison and discussion. Learners must use research to extend their understanding about the expectations of work experience placements. They must select and apply knowledge to demonstrate the relevance and purpose of their work experience plan to support their learning and development.

For pass standard, learners will recall key knowledge to demonstrate their understanding of how work experience can provide preparation for employment in engineering. Learners must use research with relevance to given situations to explain their responsibilities and limitations in a work experience placement. They must select and organise information using appropriate knowledge and concepts to produce a plan to meet their specific personal and professional development goals while on work placement.

Learning aims C and D

For distinction standard, learners will make valid judgements about the risks and limitations of techniques and processes used in relation to desired outcomes and own skills development. They must select appropriate skills and techniques in relation to the work situation and desired outcomes and show that they have developed their skills to achieve increased quality of outcomes while on placement. For example, they must communicate professionally using appropriate methods for their audience to achieve desired outcomes.

Learners must show initiative while acting within expected constraints and assess their contribution to at least three different work-related tasks and three work shadowing tasks or observations. Learners must justify any decisions taken related to their work situation. They must manage themselves successfully to prioritise activities and monitor their own progress.

They must engage actively with others and on their own initiative to gain feedback and to create opportunities for personal improvement. They must evaluate the basis for taking decisions in their work experience placement and respond effectively to feedback. They must draw together their learning and experiences gained across the learning aims, demonstrating valid insights into their own planning and performance in order to plan their future personal and professional development.

For merit standard, learners will act within given work-related contexts to show required attributes and select and deploy appropriate techniques, processes and skills with increased confidence and proficiency to meet set objectives in three different work experience situations. Learners will modify techniques and processes to suit different situations and to deal with contingencies. For example, they must select and use appropriate communication methods to suit particular audiences, such as interacting with different staff or contributing to a team meeting. They will reflect on knowledge and skills gained through three work shadowing experiences or observations. They must manage their time to prioritise activities and progress towards required outcomes.

Learners will use knowledge, skills and understanding to select and justify solutions in relation to how work experience tasks support their personal and professional development. They must monitor their achievement against their work experience plan to ensure the relevance of targets and must reflect actively on evidence of their own performance using feedback from others.

For pass standard, learners will carry out tasks and activities fully, correctly and safely to achieve required outcomes. Learners must select appropriate techniques, processes or skills in well-defined situations, and review the success of these techniques, processes and skills in relation to three work experience tasks and three work shadowing experiences or observations. They must identify the responsibilities of staff within the placement and relate this knowledge to occupational roles and organisational structures. They must communicate in a variety of ways, using appropriate English, vocational language and graphical methods, responding to communication from others. They must manage their time effectively to undertake work activities and manage outcomes.

Learners will apply knowledge, skills and understanding to explore solutions to realistic and vocational tasks in relation to the ways in which work shadowing and observation can support personal and professional development.

Learners must maintain structured records of their work experience which show how they have planned opportunities to develop their skills and gain feedback on their performance from others.

Links to other units

This unit links knowledge and skills from learners' entire programme of study, but it would be advisable if the following units were taught prior to the work placement:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 3: Engineering Product Design and Manufacture.

It may be taught alongside:

- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 5: A Specialist Engineering Project.

Employer involvement

This unit would benefit from employer involvement in the form of opportunities for observation during the work experience and assessment of any project work.

Learners must have access to a ten working-day equivalent work experience placement in an engineering setting.

Unit 10: Computer Aided Design in Engineering

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners develop two-dimensional (2D) detailed drawings and three-dimensional (3D) models using a computer-aided design (CAD) system.

Unit introduction

Computer-aided design (CAD) spans most areas of engineering, as well as aspects of other disciplines such as construction and media. Engineering is a multi-disciplinary vocational subject that uses CAD as part of other processes to develop (design and manufacture), improve and maintain cutting edge products and systems. For example, Formula 1® racing teams test all their cars on bespoke CAD packages to analyse performance and stresses, and make modifications to the cars as a result.

In this unit you will use CAD software and hardware to produce 2D and 3D drawings. You will acquire the skills to produce models of products, editing and modifying these, and exploring materials and their properties. You will output a portfolio of drawings, for example orthogonal, 3D shaded or solid model, and detail view drawings, to an international standard.

As an engineer it is important to be able to interpret and produce engineering drawings that help individuals and organisations to communicate ideas, design and manufacture products and improve product performance. Studying this unit will help you to progress to employment as a draftsman and gain other technician level roles in engineering. It also prepares you for an engineering-based apprenticeship, and for higher education.

Learning aims

In this unit you will:

- A** Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes
- B** Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes
- C** Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes	A1 3D parametric modelling A2 Develop 3D components A3 Develop a 3D model A4 Output of drawings from a model	<p>A practical drawing activity to produce a 3D model of a product and determine the material properties of components.</p> <p>A portfolio of drawings should include: orthogonal, 3D shaded or solid model, parts list/bill of material and a detail view.</p>
B Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes	B1 2D drawing commands B2 Development of 2D engineering drawings B3 Output of 2D drawings	<p>A practical drawing activity to produce 2D drawings for an assembled product.</p> <p>A portfolio of drawings should include: orthogonal, an assembly drawing, parts list/bill of material and a sectional view.</p>
C Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes	C1 3D modelling commands C2 Develop 3D components C3 Development of a 3D model C4 Output of product drawings	<p>A practical drawing activity to produce a rendered 3D model of a thin walled and fabricated product.</p> <p>A portfolio of drawings should include: orthogonal, 3D shaded or solid model, parts list/bill of material, a detail view, rendered output and flat patterns.</p>

Content

Learning aim A: Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes

A1 3D parametric modelling

- Configure the parametric modeller, including origin, units, snap and grid, correct format, project files, selection of file types and planes, e.g. XY, XZ and YZ.
- Sketching commands, including line, arc, centre line, construction line, circle, fillet, and dimension.
- Display commands, including pan, zoom, and orbit.
- Editing commands, including erase, extend, trim, and rotate.
- Construction commands, including:
 - 3D primitives, e.g. cube, cylinder
 - 3D creation, e.g. extrude, revolve
 - 3D modify, e.g. hole, move face, chamfer
 - 3D Boolean, e.g. intersect, addition, subtraction
 - 3D assembly, e.g. place, constrain
 - 3D analysis, e.g. stress, mass.

A2 Develop 3D components

- Creation of 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D model, including rotate about an axis, revolve, extrude, and Boolean manipulation.
- 3D features, including:
 - threads, male and female
 - holes, including plain, drilled
 - threads, countersunk, counterbore, fillet, chamfer, rectangular or circular copy.
- Combination of solid objects, including Boolean operations.
- 2D sketching on 3D faces.
- Modification of the 3D model, including addition of features to existing geometry, e.g. cut-outs, projected geometry and new holes and extrusions.
- Application of materials to include:
 - mass based on common engineering materials, e.g. aluminium and carbon steel
 - surface area of the whole or part of a component
 - volume of the whole or part of a component
 - density mass per unit volume of material
 - principal moments, moments of inertia of a body about its principal axis.

A3 Develop a 3D model

- Placement of 3D components, including degrees of freedom, XYZ translational freedom and XYZ rotational freedom.
- Assembly constraints and the relationships between components, including mate constraint and angle constraint assembly relationships, insert constraint and tangent constraint assembly relationships.
- Modification to 3D components due to assembly constraints.
- Consideration of assembly, including storyboarding, component relationship.

A4 Output of drawings from a model

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- 2D paper space, including drawing template, scale, size, title block, editing
- creation of component drawings, including an orthogonal base view and projected views, 3D solid model/surface model, appropriate scale, detail views, dimensioning, and centre lines
- creation of an assembly drawing, including parts list or bill of materials (BOM).

Learning aim B: Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes**B1 2D drawing commands**

- Configuration of a 2D CAD system, including format units, snap and automatic snaps, grid, precision, angular, drawing limits, layers, user coordinate system, world coordinate system, and file systems.
- Use of drawing commands, including line, arc, circle, polyline, absolute, relative, and polar.
- Use of display commands, including pan, zoom.
- Use of modify commands, including erase, trim, mirror, move, array, copy, undo and stretch.

B2 Development of 2D engineering drawings

- Drawing commands, including line types, centre line, dashed, text, offset, hatching and editing of hatching.
- Use of layers, including manipulation, creation, switching on/off, frozen and locked.
- Use of blocks/symbols, including creation of blocks/symbols, symbols library, insertion of blocks.
- Use of modify commands, including mirror, pan, scale, chamfer, and fillet.
- Use of dimensioning, including dimension styles, dimensions, and editing of dimensions.

B3 Output of 2D drawings

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- set up of output parameters, including paper size, units, plot area, scale, orientation, paper space, model space, model and layout drawing, and template
- creation of component drawings, including orthogonal views, appropriate scale, sectional view, dimensioning, and centre lines
- creation of an assembly drawing, including general arrangement, parts list or bill of materials (BOM).

Learning aim C: Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes**C1 3D modelling commands**

- Configuration of the parametric modeller, including origin, units, snap and grid, correct format, project files, selection of file types, and planes, e.g. XY, XZ and YZ.
- Creation of 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D model, including rotate about an axis, revolve, extrude, and Boolean manipulation.
- Sheet metal parameters, including folding rule, bending rule, corner reliefs.
- Use of sketching commands, including line, arc, centre line, construction line, circle, fillet, and dimension.
- Use of construction sheet metal commands, including face, material thickness, bends, flange, holes, slots, 3D modify, e.g. hole, move, face, chamfer.
- Use of construction thin walled commands, including 3D creation, imprint/shell, Boolean manipulation, sweep, loft, shell, work planes, emboss, 3D modify, e.g. hole, move, face, chamfer.

- Use of display commands, including pan, zoom, and orbit.
- Use of editing commands, including erase, extend, trim, and rotate.

C2 Develop 3D components

- Create 2D sketches, including basic shape, dimensioning, modifications, and geometric constraints.
- 2D sketch to a 3D component and sheet metal fabrication, including folding, bending, slots, revolve, extrude, and Boolean manipulation.
- 3D features of the components, including:
 - threads – male and female
 - holes – plain, drilled, threads, countersunk, fillet, chamfer
 - combination of solid objects, including Boolean operations.
- 3D features of the thin walled components, including shell/imprint, loft, fillet, chamfer, array (rectangular or circular), and combination of solid objects, including Boolean operations.

C3 Development of a 3D model

- Placing 3D components, including degrees of freedom, XYZ translational freedom and XYZ rotational freedom.
- Assembly constraints and the relationships between components, including mate constraint and angle constraint assembly relationships, insert constraint and tangent constraint assembly relationships.
- Modification to 3D components due to assembly constraints.
- Consideration of assembly, including storyboarding, component relationship.
- Use of rendering, including render, shadows, reflections, lights, materials, textures, ray tracing.

C4 Output of product drawings

Drawings to be produced to British Standard BS 8888 or other relevant international equivalents:

- 2D paper space, including drawing template, scale, size, title block, editing
- creation of component drawings, including an orthogonal base view and projected views, 3D solid model/surface model, appropriate scale, detail views, rendered models, dimensioning, flat patterns, and centre lines.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Develop a three-dimensional computer-aided model of an engineered product that can be used as part of other engineering processes		A.D1 Refine models and drawings to an international standard of an accurate and correctly orientated 3D assembled product that is fit for purpose, applying appropriate materials to all components and create a drawing template.
A.P1 Create models and drawings of at least five 3D components from an assembled product, and apply a material to two or more components. A.P2 Create a model and drawings of an assembled product containing at least five components with two or more components well orientated.	A.M1 Produce accurate models and drawings that mainly meet an international standard of an assembled 3D product containing at least seven well orientated components and apply a material to all components.	
Learning aim B: Develop two-dimensional detailed computer-aided drawings of an engineered product that can be used as part of other engineering processes		B.D2 Refine, using accurate layers from a master layer, drawings to an international standard of an accurate and correctly orientated 2D assembled product that is fit for purpose.
B.P3 Create, using layers, drawings of at least six 2D components from an assembled product. B.P4 Create a 2D assembly drawing containing at least six components, with at least two components well orientated.	B.M2 Produce, using accurate layers, drawings that mainly meet an international standard of an assembled product containing at least ten accurate and well orientated components.	
Learning aim C: Develop a three-dimensional computer-aided model for a thin walled product and a fabricated product that can be used as part of other engineering processes		C.D3 Refine drawings to an international standard of two accurate and correctly orientated 3D models with realistic rendering that are both fit for purpose.
C.P5 Create partially rendered models and drawings of at least two 3D components from a thin walled assembled product. C.P6 Create partially rendered models and drawings of at least four 3D components from a fabricated assembled product.	C.M3 Produce an accurate model and drawings, that mainly meet an international standard of at least two well orientated and fully rendered 3D components from a thin walled assembled product. C.M4 Produce an accurate model and drawings, that mainly meet an international standard of at least four well orientated and fully rendered 3D components from a fabricated assembled product.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- suitable CAD workstations and output devices, e.g. printers and plotters
- 2D CAD software that is capable of professional 2D drawings and their output, e.g. AutoCAD 2D, AutoCAD LT, TurboCAD Deluxe, and DraftSight
- 3D modelling software that is capable of professional solid 3D models and fabricated models, creates assemblies and outputs 2D drawings, e.g. AutoCAD 3D, AutoCAD Inventor, SolidWorks, and SolidEdge.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will show consistently accurate components with a material applied correctly to every component, for example, an engine/cylinder block material could be made from either aluminium or cast iron. The components should be assembled into a model, for example a model Formula 1® racing car or a model aircraft landing gear, with all the components orientated correctly.

A drawing template should be created and used so that a professional portfolio of drawings can be output. The evidence should include orthogonal drawings, a 3D shaded/solid model, and a detail view. Overall, the drawings should be to an international standard, such as BS 8888, and the model should fully meet its purpose, for example to display accurate visualisation to a potential customer, and be clear for a third party to understand.

For merit standard, learners will accurately draw at least seven components, for example they should be the correct size and compatible when assembled. At least five of the components should be correctly orientated when assembled, for example an incorrectly orientated component could be orientated correctly from one angle but not another. A material should be applied to all components.

A drawing template from the standard library should be used to output a portfolio of drawings that should generally be to an international standard, such as BS 8888. Specifically, orthogonal drawings may contain at most a couple of missing dimensions and/or a couple of dimensions may be inappropriately positioned or inconsistent, and a detail view that may have minor errors, for example an incorrect scale applied, or incorrectly labelled. The 3D shaded/solid model should contain no inaccuracies in the drawing layout and title block and an accurate parts list/bill of materials should be given.

Overall, the evidence should provide an appropriate 3D model that generally meets its purpose.

For pass standard, learners will draw at least five components but they may not all be fully accurate, for example an incompatibility in a male and female thread, or incorrect depth of thread could be used, causing a bolt not to seat correctly. Components such as pins, washers and basic fasteners do not contribute towards the component count. The components should be assembled into a model with at least two components orientated correctly and a material will be applied to at least one component.

A drawing template from the standard library should be used to output a portfolio of drawings. Specifically, orthogonal drawings, which may contain some missing dimensions and/or some dimensions may be inappropriately positioned or inconsistent, and a 3D shaded/solid model may have some minor errors within the drawing layout and/or title block.

Overall, the evidence should demonstrate a 3D model that partially meets its purpose.

Learning aim B

For distinction standard, learners will show accurate components that form an assembly and all components should be orientated correctly. Layers should be used so that component attributes are grouped on one layer, for example, hatching is contained on a single layer and should be used to create different assemblies and/or components possessing similar attributes from the master layer. Another example would be a series of brackets with common attributes, such as a bar with a differing series of holes on a pitch circle diameter (PCD), which would be created from one master layer with the PCDs on separate layers to enable the output of several drawings.

A drawing template should be created to output professional drawings, to include a general arrangement, component drawings, and a sectional view. Overall, the portfolio of drawings should be to an international standard, such as BS 8888, and they should demonstrate a clear and accurate 2D model that fully meets its purpose, for example to manufacture the component(s), and is clear for a third party to understand.

For merit standard, learners will draw ten components, which may have minor inaccuracies, for example external dimensions are created incorrectly but they do not affect final assembly, or components may not be fully compatible. Layers should be used to create components and they should be well oriented to create the assembly.

A drawing template from the standard library should be used to output professional drawings, to include a general arrangement, component drawings, and a sectional view. These drawings should be to an appropriate international standard.

Overall, the evidence should provide an appropriate 2D model that generally meets its purpose.

For pass standard, learners will draw six components, which may have some inaccuracies, such as errors in sizes and compatibility. Components such as pins, washers and basic fasteners do not contribute towards the component count. Also, the assembly should contain at least two correctly orientated components. Layers should be utilised so that components are created using layers, with some minor errors, for example layers may have been left frozen, or only partially printed.

A drawing template from the standard library should be used to output a professional portfolio of drawings, to include a general arrangement and orthogonal drawings. The orthogonal drawings may contain some minor errors within the drawing layout, title block and dimensioning.

Overall, the evidence should demonstrate a 2D model that partially meets its purpose.

Learning aim C

For distinction standard, learners will show in their portfolios accurately modelled fabricated and thin walled components. The fabricated components together should contain a minimum of four folds, two bends and four slots. The components should be assembled into a model that contains a minimum of six components that are orientated correctly, containing a minimum of three fabricated components, plus rods, dowels and shafts may be included, for example a lever and linkage system or a scissor lifts. The thin walled components should be assembled together to create one assembly with no inaccuracies, for example a small hairdryer or a computer mouse. Both models should be rendered to show a realistic product.

A drawing template should be created to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication.

Overall, the portfolio should provide 3D models that fully meet their purpose, for example to display accurate visualisation to a potential customer, and are clear for a third party to understand.

For merit standard, learners will show accurate, fabricated and thin walled components. The fabricated components should contain a minimum of two folds, two bends and two slots, containing a minimum of two fabricated components, plus rods, dowels and shafts may be included. The components should be assembled into a model that contains a minimum of four components that are orientated correctly. The thin walled components should be assembled together to create one assembly, which may contain minor inaccuracies, for example minor misalignments, but correctly orientated. Both models should be rendered but it may not be fully realistic, for example, there may be minor errors in shadows, lighting, reflections, and views.

A drawing template from the standard library should be used to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication. Drawings may contain minor dimensioning errors or missing dimensions.

Overall, the evidence should provide an appropriate 3D model that generally meets its purpose.

For pass standard, learners will show generally accurate, fabricated and thin walled components. The fabricated components should contain a minimum of one fold, one bend and one slot. The components should be assembled into a model that contains a minimum of three components and some may be orientated incorrectly. The thin walled components should be assembled together to create one assembly, with some inaccuracies, for example inaccuracies in component orientation or alignment. Components such as split pins and washers do not contribute towards the component count. One component may be rendered, with some errors in shadows, lighting, reflections, and views.

A drawing template from the standard library should be used to output a professional portfolio of drawings, including orthogonal drawings, a 3D shaded/solid model, a sectional view of the thin walled components and a detail view of the fabrication. Drawings may contain minor dimensioning errors or some missing dimensions.

Overall, the evidence should provide an appropriate 3D model that partially meets its purpose.

Links to other units

This unit links to:

- Unit 3: Engineering Product Design and Manufacture
- Unit 5: A Specialist Engineering Project
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 43: Manufacturing Computer Numerical Control Machining Processes
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations
- contribution of ideas to unit assignment/project materials.

Unit 11: Engineering Maintenance and Condition Monitoring Techniques

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore types of engineering maintenance, their use and impact on the monitoring and maintenance of engineered plant and equipment.

Unit introduction

The maintenance and monitoring of engineered plant and equipment are key to productivity, profitability, safety and efficiency wherever such items are used. For example, in manufacturing plant breakdowns, malfunctions and unscheduled stoppages cost money and can compromise quality and performance.

In this unit, you will investigate and explore different types of maintenance and condition monitoring techniques and their applications across a variety of engineered plant and equipment. You will examine the relative costs and benefits of monitoring and maintaining engineered plant and equipment in good order. Additionally, you will analyse condition monitoring data and undertake a practical, planned maintenance procedure on an item of engineered plant or equipment.

Engineering maintenance and condition monitoring are key functions across a range of sectors, for example advanced manufacturing, aerospace, automotive, power and chemical engineering. The knowledge, skills and understanding you gain in this unit are relevant to a range of job roles, for example facilities maintenance, manufacturing planning and control, specialist machine tool design and construction, installation and commissioning. This unit also helps to prepare you for a relevant apprenticeship or entry to higher education.

Learning aims

In this unit you will:

- A** Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely
- B** Examine the use of condition monitoring techniques to detect faults and potential failures before they occur
- C** Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely	A1 Types of maintenance and common maintenance techniques A2 Maintenance cost considerations A3 Reasons for maintenance	A report on the use of three different types of maintenance as they are applied to items of engineered plant or equipment.
B Examine the use of condition monitoring techniques to detect faults and potential failures before they occur	B1 Condition monitoring techniques B2 Condition monitoring equipment and data B3 Principles of and factors contributing towards potential faults and failures	A report focusing on condition monitoring techniques and an analysis of given monitoring data to identify potential faults and failure.
C Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation	C1 Maintenance and condition monitoring plan C2 Health and safety requirements when undertaking maintenance activities C3 Preparation for maintenance activities C4 Completion of a maintenance activity	A detailed maintenance and condition monitoring plan and log, including supporting paperwork, when carrying out maintenance and condition monitoring activities safely. Observation records and witness statements of completing the routine maintenance activity.

Content

Learning aim A: Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely

A1 Types of maintenance and common maintenance techniques

Types of engineering maintenance and common techniques, including:

- reactive or breakdown maintenance – repairs and replacement undertaken once a breakdown has occurred
- planned maintenance – maintenance carried out on specific items of plant and equipment according to a fixed plan at prescribed intervals, e.g. monthly, yearly
- preventative maintenance – regular inspection, detection and correction of plant and equipment to prevent breakdown, e.g. visual inspection, checking alignment, making routine adjustments, cleaning, lubrication
- corrective maintenance – a fault is detected, reported and rectified in order to restore an item to normal working order
- total productive maintenance (TPM) – integrated means of ensuring that all plant and equipment is maintained in excellent working condition so that manufacturing processes run continuously without disruption
- predictive maintenance – doing what is required to monitor and diagnose the condition of an item of plant or equipment, e.g. condition monitoring and statistical process control and quality assurance data.

A2 Maintenance cost considerations

Costs and impact upon profitability of maintenance activities, including the cost of:

- different types of maintenance as a proportion of total expenditure
- the type of maintenance applied and the benefits that result
- direct and indirect labour
- spares and consumables held
- lost output
- equipment hire and replacement
- outside contracting
- health and safety and the environment.

A3 Reasons for maintenance

Understand the reasons for engineering maintenance, including:

- to improve plant reliability
- to improve productivity
- to reduce wastage
- to reduce costs
- to improve safety
- to improve quality
- to improve comfort and welfare
- to adhere to legal and statutory requirements, e.g. noise levels
- to adhere to manufacturer's guidance and instructions, e.g. warranty.

Learning aim B: Examine the use of condition monitoring techniques to detect faults and potential failures before they occur

B1 Condition monitoring techniques

Measuring and monitoring a specific function, parameter or item of plant or equipment, including:

- vibration analysis, e.g. monitoring and recording the vibration of a rotating shaft in a motor
- temperature analysis, e.g. detecting changes in temperature in a critical component, such as a bearing, fuse, or relay
- flow analysis, e.g. monitoring the performance of a pump
- crack detection, e.g. identifying surface cracks in heat-treated components
- thickness analysis, e.g. monitoring the wall thickness of tubes in a continuous tube manufacturing mill
- oil analysis – the detection of contaminants in a lubricating oil, e.g. water in a turbine
- corrosion detection, e.g. monitoring the degradation of critical surfaces in an aircraft fuselage
- emissions analysis, e.g. the measurement of pollutants discharged by an internal combustion engine.

B2 Condition monitoring equipment and data

Condition monitoring equipment and data collection, including:

- manual or remote fixed and portable equipment for online and offline data
- collection, e.g. hand-held data logger able to measure and transmit a range of information, e.g. temperature, light, pressure
- equipment performance data, including self-diagnostics
- smart sensors, e.g. onboard vibration sensors built into an electric motor that monitor and distribute information continuously
- statistical process control and quality assurance data.

B3 Principles of and factors contributing towards potential faults and failures

- Causes of faults and failure, including:
 - failure rate – the predicted frequency of failure of a component or system over a period of time or number of cycles
 - failure mode – the way in which failure occurs
 - functional failure – the point at which a component or system no longer functions as required and is considered to have failed.
- Calculations concerning failure:
 - mean time to failure (MTTF) – the average period of time a component or system will operate before failing
 - mean time to repair (MTTR) – can be either the average period of time to repair a fault or the average time between successive needs to repair a component or item of equipment
 - mean time between failures (MTBF) – the average period of time between successive failures of a component or item of equipment.
- Factors that may contribute to faults and failures, including:
 - design and capability – a fault in the design features of a component or item of equipment, e.g. poor material specification
 - mode of operation – the manner and purpose for which an item of equipment is used, e.g. overloading a machine beyond its capability
 - environment – the conditions in which an item of equipment is used, e.g. temperature and humidity
 - manufacturing processes – inappropriate method(s) of manufacture.

Learning aim C: Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation

C1 Maintenance and condition monitoring plan

A typical maintenance plan for an item of engineered plant or equipment should include the following detail:

- equipment type, description, location, identification number
- type of maintenance procedure
- maintenance procedure description
- frequency of procedure
- date of next procedure
- specialist skills required, e.g. mechanical, electrical, fluid engineering
- personnel involved
- equipment status, e.g. running, shutdown, isolated
- task list
- estimated time and actual time for each task
- tools, equipment and materials required
- health and safety requirements including personal protective equipment (PPE)
- item checked, tested, handover
- task report including the identification of any further maintenance needs.

C2 Health and safety requirements when undertaking maintenance activities

- Key features of regulations, or other relevant international equivalents, including:
 - isolation and permit to work systems
 - working in confined spaces and at heights
 - Current Control of Substances Hazardous to Health (COSHH) Regulations and amendments, including lubricants, degreasing agents and other hazardous substances dependent upon the nature of the plant or equipment being maintained
 - Current Personal Protective Equipment (PPE) at Work Regulations and amendments, where hazards exist to lungs, eyes, head, feet, skin or the body
 - Current Lifting Operations and Lifting Equipment Regulations and amendments, including the safe use of appropriate lifting equipment, e.g. hoist
 - Current Manual Handling Operations Regulations (MHOR) and amendments, referring to the HSE manual handling assessment charts.
- Other safe working practices relevant to an engineering maintenance activity, including:
 - organisation rules and maintenance protocols
 - environmental issues
 - health and safety procedures
 - reporting of accidents
 - reporting of hazardous items of plant or equipment
 - emergency procedures
 - reporting and treatment of injuries.
- Risk assessment of the general working environment and specific maintenance procedure, including:
 - defining hazard by inspection of the general environment and location, e.g. remove and clean jets in a gas-powered heat treatment furnace
 - defining risk by determining how hazards may cause injury, e.g. falling objects when maintaining a crane
 - putting control measures in place to reduce risk, e.g. isolating the work area
 - Health and Safety Executive (HSE) guidance on risk assessment to include the five steps and the use of standard pro forma.

C3 Preparation for maintenance activities

Obtain available supporting documentation for an engineering maintenance procedure, e.g. manufacturer's drawings, parts list, service manual, maintenance documentation, maintenance/service history, plant register, standing instructions, permit to work, handover documents, maintenance reports, condition monitoring data.

- Select materials, spares and equipment to complete the maintenance activity:
 - hand tools, e.g. spanners, wire strippers, bearing puller
 - consumables, e.g. lubricants, electrical wire
 - replacement parts, e.g. bearings, filter.

C4 Completion of a maintenance activity

Complete a maintenance activity on an item of equipment or plant safely, including:

- disassemble, remove or strip item
- visually inspect components
- repair, replace or replenish as required
- reassemble item
- inspect and test
- complete documentation
- return item to service
- complete documentation.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely		A.D1 Evaluate, using language that is technically correct and of a high standard, the characteristics and suitability of three different types of maintenance used for the continued operation of plant and equipment.
A.P1 Explain, using examples, the characteristics of and reasons why three different types of maintenance are used for the continued operation of plant and equipment.	A.M1 Compare, using examples, the characteristics and suitability of three different types of maintenance used for the continued operation of plant and equipment.	
Learning aim B: Examine the use of condition monitoring techniques to detect faults and potential failures before they occur		B.D2 Evaluate the condition monitoring practice for a piece of plant or equipment and the results from a given condition monitoring exercise on a piece of plant or equipment, recommending appropriate interventions to rectify the faults and failures.
B.P2 Explain the different condition monitoring techniques and equipment used to detect faults and potential failures. B.P3 Interpret the results from a given condition monitoring exercise on a piece of plant or equipment, identifying the possible causes.	B.M2 Analyse the condition monitoring techniques and equipment used to detect potential faults and failures in a piece of plant or equipment, including the contributory factors. B.M3 Analyse the results from a given condition monitoring exercise on a piece of plant or equipment, identifying realistic causes for the faults or failures.	
Learning aim C: Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation		C.D3 Refine, during the process, the planning and performance of a maintenance activity on an item of plant or equipment safely, accurately and efficiently, returning it to service, and identifying any future maintenance requirements and/or advice.
C.P4 Produce a plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. C.P5 Prepare materials, equipment, and procedures to complete maintenance activity on a piece of plant or equipment. C.P6 Complete a maintenance activity safely on a piece of plant or equipment, returning it to service.	C.M4 Produce a detailed and accurate plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. C.M5 Perform a maintenance activity safely and accurately on a piece of plant or equipment, returning it to service.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- items of engineered plant and equipment – these could be items of workshop equipment, modern motor vehicles or items of plant and equipment located elsewhere in the institution or made available by local companies
- hand-held condition monitoring equipment
- condition monitoring data for an item of plant or equipment
- a range of hand and power tools suitable for maintenance activities
- the provision of consumable items for maintenance tasks
- accompanying documentation for the equipment referred to above and relevant health and safety regulations, as required by the unit content
- appropriate websites such as the HSE.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a balanced evaluation of the characteristics and suitability of three different types of engineering maintenance. They will identify the items being maintained, the purpose of the maintenance, the techniques used and why the type of maintenance is appropriate. Learners will provide a conclusion regarding the suitability of each type of maintenance. For example predictive maintenance is employed on a gas turbine engine because of the safety critical nature of the product as well as the availability and increased capabilities of diagnostic tools to monitor the performance and condition of the engine that form the basis for this type of maintenance.

Overall, learners' evaluations will be easy to read and understand by a third party who may or may not be an engineer. They will be well structured and presented in a logical way using the correct, technical engineering terms and will be a high standard of written language regarding spelling and grammar. Also, charts and illustrations will be clear and easy to understand.

For merit standard, learners will produce a detailed comparison of the characteristics (types of maintenance procedure undertaken, the techniques applied, and the costs) and suitability of three different types of maintenance applied to plant or equipment. Learners will select and research the applications and will make a personal judgement on the suitability of the maintenance chosen. For example using planned maintenance for a continuous tube manufacturing mill to ensure that the plant is able to run continuously between scheduled shutdowns, whereas breakdown maintenance is acceptable for a lawn mower in a non-commercial setting, as the costs would outweigh the benefits of operating a planned maintenance system.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the characteristics and suitability of three different types of maintenance for the particular applications they have chosen, for example a domestic lawn mower, a gas turbine engine, a continuous tube manufacturing mill. The characteristics referred to will cover the type of maintenance undertaken, the techniques applied, the costs and reasons why the approach is used, for example the continuous tube manufacturing mill may be maintained using planned maintenance to ensure the reliability of the plant and the quality tube it produces. Learners will refer to an experienced and available maintenance team to complete the work, as well as the cost benefits to the organisation of maintaining continuous running of the mill greatly outweighing the wider disruption caused by breakdowns.

Overall, learners' evidence will be logically structured, although it may be basic in parts, for example they may only provide simple reasons for their use, perhaps missing out a reference to cost, and it may contain minor technical inaccuracies relating to engineering terminology, such as 'mending' faults rather than 'rectifying' faults.

Learning aim B

For distinction standard, learners will produce a balanced evaluation of condition monitoring techniques and equipment. They will analyse in detail the results from a given condition monitoring exercise, identifying the item, the parameters measured, and the techniques and equipment used. They will identify factors that may contribute to a fault or potential failure and recommend appropriate interventions to rectify the fault(s) and/or failure(s). For example, learners may refer to the data obtained from frequently monitoring the condition of a lubrication oil in a production machine, possibly identifying the presence of water, wear debris or other contaminants that might compromise the machine's reliability and performance and lead to fault(s) or potential failure(s).

Overall, learners' evidence will 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, charts, tables and illustrations will be clear and understandable.

For merit standard, learners will provide a detailed analysis of condition monitoring techniques and equipment used to detect potential faults or failures in an item of plant or equipment. For example, learners may refer to using a hand-held optical pyrometer to record temperature variations in a heat treatment furnace that may, if not addressed, compromise the mechanical properties of the components being manufactured.

Learners will interpret the results from a condition monitoring exercise, identifying some realistic causes for the faults or failures which could cover the design, mode of operation and conditions in which it is used. For example, they may identify significant variations in temperature in a heat treatment furnace possibly due to blocked gas jets.

Overall learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the different types of condition monitoring techniques and equipment, the parameters they measure and the faults and failures they can identify and predict. For example, learners may refer to motor vehicle exhaust emission test equipment to measure and record the level of gases and other pollutants.

Learners will interpret the results of data from a given condition monitoring exercise on a piece of plant or equipment, for example recording temperature measurements from a heat treatment furnace over a prescribed period of time, calculating mean time to repair. They will also identify the possible causes for the failure, although the causes may not be realistic.

Overall learners' evidence will be logically structured, although it may be basic in parts, for example a limited explanation of different types of condition monitoring equipment, perhaps misinterpreting some of the results from the exercise, and it may contain some minor technical inaccuracies, for example misspelling 'thermocouple'.

Learning aim C

For distinction standard, learners will produce logical refinements to their detailed maintenance plan and risk assessment, making refinements as they plan, prepare and complete the maintenance activity on a piece of plant or equipment.

Learners will prepare and perform the activity safely, accurately and efficiently, rectifying the fault and/or performing routine maintenance and returning the piece of plant or equipment to service, for example removing and replacing a set of bearings for a roller on an airport luggage conveyor system and returning the system back to service. Throughout the activity learners will be efficient, for example by thinking ahead to organise the tasks, preparing any consumables and other materials and completing tasks in the correct order while making any adjustments for unforeseen problems as they occur.

Also, learners' evidence, for example the task report, will identify any future maintenance requirements and/or advice. For example, when changing an oil filter, learners may observe that a bearing needs replacement and/or that the head of a casing bolt is worn so care is needed during the assembly and disassembly procedure and replacement may be advised during the next scheduled maintenance activity.

Overall, learners' evidence will be easy to read and understand by a third party who may not be an engineer. It will be well structured and presented in a logical way using the correct, technical engineering terms. Also charts, forms, plans and illustrations will be clear and understandable.

For merit standard, learners will produce a detailed and accurate plan and risk assessment to complete a maintenance activity on a piece of plant or equipment. For example, learners will break down the maintenance procedure into logical and easy to understand steps, and all the tools required for the job will be listed.

Learners will prepare and perform the activity safely and accurately, rectifying the fault and/or performing routine maintenance and returning the piece of plant or equipment back to service. For example, accuracy means applying the correct torque to bolts and sealing bearings correctly or ensuring gas jets are thoroughly free of rust and dust before being reassembled into the furnace.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand. For example, the task report/documentation will reference quality control checks and provide details of the condition of the parts replaced so maintenance schedules can be adjusted, such as to increase the frequency of cleaning and lubricating bearings on a conveyor system.

For pass standard, learners will produce a maintenance plan and risk assessment for a maintenance activity on an item of plant or equipment. Learners' risk assessments will include consideration of all significant hazards, be laid out on in appropriate template and include suitable control measures.

They will prepare for the activity by selecting materials and equipment, following prescribed procedures and complete the activity safely by rectifying any faults and/or completing routine maintenance, returning the piece of plant or equipment back to service, for example by replacing the brushes in an electric motor. Some tasks, however, may not be completed in the most efficient order.

Overall, learners' evidence will be logically structured, although it may be basic in parts, for example the plan may lack details of estimated and actual time taken, the task report/documentation may make limited reference to quality control checks and there may be some minor technical inaccuracies, for example specifying the wrong tool to remove the gas jets in a heat treatment furnace, or a missing a spring washer from a securing bolt.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 15: Electrical Machines
- Unit 24: Maintenance of Mechanical Systems
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 50: Aircraft Gas Turbine Engines
- Unit 53: Airframe Mechanical Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in maintenance and/or condition monitoring techniques
- contribution of ideas to unit assignment/project materials.

Unit 12: Pneumatic and Hydraulic Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the safe operation of pneumatic and hydraulic systems, including simulation of circuits using software and practical system assembly and testing.

Unit introduction

Pneumatic and hydraulic systems are an important part of many modern engineering products and systems. For example, aircraft landing gear relies on hydraulics, as do the robotic machines that are used in vehicle assembly plants. Pneumatic systems are widely used in the manufacturing industry and pneumatically operated tools are commonplace in garages and engineering workshops.

You will study the safe operation and maintenance of pneumatic and hydraulic power systems by investigating industrial case studies. You will learn how to use computer-aided design (CAD) software to create circuit diagrams of pneumatic and hydraulic systems and then simulate their function before gaining practical experience of assembling and testing a physical system.

As an engineer you may need to operate, maintain and repair pneumatic and/or hydraulic systems safely. This unit helps to prepare you for an engineering apprenticeship, for higher education and for technician-level roles, such as in plant maintenance or as a hydraulic/pneumatic technician.

Learning aims

In this unit you will:

- A** Examine the safe operation and maintenance of pneumatic and hydraulic powered systems
- B** Develop pneumatic and hydraulic circuit diagrams and simulate their operation
- C** Explore the safe development of pneumatic or hydraulic powered systems.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the safe operation and maintenance of pneumatic and hydraulic powered systems	<p>A1 Hydraulic and pneumatic power supply components</p> <p>A2 Hydraulic and pneumatic actuator components</p> <p>A3 Hydraulic and pneumatic system control components</p> <p>A4 General system safety and maintenance</p> <p>A5 Common applications of industrial hydraulic and pneumatic power systems</p>	An illustrated technical report based around two contrasting case studies that include an evaluation of pneumatic and hydraulic systems and how they are used in industry.
B Develop pneumatic and hydraulic circuit diagrams and simulate their operation	<p>B1 Creating hydraulic and pneumatic power circuit diagrams</p> <p>B2 Simulating the operation of hydraulic and pneumatic power circuits</p>	Hydraulic and pneumatic power circuit diagrams and annotated screenshots of circuit simulation will be supported by witness statements and/or observation records.
C Explore the safe development of pneumatic or hydraulic powered systems	<p>C1 Health and safety requirements for the safe operation of hydraulic and pneumatic power systems</p> <p>C2 System assembly</p> <p>C3 Testing and fault finding pneumatic and hydraulic powered systems</p>	Evidence from practical tasks will be evidenced by a logbook, written notes, annotated photographs, witness statements and observation records.

Content

Learning aim A: Examine the safe operation and maintenance of pneumatic and hydraulic powered systems

A1 Hydraulic and pneumatic power supply components

- Function and operation of pneumatic power supply system components:
 - compressor types, including piston, diaphragm, rotary vane, screw, typical operating pressures, compressor delivery volume
 - storage receivers, including constructional and safety features, shape and qualitative understanding of sizing factors, e.g. air consumption, network size
 - fluid conditioning equipment, including filters, lubricators, exhaust silencers, pressure regulators, dryers, drainage points and oil separators
 - key parameters, including operating pressures, compressor delivery volume, cycle regulation.
- Function and operation of hydraulic power supply system components:
 - pump types, including fixed displacement, e.g. gear, lobe, balanced vane, piston, variable displacement, e.g. vane, piston
 - fluid storage, including gas-pressurised and spring-loaded accumulators, simple tank and pressurised reservoirs, reservoir safety features, including stack pipe, de-aeration features, filters
 - fluid conditioning equipment, including supply and return reservoir filters, component filters and heat exchangers
 - key parameters, including pump flow rates, pressure limits, reservoir capacity.

A2 Hydraulic and pneumatic actuator components

- Function, operation and practical applications of:
 - linear actuator components, including single-acting cylinders, double-acting cylinders, cylinders with cushioning
 - rotary actuator components, including piston motors, sliding vane motors and gear motors.
- Key parameters, including actuator stroke length, load resistance, speed of operation.

A3 Hydraulic and pneumatic system control components

- Control component function and operation:
 - directional control valves, including 4-or 3-way valve, closed/neutral position
 - flow control valves, including throttle valve, sequence valve
 - pressure control valves, including pressure relief valve (PRV), thermal relief valve (TRV), pressure reducing valve
 - non-return valves, including check valve
 - position sensors, including pressure switch, microswitch
 - control component actuation methods, including pressure, manual, mechanical, electrical (solenoid) and pilot pressure actuation.
- Key parameters, including operating pressure, flow rate, temperature and control component requirements.

A4 General system safety and maintenance

- Safe maintenance of pneumatic systems, including compliance with maintenance manuals and procedures for checks on:
 - filter condition, water traps, lubricator fluid level, leaks, physical damage, security of attachment of components and fittings, lubrication of moving parts and linkages and system functional tests and checks.

- Safe maintenance of hydraulic systems, including compliance with maintenance manuals and procedures for checks on:
 - fluid levels, filter condition, accumulator pre-charge pressures, fluid plumbing and component leaks, physical damage and security of attachment of components, fittings and fluid plumbing, component fouling, aerated oil, lubrication of moving parts, functional tests and checks.
- Main hazards associated with fluid power systems:
 - sudden release of pressurised fluid, including impact injuries from pressure vessel rupture, ejected components/debris, flailing hoses
 - contact with pressurised fluid, including high temperature hydraulic fluid causing burns, cuts or injection injury
 - entrapment in moving parts
 - hydraulic fluid, including contamination due to leaks, harmful effects of skin contact, long term health implications.
- Safety design features, including pressure relief valves (PRVs), emergency stops, guarding, use of abrasion resistant flexible hoses, safe shutdown procedures, fail-safe systems.

A5 Common applications of industrial hydraulic and pneumatic power systems

- Pneumatic power systems, e.g. automotive paint spray booth, workshop equipment, rail, automotive, automated manufacturing systems.
- Hydraulic power systems, e.g. agricultural machines, motor transport, aircraft systems, industrial equipment.

Learning aim B: Develop pneumatic and hydraulic circuit diagrams and simulate their operation

B1 Creating hydraulic and pneumatic power circuit diagrams

- Symbols and circuit diagrams for hydraulic and pneumatic power systems and components to BS ISO 1219-1:2012 or other relevant international equivalents.
- Use of CAD software to create pneumatic circuit diagrams to BS ISO 1219-1:2012 or other relevant international equivalents, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell, clamp an object using a two-cylinder arrangement, rotary actuator with reversing action, cylinder with deceleration air cushion.
- Use of CAD to create hydraulic circuit diagrams to BS ISO 1219-1:2012 or other relevant international equivalents, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell and regeneration, motor with variable speed and reversing action.

B2 Simulating the operation of hydraulic and pneumatic power circuits

- Simulating the behaviour of hydraulic and pneumatic power circuits during operation.
- Recording output variables, e.g. generating plots of cylinder velocity versus time.
- Changing circuit and component input parameters and component type or layout, observing changes to circuit output variables and their effect on circuit performance, e.g. changing flow control valve settings to determine the effect on cylinder velocity, improving pressure losses by reducing the complexity of circuit layout and/or component selection.

Learning aim C: Explore the safe development of pneumatic or hydraulic powered systems

C1 Health and safety requirements for the safe operation of hydraulic and pneumatic power systems

- Main regulations and Approved Codes of Practice (ACOP) or other relevant international equivalents covering pressure systems, e.g.:
 - Pressure Equipment Regulations 1999 and amendments, (deals with the design, manufacture and supply of pressure systems)
 - Pressure Systems Safety Regulations (PSSR) 2000, (deals with the safe operation of a pressure system)
 - ACOP and guidance on Regulations L122 Second Edition 2014 (provides further advice on pressure systems safe operation).

- Safe working practices, including:
 - care and handling of pressurised gases, including storage bottles and receivers, airlines and pressurised systems
 - control of hazardous substances, including hydraulic fluid and lubricants
 - personal protection when handling gases and liquids and pneumatic and hydraulic system components, including use of barrier creams and other precautions to avoid dermatitis and the inhalation of noxious fumes
 - ensure system is depressurised prior to work
 - avoid checking for system leaks using hands
 - ensure correct fluids are used for replenishment
 - keep clear of system components when carrying out functional tests and checks.

C2 System assembly

- Component assembly, including:
 - familiarisation with safe and appropriate use of fluid system power supply components, fluid compressors, motor pump combinations, supply pressure regulation and safety features, fluid storage and conditioning components
 - component use, selection, physical and functional requirements, including system service loading, pressure and flow limits, linear and rotary movement parameters, sizing, porting, component actuation and control methods
 - component mounting and safe connection systems.
- Identification, selection and assembly of fluid conductors, including:
 - qualitative understanding of conductor sizing factors, including standard tubing sizes, flow velocity, operating pressure
 - pipework materials and types, including steel, aluminium alloy, copper rigid pipes and tubing, plastic tubing, rubber, neoprene and steel reinforced flexible hoses
 - fittings, including threaded and quick release couplings and connectors, pipe elbows, flared tube fittings, clamped and sealed end fittings.

C3 Testing and fault finding hydraulic and pneumatic powered system

- Functional tests and checks in accordance with maintenance manuals:
 - checking, including correct assembly, security of attachment, fluid plumbing and leaks, physical damage, fluid levels
 - system testing, including freedom of movement, fouling, operating in the correct sense, correct sequencing, spongy operation, range and freedom of movement, cycle speeds, operating pressures.
- Fault finding, including:
 - fault finding aids, e.g. circuit diagrams, flow charts, isolation methods
 - causes of failure, including fluid quality and contamination, overloading of components, lack of maintenance, fouling
 - common modes of failure, e.g. seizing of components, leakage, slow or sluggish movement.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the safe operation and maintenance of pneumatic and hydraulic powered systems		A.D1 Evaluate, using language that is technically correct and of a high standard, the safe operation, maintenance requirements, component selection and key parameters necessary for a hydraulic and a pneumatic system to meet service requirements, including any improvements.
A.P1 Explain the safe operation, maintenance requirements, and component selection for a hydraulic and a pneumatic powered system.	A.M1 Analyse the safe operation, maintenance requirements, component selection, and key parameters for a hydraulic and a pneumatic powered system to meet service requirements.	
Learning aim B: Develop pneumatic and hydraulic circuit diagrams and simulate their operation		B.D2 Optimise the performance of the pneumatic and hydraulic circuit simulations, ensuring that the requirement of the client brief is met.
B.P2 Create circuit diagrams for a hydraulic and a pneumatic circuit that each contain at least eight components. B.P3 Simulate the operation of a pneumatic and a hydraulic circuit that each contain at least eight components.	B.M2 Produce accurate diagrams for a hydraulic and a pneumatic circuit containing at least eight components to an international standard, to meet the client brief. B.M3 Simulate the correct operation of a pneumatic and a hydraulic circuit determining the effect of changing component parameters to meet the system purpose.	
Learning aim C: Explore the safe development of pneumatic or hydraulic powered systems		C.D3 Refine, during the process, the performance of a fully functioning pneumatic or hydraulic system to better meet the client brief, while explaining the importance of safe working practices.
C.P4 Explain the importance of safe working practices when assembling and testing pneumatic and hydraulic circuits. C.P5 Assemble a hydraulic or pneumatic system containing at least eight components safely. C.P6 Test the operation of a hydraulic or a pneumatic system safely, identifying any faults.	C.M4 Develop a fully functioning hydraulic or pneumatic system, safely rectifying faults, while explaining the importance of safe working practices.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- specialist fluid power systems, CAD software for the creation of circuit diagrams to ISO standards and the simulation of hydraulic and pneumatic system operation, e.g. Automation Studio™
- software that allows system and component parameters to be adjusted to optimise circuit function and is capable of calculating and plotting system variables, such as cylinder velocity during the operating cycle
- hydraulic or pneumatic system test rig or mock-up that allows a range of components to be safely fixed, connected, tested and adjusted to refine the system function
- a range of health and safety regulations and guidance documents, maintenance manuals, procedures and fault finding aids, as specified in the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce detailed and comprehensive evaluations of the hydraulic and pneumatic systems, demonstrating a clear understanding of how the systems and components in the system operate and function. Key parameters will be stated and their importance explained for each of the major system components, for example piston cross-sectional area for a simple hydraulic cylinder determines the maximum force that it can apply at any given pressure.

Learners will evaluate the type of system and components selected to meet a specific industrial service requirement. For example, the evidence might suggest the selection of hydraulics for an industrial press, by virtue of the high power, high force, accuracy and repeatability required, and then a reasoned argument would be given as to why these service requirements would not be achieved to the same standard using pneumatics.

In addition, the evaluation will include suggestions for improvement to the safety and maintenance of the system, for example improving maintenance efficiency by replacing a piston accumulator with a bladder accumulator thus avoiding the need for repeated pre-charging in the event of piston seal leakage.

Overall, 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 use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse the hydraulic and pneumatic systems in sufficient depth and demonstrate a clear understanding of how the systems and components in the system operate and function, and how the required maintenance continues to ensure that the systems remain safe and fit for purpose. Key operating parameters will be stated and their importance explained for each of the major system components.

Learners will also analyse how the system and component operating parameters influence the choice of system and the system architecture needed to meet a specific industrial service requirement. For example, by considering the constraints on the required system layout and the service loads acting on a wheel braking system, learners will decide whether the system should be pneumatically or hydraulically powered.

Overall, the analysis, such as an illustrated written report, will be logically structured, technically accurate and easy to understand.

For pass standard, learners will provide an explanation of how pneumatic and hydraulic systems and components in the system operate, including key parameters and function of the system and corresponding components. Learners will explain the maintenance requirements for each type of fluid system and its associated components to ensure its continued safe operation. The explanation will include details on the industrial applications best suited to pneumatically or hydraulically powered systems, as used in industry.

Overall, the evidence, such as an illustrated written report, will be logically structured, although basic in parts and may lack some depth and breadth of understanding. The explanations must, however, cover all essential aspects of safety when working on or maintaining pneumatic and hydraulic powered systems and their associated components.

Learning aim B

For distinction standard, learners will accurately produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components, to meet the system purpose and then optimise the performance of the circuit by iteratively adjusting operating parameters to produce circuit simulations that accurately meet all aspects of the client brief. For example, in combination with changing system pressure, learners will alter bleed valve settings in a pneumatic cylinder to vary cylinder extension speed or change the pneumatic cylinder to a different size or type.

Overall, learners will demonstrate a logical and systematic approach throughout and will present clear, accurate and well-structured circuit diagrams and simulation data. Sufficient, detailed evidence of the simulation and optimisation processes will be presented so that it could be repeated by a third party, and correct engineering terms will be used throughout.

For merit standard, learners will accurately produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components, to meet the intended purpose of the system.

Learners must systematically record the effects of changing component parameters on circuit operation and determine the values required for the system's intended purpose to be met. For example, learners will change bleed valve settings in a pneumatic cylinder to vary cylinder extension speed.

Overall, learners will demonstrate a systematic approach throughout and will present clear and accurate circuit diagrams, simulation data and will use appropriate technical terms.

For pass standard, learners will produce and simulate a pneumatic and a hydraulic circuit, each with a minimum of eight components.

Learners must make an accurate record of the circuit simulation, including the system and component settings. For example, after setting and recording the initial system and component parameters for a circuit controlling a pneumatic cylinder, learners will then record its displacement versus time characteristics in operation.

Overall, learners will present clear and well-structured circuit diagrams, simulation data and will use limited or inappropriate technical engineering terms.

Learning aim C

For distinction standard, learners will provide evidence of how refinements were made safely throughout the assembly, testing and fault finding of their chosen system, improving its functionality and performance to better meet the client brief. For example, evidence may show learners manually adjusting a flow control valve to obtain optimum actuator speed, eliminating kinks in feed lines, replacing blocked filters.

Learners will demonstrate consistently good technical understanding of safe system assembly, testing and fault diagnosis. For example, when assembling system components, learners will ensure that they are securely attached to the system structure, correctly coupled, tested for leaks and correct operation, and adjusted appropriately to refine the system operation before any of the component adjusters are finally locked into position.

Overall, the evidence presented will cover all aspects of the practical system development and 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 throughout.

For merit standard, learners will provide evidence showing how safe assembly, testing and fault finding was used to develop a fully functional system. For example, the evidence may show learners changing system and component parameters, testing function and rectifying faults, such as tightening leaking unions.

Learners will demonstrate safe practice and a good technical understanding of most aspects of system assembly, testing and fault diagnosis. For example, they will, by following the circuit diagrams, be able to physically assemble components safely, securely and in the correct order within the system. This will ensure that system actuators not only operate in the correct sense and range but also in the correct sequential order.

Overall, the evidence presented, for example an illustrated portfolio or report, will be easy to read and understand. It will be logically structured and will use appropriate technical engineering terms.

For pass standard, learners will provide evidence explaining how assembly, testing and fault finding of a hydraulic or a pneumatic system was carried out safely. For example, evidence may show learners setting initial system and component parameters, testing the system and identifying faults, for example leaking unions, incorrect connections. They will also explain the importance of safe working practices required when working with physical systems.

Learners will demonstrate safe practice and some technical understanding of system assembly, test and fault diagnosis. For example, after the correct assembly of system components, learners will be able to identify the correct checks and test procedures that need to be carried out to ensure correct system operation but, when physically carrying out such checks and tests, may omit minor aspects of the test procedure that would have ensured all aspects of the system operation had been covered.

Overall, the evidence presented, for example an illustrated portfolio or report, will be easy to read and understand. It will be logically structured and learners will make limited or inappropriate use of technical engineering terms.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 10: Computer Aided Design in Engineering
- Unit 11: Engineering Maintenance and Condition Monitoring Techniques
- Unit 24: Maintenance of Mechanical Systems
- Unit 29: Principles and Applications of Fluid Mechanics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in pneumatic and/or hydraulic systems
- contribution of ideas to unit assignment/project materials.

Unit 13: Welding Technology

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine the principles and technology used in common welding processes and produce welded joints in differing materials and welding positions.

Unit introduction

A diverse range of welding processes are used in the manufacturing sector and in industry, including manual, automated and mechanised processes. The selection and application of these welding processes is vital in terms of the integrity, safety and the economic viability of the finished product.

In this unit, you will examine the common welding processes used to produce high-quality, permanent metal joints. You will select the most appropriate welding processes for a specific application. You will understand and apply strict safe working practices designed to protect you and colleagues from various hazards that are inherent to the welding process, such as electric currents, combustible gas mixtures and parts rotating at high speed. You will examine the materials and their behaviour during the welding process, helping you to create 'good' welded joints. Finally, you will plan and carry out a welding task to join different materials and joints together in different welding positions safely.

As an engineer, it is important to understand the welding technology, processes and the mechanisms of planning and creating joints and components. This unit helps to prepare you for employment, for example as a welding technician, for an apprenticeship or for entry to higher education to study engineering.

Learning aims

In this unit you will:

- A** Examine common welding processes used to produce welded joints safely for different applications
- B** Examine weldable materials and their behaviours during the welding process
- C** Carry out practical welding skills safely to join metallic materials together.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
<p>A Examine common welding processes used to produce welded joints safely for different applications</p>	<p>A1 Welding terminology for processes and equipment A2 Gas-shielded arc welding – shielding gases A3 Common welding processes A4 Welding electrotechnics</p>	<p>A written report examining the suitability of welding processes for at least two different applications. The report will also cover the safe working practices and equipment required.</p>
<p>B Examine weldable materials and their behaviours during the welding process</p>	<p>B1 The properties and behaviours of materials B2 Unalloyed steel materials B3 Alloyed steel and non-ferrous materials B4 Defects and irregularities in welded joints</p>	<p>A written report about the properties and structures of alloyed and unalloyed steel and non-ferrous materials, determining how defects are prevented and which tests are applied to detect defects.</p>
<p>C Carry out practical welding skills safely to join metallic materials together</p>	<p>C1 Prepare for welding operations C2 Welding parameters and settings C3 Welding of joints safely</p>	<p>Preparation activities before the welding of joints, including tools, equipment and consumables. A welding procedure specification (WPS) should also be used.</p> <p>Carry out welding operations to produce safely welded joints in two different materials, in two different welding positions and using two selected welding processes.</p>

Content

Learning aim A: Examine common welding processes used to produce welded joints safely for different applications

A1 Welding terminology for processes and equipment

- Types of manual welding process, e.g. manual metal arc (MMA), tungsten inert gas (TIG), metal inert gas (MIG)/metal active gas (MAG), flux-cored arc welding (FCAW).
- Automated and mechanised welding processes, e.g. orbital welding, resistance welding.
- The major differences between types of welding process, correct use of abbreviations, range of applications, advantages and disadvantages, potential problems, and potential hazards and methods of safe handling and working.

A2 Gas-shielded arc welding – shielding gases

The characteristics and operating principles:

- processes, including TIG, MIG/MAG, flux-cored welding
- shielding gas used for each process
- safe handling and storage of shielding gases
- standards for shielding gases and filler materials
- potential hazards and methods of safe handling and working.

A3 Common welding processes

Welding processes:

- TIG welding process, including arc ignition methods and their applications, common applications for each type of current, polarity and electrode type, use of and care for the equipment and accessories, standards for consumables, joint preparation and potential problems to overcome and potential hazards, and methods of safe handling and working
- MIG/MAG welding, including metal transfer modes and their applications, selection of appropriate type of current, polarity and electrode according to application, appropriate joint preparations and potential problems to be overcome, welding parameters on the weld bead and be able to outline the welding parameters for particular applications, main components of the equipment and accessories, appropriate standards for consumables and how they are to be selected, care for the equipment and accessories, potential hazards and methods of safe handling and working
- FCAW process, including common applications for each type of current, polarity and electrode, appropriate joint preparations and potential problems to be overcome, appropriate welding parameters on the weld bead and outlining welding parameters for particular applications, potential hazards and methods of safe handling and working, functions of the main components of the equipment and accessories, appropriate standards for consumables, how consumables should be selected, and care for the equipment and accessories
- MMA welding process, including principles of MMA welding, selection of the appropriate type of current, polarity and electrode according to application, applications, appropriate joint preparations and potential problems to be overcome, range of welding parameters for particular applications, hazards and methods of safe handling and working, component of the equipment and accessories, handling, control and storage of the various types of electrodes, use of appropriate standards, influence of electrode coating on droplet transfer and weld metal properties.

A4 Welding electrotechnics

- The function of welding power source components:
 - alternating current (AC) and direct current (DC) and give examples of their individual application to different welding processes
 - transformers
 - rectifiers, including bridge (half and full wave).

- Power sources for arc welding:
 - how a welding power source works (AC and DC), including the most common devices used
 - arc welding power source, including the voltage static characteristic, operation point and control of arc stability
 - open-circuit voltage, arc voltage short-circuit current, duty cycle of a power source, voltage losses, and current to cable section relationship
 - appropriate power sources for a given welding process
 - settings and switches on different power sources and their effects on the welding process.

Learning aim B: Examine weldable materials and their behaviours during the welding process

B1 The properties and behaviours of metallic materials

- Properties of metallic materials:
 - mechanical properties of metals, e.g. plasticity, elasticity, cold and hot deformation, work hardening and strain ageing
 - loading conditions on the properties of metallic materials, e.g. temperature, loading speed, environment.
- The behaviour of metallic structures under loading:
 - stress – normal stress, shear stress
 - deformation – axial strain, shear strain
 - stress-strain relationship graphically
 - stress resulting from internal forces and moments.

B2 Unalloyed steel materials

Behaviour of structural steels in fusion welding:

- temperature distribution in welds and the microstructure formed as a result for a single-pass weld versus a multi-pass weld
- effects of heat input, cooling rate and multi-pass operation on weld metal solidification
- the microstructure formed for a single-pass weld versus a multi-pass weld
- the effects of the weld protection, the type of consumables on the microstructure of the weld metal and on its properties for a single-pass weld versus a multi-pass weld
- recognise areas of the heat-affected zone (HAZ), the reasons for grain size and microstructure changes and their effects on properties for a single-pass weld versus a multi-pass weld.

B3 Alloyed steel and non-ferrous materials

- Nickel and nickel alloys:
 - nickel and nickel alloy weldability
 - applicable welding processes and types of consumable for nickel and nickel alloys.
- Aluminium and aluminium alloys:
 - aluminium and aluminium alloy weldability
 - applicable welding processes and types of consumable for aluminium and aluminium alloys.
- Titanium and other metals and alloys:
 - the welding metallurgy of specified metals, e.g. titanium, magnesium
 - the weldability of the specified metals
 - appropriate welding processes.
- Joining dissimilar materials, including the weldability aspects involved when joining dissimilar materials.

B4 Defects and irregularities in welded joints

- Cracking phenomena in welded joints:
 - metallurgical mechanisms for each of the major types of cracking
 - susceptibility to cracking and suggest appropriate precautions to avoid cracking
 - type of cracking and the reason for its occurrence from study of fractured material and its history
 - reduce or eliminate the occurrence of lamellar tearing in welded construction/fabrication.
- Fractures and different kinds of fractures:
 - recognise the differences between cracks and fractures
 - recognise the differences between ductile and brittle fractures.
- Heat treatment of base materials and welded joints:
 - recognise the necessity to perform heat treatment after welding, depending on the type and thickness of steel, the application
 - post weld heat treatment (stress relieving).
- The various types of corrosion:
 - the chemical and electrochemical phenomena involved in corrosion
 - the most common types of corrosion, including intercrystalline, transcrystalline, knife-line attack, pitting, crevice, and stress-corrosion
 - common protection methods.
- Destructive and non-destructive testing of materials and welded joints:
 - destructive testing and the limitations of the data generated
 - testing methods and the parameters to be measured, including destructive and non-destructive, e.g. tensile, bend, impact, hardness, creep, root and face bend, nick break, and x-ray
 - recognise when and why special testing should be specified.

Learning aim C: Carry out practical welding skills safely to join metallic materials together

C1 Prepare for welding operations

- Information sources, e.g. safety instructions, job instructions, engineering drawings, quality control documentation, weld procedure specification (WPS), record and reporting sheets.
- Tools and equipment:
 - function and condition relevant to the welding process, e.g. cables, hoses, torches and electrode holders, gas pressure regulators, flow meters
 - working environment, e.g. workshop, site work, conditions for machinery and plant
 - assembling welding equipment, e.g. cables, weld return clamps, electrode holders, gas cylinders, regulators, valves, safety devices.

C2 Welding parameters and settings

- Manual processes, including gas pressure, flow rates, voltage, current (either AC or DC), according to electrode or filler size.
- Mechanised processes:
 - safety devices
 - welding speed
 - parameters, including electrical current and voltage, wire feed rate, filler diameter, gas shielding system
 - mechanical functions, including handling, loading, work holding, transfer.
- Weld bead and morphology in relation to the settings and parameters used, e.g. parameters affecting bead shape.
- Consumables, e.g. appropriate to process, electrode (rutile, basic, nickel alloy, cellulosic, stainless steel, other electrodes), filler wire, gases (oxygen, shielding gases), inert and active gases, and safe storage of consumables.

C3 Welding of joints safely

- Safe working practices:
 - fire prevention
 - electrical safety
 - electromagnetic (EM) and ultraviolet (UV) radiation
 - accident prevention and reporting
 - using risk assessments
 - manual handling
 - equipment maintenance
 - checking conditions, e.g. gas leaks, voltage and amperage, fuses, circuit breakers, leads
 - wearing personal protective equipment (PPE)
 - ventilation and extraction fumes
 - using ventilation and extraction
 - closing down equipment safely after use.
- Joints and components:
 - for manual processes – butt, fillet, autogenous weld (without filler wire)
 - for semi-automatic processes – two different joint configurations, two different material groups.
- Welding positions, e.g. flat (PA), horizontal vertical (PB), horizontal (PC), vertical upwards (PF), vertical downwards (PG), overhead (PE).
- Welding technique, e.g. torch angle, filler angle.
- Material:
 - forms, e.g. plate (thickness appropriate to process, up to 6 mm, section, sheet < 3 mm), other forms
 - types, e.g. carbon steel, stainless steel, aluminum.
- Welding discontinuities and faults, considering the chosen welding process and the applied parameters.
- Meet the required accuracy as specified, e.g. dimensions, tolerances, weld quality, visual checks, uniformity, alignment, correct fusion, fillet of appropriate size, porosity, slag inclusions, parent metal substantially free from arcing or chipping marks.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine common welding processes used to produce welded joints safely for different applications		A.D1 Justify, using language that is technically correct and of a high standard, the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.
A.P1 Explain the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.	A.M1 Analyse the choice of welding processes, parameters and settings for two given welding applications, explaining the equipment, terminology and safe working practices that apply.	
Learning aim B: Examine weldable materials and their behaviours during the welding process		B.D2 Evaluate the structure, mechanical properties and defects of alloyed and unalloyed steel and non-ferrous materials used in welding processes, including the effects of irregularities, forces and loading on the joints.
B.P2 Explain the structure and mechanical properties of alloyed and unalloyed steel and non-ferrous materials used in welding processes. B.P3 Explain the effect of forces and loading on welded joints. B.P4 Explain the defects and irregularities that occur in alloyed and unalloyed steel and non-ferrous materials used in welding processes.	B.M2 Analyse the structure, mechanical properties, and defects of alloyed and unalloyed steel and non-ferrous materials used in welding processes, including the effects of irregularities, forces and loading on the joints.	
Learning aim C: Carry out practical welding skills safely to join metallic materials together		C.D3 Refine, during the process, the planning and production of welded joints using two different materials, processes and welding positions safely accurately, efficiently and effectively.
C.P5 Produce a plan to create two welded joints, using two different welding processes safely. C.P6 Produce welded joints using two different materials, processes and welding positions safely.	C.M3 Produce a detailed and accurate plan to create two welded joints, using two different welding processes safely. C.M4 Produce welded joints using two different materials, processes and welding positions, safely and accurately.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.P4, B.M2, B.D2)

Learning aim: C (C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to appropriate:

- welding equipment
- welding consumables and materials
- destructive and non-destructive testing equipment
- health and safety materials and procedures.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will give a balanced justification for the choice of at least two welding processes for two different welding applications given to them. For example, their evidence could cover why welders use the MIG process in preference to MMA for thin sheet steel, particularly exploring why warping (distortion) occurs and the HAZ effects on the material. The justification will also cover different types of materials, shielding gases and safety considerations. For example, learners could examine the welding of aluminium using the optimum electrode, filler rod and inert gas and compare this to the MIG process. Learners will also detail how safe working practices vary by process.

Overall, the 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. Learners' written language will be of a high standard, for example they will use correct grammar.

For merit standard, learners will analyse the choice of at least two welding processes for two different welding applications given to them. For example, welding using the MIG process is considered easier to learn and quicker to master than MMA, although a comparison of the joint quality may contradict this argument. The evidence will demonstrate how the material and joint can influence the welding process. For example, why 18/8 (chromium/nickel) stainless steel may produce a better weld than welding stainless steel with 12% chromium.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain the choice of welding process for at least two different welding applications given to them, for example the reasons why low carbon steel can be welded using most processes, but cast iron requires a specific process and special welding rods. Learners will also explain the equipment and safe working practices required.

Overall, the evidence, such as a report, will be logically structured, although basic in parts. Learners will likely include minor technical inaccuracies relating to engineering terminology, such as mentioning 'MIG' instead of 'MAG'.

Learning aim B

For distinction standard, learners will give a balanced evaluation of different welding processes with regard to the weldable materials used and their behaviours. For example, their evaluation could cover why temperature differences cause a HAZ and a change in material properties and to the materials' microstructure. In addition, certain materials require the HAZ to be removed for cosmetic reasons and others due to the material becoming hard and brittle. Learners will evaluate the defects found in weldable materials. For example, they could examine how and why a longitudinal crack has occurred along the centre of a weld. They will explore the rationale for propagating cracks and their detection using non-destructive tests, including why it is advantageous to use an x-ray method in some cases and dye penetrate in others.

Learners will also evaluate the effects of forces and loading on welded joints, such as those caused by fatigue. For example, the internal structure of the weld may be porous or contain internal tensile stresses, which cause the welded joint to fail under fatigue loads. Therefore, it is important to understand the relationship between maximum stress and the loading or cyclic loading on the weld.

Overall, the justification will be easy to read and understand by a third party, who may or may not be an engineer.

For merit standard, learners will give a balanced analysis of different welding processes with regard to weldable materials and their behaviours. For example, they could cover why it is important to remove the thin layer of aluminium oxide before welding and the effect on temperatures and the cleaning solution that gives the best and safest results. Learners will also give a rationale for welding defects. For example, some metals, such as pure aluminium, do not show any colour change due to temperature increase which makes it difficult for technicians to know when to start welding.

Learners will analyse the effects of forces and loading on welded joints. Their analysis will cover why the creation of stress points is an issue in welded joints and how the application of preheating or stress relieving can mitigate this issue.

Overall, the analysis will be logically structured, be technically accurate and easy to understand.

For pass standard, learners will give a balanced explanation of the materials and their behaviours during welding. For example, they could cover why it is important to use the correct flux so that it may improve the alloying elements across the arc. Learners will give reasons for fractures occurring and the testing methods employed. For example, hidden porosity or lack of fusion and a destructive test such as 'nick break' may be used to check for this. Non-ferrous alloys have different material properties when compared to alloyed or unalloyed steels. For example, pure aluminium is very reactive and an oxide film forms quickly. This oxide needs removing before welding, but it is highly flammable, especially when mixed with steel dust.

Learners will also explain the effects of forces and loading on welded joints. For example, the effect on loaded joints of an effective throat thickness to ensure that sufficient heat is generated to give a good bond between the parent metal and the weld metal. This would then enable the weld to carry the designed forces.

Overall, the evidence, such as a report, will be logically structured, although basic in parts. Learners will likely include minor technical inaccuracies relating to engineering terminology, such as mentioning 'stress' instead of 'strain'.

Learning aim C

For distinction standard, learners will refine during the process the WPS plan to ensure that the equipment parameters and settings produce 'good' results, and that all preparation is completed methodically and thoroughly. For example, learners could discuss and decide on the most appropriate welding settings for voltage, wire speed and gas flow rates to ensure a 'good' weld using a specific material and electrode. Learners will select appropriate materials and welding positions to successfully complete two welds safely and accurately. The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners may select a vertical up-weld, in 3 mm low-carbon steel plate, using the MMA process for one weld, while ensuring it meets the appropriate weld specification. Effectiveness and efficiency of weld production will also be demonstrated, for example:

- effectiveness will be evidenced by considering the electrode selection and welding parameters to complete the weld with compliance to all safety requirements
- efficiency will be evidenced by optimising run speed and monitoring for weld quality to ensure there are no distortion, cracks, or porosity and minimising slag.

Overall, the evidence will be presented clearly in a way that would be understood by a third party, who may or may not be an engineer. There will be a comprehensive record of the safety procedures followed, together with accurately and correctly completed planning and checking documentation for each of the tasks completed. Learners' evidence, such as annotated photographs and observation records, will show clearly how they worked effectively, efficiently, accurately and safely during the welding processes.

For merit standard, learners will create a detailed and accurate WPS plan to ensure that the correct equipment is selected for the process and all preparation is completed. For example, learners will probably follow the vast majority of the manufacturers' recommended settings, except to use trial and error to select the most appropriate gas flow rate setting to ensure enough heat is available without burning a hole in the component. Learners will select appropriate materials and welding positions to successfully complete two welds. The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners could select a flat fillet weld, in 6 mm low-carbon steel plate, using MIG safely and accurately, ensuring it meets the appropriate weld specification.

Overall, the evidence will be logically presented, technically accurate and easy to understand. It will include the safe working practices that were applied throughout the welding tasks. Learners' evidence, such as annotated photographs and observation records, will show clearly how working accurately and safely was considered throughout the welding processes.

For pass standard, learners will create a welding plan to ensure that suitable equipment is selected for each welding process and some preparation is completed. Learners will probably follow the manufacturers' recommended settings for all parameters. Learners will select appropriate materials and welding positions to successfully complete two welds, using two different welding processes (two welds for each process). The welds must each be a minimum 50 mm in length, using two different materials and in two different welding positions. For example, learners could safely produce a flat butt weld, in 2 mm aluminium sheet, using the TIG process for one weld, while ensuring it meets the appropriate welding specification.

Overall, any supporting evidence may be limited, for example there may only be some evidence of preparation tasks and the inspection documentation may lack the required detail. Learners' evidence, such as annotated photographs and observation records, will show clearly how working safely was considered and applied throughout the welding tasks.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 24: Maintenance of Mechanical Systems
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 45: Additive Manufacturing Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and fabrication organisations with expertise of welding
- contribution of ideas to unit assignment/project materials.

Unit 15: Electrical Machines

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the safe operation of electrical machines such as direct current (DC) motors and their practical applications in industry.

Unit introduction

Electrical machines are an important but often unseen part of modern engineering products and systems. For example, the air-conditioning system on an aircraft contains an electric motor at its heart, while in the home, food processors and fan ovens have electric motors.

You will explore the safe operation, including construction, of the most common electrical machines, from step-up/down transformers commonly used in stabilised power supplies, through to direct current (DC) and alternating current (AC) motors. You will study single-phase machines and the more common three-phase induction machines used in industry.

As an electrical engineer you may need to safely operate, maintain and repair electrical machines. To do this well, and to design feasible solutions to engineering problems, you need to incorporate electrical machines as well as theoretical and practical skills. This unit prepares you for an electrical, electronic or mechatronic-based engineering apprenticeship, for higher education and for technician-level roles such as that of electrician and electrical fitter.

Please note that you may only take one unit from *Unit 15: Electrical Machines* or *Unit 59: Principles of Electrical Machines*, you cannot take both.

Learning aims

In this unit you will:

- A** Examine how to operate electrical machines safely to prevent injury or loss of life
- B** Explore the safe operation of direct current electrical machines as used in industry
- C** Explore the safe operation of alternating current electrical machines as used in industry.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how to operate electrical machines safely to prevent injury or loss of life	<p>A1 Health and safety requirements for the safe operation of electrical machines</p> <p>A2 Risk assessment</p>	<p>A report exploring how key regulations and guidance notes relate to the safe operation of electrical machines.</p> <p>A risk assessment and evaluation on testing electrical machines.</p>
B Explore the safe operation of direct current electrical machines as used in industry	<p>B1 Function and operation of electrical test meters</p> <p>B2 Operation of DC motors and generators</p> <p>B3 Control circuits used in DC motors</p> <p>B4 Applications of DC machines</p>	<p>A portfolio of results gathered through practical experiments to safely explore the operation of electrical machines, including construction and appropriate control circuitry, and to justify the selection of the most appropriate machine for an application. Supported by a developmental logbook, images, observations records, theoretical data and calculations.</p>
C Explore the safe operation of alternating current electrical machines as used in industry	<p>C1 Function and operation of electrical test meters</p> <p>C2 Operation of single-phase AC transformers</p> <p>C3 Operation of single-phase AC machines</p> <p>C4 Operation of three-phase AC induction motors</p> <p>C5 Control circuits used in AC motors</p> <p>C6 Applications of AC machines</p>	

Content

Learning aim A: Examine how to operate electrical machines safely to prevent injury or loss of life

A1 Health and safety requirements for the safe operation of electrical machines

- Key features of regulations, or other relevant international equivalents, including:
 - Electrical Equipment (Safety) Regulations 1994 and amendments, for example outlining how equipment is safe, well maintained and constructed to CE (*Communauté Européenne*) standards
 - Machinery directives, including British and International Standards (BS 7671 and 17th Edition IEE Wiring Regulations), e.g. covering the correct rating of protection devices.
- Guidance notes or other relevant international equivalents, including:
 - GS38 electrical test equipment for use by electricians, e.g. outlining safe isolation procedures and when working live is permitted
 - codes of practice for specific industries, for example Civil Aviation Authority (CAA) for aeronautical engineers and the Institution of Electrical Engineers (IEE) for electrical and electronic engineers.

A2 Risk assessment

Risk assessment of the working environment and specific requirements to operate and test DC and AC electrical machines. To include hazard identification and classification.

- Defining a hazard, including any that can cause an adverse effect, e.g. rotating machinery causes an entrapment hazard to loose clothing/hair.
- Defining risk of the severity of any hazard, normally calculated as a risk rating of likelihood multiplied by severity.
- Putting control measures in place to reduce risk, e.g. using correctly rated and shrouded cables and guarding rotating components.
- Five steps of a risk assessment as defined in the Health and Safety Executive (HSE) template.

Learning aim B: Explore the safe operation of direct current electrical machines as used in industry

B1 Function and operation of electrical test meters

- Function and operation of a volt, amp and watt meter, including:
 - how watt meters can be connected to a voltage coil across the load
 - how an amp meter can be connected in series with the load to calculate power output ($P = VI$)
- Function and operation of a swinging field dynamometer, including:
 - switching off the power to the meter when it is not in use
 - how to set torque to zero before testing.

B2 Operation of DC motors and generators

- Purpose of pole segments and field windings to create a fixed magnetic field, as determined by Fleming's right-hand rule.
- Interaction of the fixed magnetic field with an armature winding to create movement, as determined by Fleming's left hand rule and rotation due to the armature being fixed at a central pivot point.
- Connection of the field and armature windings to create three types of DC motor, series, shunt and compound, and the difference in operation between all three.
- Construction of the rotor with conductor coils embedded within a laminated iron core to increase magnetic field strength and reduce power losses due to eddy currents.

- Purpose of input voltage commutation and how the commutator component achieves this.
- Starting issue with the use of single commutator segments and how these issues are minimised.
- Current contact with the armature windings through carbon brushes and the reasons for using carbon, to include good electrical conductivity, self-lubricating material and reduced switching noise.
- Causes and consequences of overheating motors, including reduced power output.
- Methods for cooling motors to include:
 - fins on the yoke to increase surface area
 - fan on the rotor to create forced air cooling during operation.
- Measurement of speed and torque characteristics in DC motors (series, shunt and compound) to include:
 - input current and input voltage
 - power output $P_{out} = \frac{2\pi\tau N}{60}$ and motor efficiency, $\eta = \frac{P_{out}}{P_{in}}$
 - the effect of cogging torque on the motor and how it can be minimised, including using skewed poles.
- Measurement of speed and torque characteristics in DC generators:
 - terminal voltage and current
 - voltage regulation of the generator using a fixed speed and a range of output loads.

B3 Control circuits used in DC motors

- Speed control methods for DC machines to include field weakening and rheostat (variable resistor) control.
- The use of starting circuitry in DC motors to avoid large spike in current on start-up created by the absence of back electromotive force (emf). Understand the operation of a faceplate starter circuit to help overcome this problem.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips, how these devices are connected to the control circuitry.

B4 Applications of DC machines

The selection of DC motors and generators for different applications, including:

- a shunt motor is used as an electric vehicle drive motor, in a robot arm and as part of an aircraft's autopilot system
- a series motor is used as a car starter motor
- a DC generator (dynamo) is used as a power source for bicycle lights.

Learning aim C: Explore the safe operation of alternating current electrical machines as used in industry

C1 Function and operation of electrical test meters

- Function and operation of a volt, amp and watt meter, including:
 - how watt meters can be connected to a voltage coil across the load
 - how an amp meter can be connected in series with the load to calculate power output ($P = VI$)
- Function and operation of a swinging field dynamometer, including:
 - switching off the power to the meter when it is not in use
 - how to set torque to zero before testing.

C2 Operation of single-phase AC transformers

- Construction of primary and secondary windings to include the diameter of the wire and insulation methods, e.g. varnish or shellac, to avoid short circuiting.
- Principles of mutual induction, where an alternating current creates a changing magnetic field around one coil that creates a changing current in the secondary coil.

- Both coils being wound on a ferromagnetic core (soft iron) to increase the efficiency of the transformer through increasing the flux density.
- Transformer efficiency to include transformer losses, eddy currents, magnetic leakage and power losses, I^2R
- Different methods for winding the coils to help reduce leakage losses, including shell, core and toroidal types of transformer.
- Lamination of the soft iron core to reduce eddy current power losses.
- Additional secondary windings on the same primary core allowing for multiple output voltages from a single input and negligible voltage losses.
- Measurement of single-phase transformer characteristics to include:
 - input and output voltage, current and power
 - ideal transformer equation $\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$
 - transformer efficiency, $\eta = \frac{P_{out}}{P_{in}}$

C3 Operation of single-phase AC machines

- Field windings in a single-phase AC motor generate a magnetic field.
- The smoothness of the machine's rotation is determined by the number of pole pairs that each create an additional magnetic field.
- The rotor has conductors embedded in a laminated iron core, which needs a permanent connection to the power supply to operate. This is achieved through the use of slip rings and carbon brushes.
- Single-phase AC motors require starting circuitry to set up a magnetic field allowing the motor to operate.
- Single-phase AC generators produce an AC waveform, where the terminal voltage is proportional to the speed of rotation.

C4 Operation of three-phase AC induction motors

- The stator in three-phase induction motors generates a rotating magnetic field.
- Synchronous speed is calculated by $n_{sync} = \frac{f \times 60}{P}$
- Wound rotors and squirrel-cage rotors use laminations in the core to reduce power losses.
- Understand how a current is induced in the rotor bars or windings and how this current produces torque in the rotor.
- For wound rotor motors the purpose of slip rings and brushes is to continuously connect the windings to the alternating power supply during operation. Benefits of wound rotor motors in using starting circuits include access to the windings so that increased resistance can be added and removed in resistance starters.
- Definition of slip speed is the difference between shaft speed and synchronous speed and also how to determine slip as a percentage of the rated speed $\frac{n_{sync} - n_m}{n_{sync}}$
- Speed control of three-phase induction motors to include variable frequency drives, inverters and pulse width modulation (PWM) systems.
- Measurement of single- and three-phase induction motor characteristics to include:
 - single-phase motor currents on start-up and the phase shift required to self-start
 - synchronous speed for an induction motor with a known number of poles
 - motor shaft speed and motor slip
 - torque versus speed for induction motors.
- Input power, current and voltage using $\sqrt{3}V_L V_I \cos\phi$ and output power using $P_{out} = \frac{2\pi\tau N}{60}$ to calculate the efficiency of the induction motor.

C5 Control circuits used in AC motors

- Types of single-phase AC motor starting circuits include capacitor start, capacitor start and run, shaded pole and split phase. Understand how each method creates two separate magnetic fields that are out of phase with each other, causing the rotor to start moving.
- Circuit diagrams and operation of starter circuits to include direct on line (DOL), star-delta and rotor resistance.
- Other control circuitry to include overload protection, short circuit protection, interlocks and trips, and how all devices are connected into the control circuitry.

C6 Applications of AC machines

The selection of AC motors, transformers and generators for different applications, including:

- a three-phase induction motor is used as a lathe drive motor and as part of an air-conditioning unit in cars and aircraft
- a step-up/down transformer is used as a laptop power supply
- a single-phase generator is used as an alternator in a car engine.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how to operate electrical machines safely to prevent injury or loss of life		A.D1 Evaluate, using language that is technically correct and of a high standard, the local risk assessments against relevant regulations and guidance notes, justifying appropriate control measures for electrical machines.
A.P1 Explain how one regulation and one guidance note relate to the safe operation of electrical machines. A.P2 Produce a risk assessment on operating a range of electrical machines safely.	A.M1 Compare the practicality of the risk assessment against local control procedures already in place to manage hazards from electrical machines.	
Learning aim B: Explore the safe operation of direct current electrical machines as used in industry		B.D2 Evaluate the DC electrical machines, comparing the results from safely conducted experiments and theoretical curves and calculations, and explain the conditions for optimal performance and suitable applications.
B.P3 Conduct experiments safely to determine the characteristics of two types of DC motor and a DC generator. B.P4 Explain, using the experimental results and theoretical data, how the two DC motors and a generator operate, including any required control circuitry, and suggest suitable applications.	B.M2 Conduct experiments accurately and efficiently to determine the characteristics of three types of DC machine. B.M3 Analyse, using the results and theoretical data and calculations, the operation of three types of DC machine.	
Learning aim C: Explore the safe operation of alternating current electrical machines as used in industry		C.D3 Evaluate the operation of AC electrical machines, comparing the results from safely conducted experiments and theoretical curves and calculations, and explain the conditions for optimal performance and suitable applications.
C.P5 Conduct experiments safely to determine the characteristics of a single-phase transformer, motor and generator and a three-phase motor. C.P6 Explain, using the experimental results and theoretical curves, how the single-phase transformer, motor and generator and a three-phase motor operate, including any required control circuitry, and suggest suitable applications.	C.M4 Conduct experiments accurately and efficiently to determine the characteristics of four AC machines. C.M5 Analyse, using the results and theoretical curves and calculations, the operation of four AC machines.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of two summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aims: B and C (B.P3, B.P4, C.P5, C.P6, B.M2, B.M3, C.M4, C.M5, B.D2, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- two of the three types of DC motor, series, shunt and compound – note that the shunt motor can also be used as a DC generator
- at least one single-phase AC transformer, a single-phase AC capacitor start or start and run AC motor, and a three-phase AC induction motor
- associated test meters and equipment, including voltmeters, ammeters, watt meters and a dynamometer
- feedback systems which produce a series of modular test equipment ideal for the range of experiments to be undertaken, for example the Powerframes series
- a range of health and safety regulations and guidance documents, as specified in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce a professional, balanced evaluation of their risk assessment, including the identification of hazards, justification of how they have determined the risk rating and how they selected the control measures. Overall, the evaluation will use correct technical engineering terms and will be written in a way that is easy for a third party, who may or may not be an engineer, to understand.

Learners should evaluate possible alternative approaches, including those found in a locally produced risk assessment (by the school or college), that could have been used to improve efficiency or reduce impact on the operator, while meeting relevant regulations and following guidance notes. For example, learners could suggest placing physical guarding around the entire machine, but that would increase the time it takes to conduct the experiments (or to operate the machines in industry).

For merit standard, learners will produce a comparison of their risk assessment against the local control measures (produced by the school or college) already in place to eliminate and reduce the hazards. The comparison will discuss the practicalities of implementing control measures, including the principle contained in the regulation and guidance documents of being 'reasonably practicable', but not necessarily covering any additional measures highlighted in the risk assessment.

For pass standard, learners will provide evidence explaining, for example, that as part of the Electrical Equipment (Safety) Regulations 1994 and amendments, all equipment should be checked for the CE or BS Kitemark stamp and to check that it is not damaged, before undertaking any work. Learners' evidence may contain some errors in the engineering terminology used, for example stating that current runs 'across a device' rather than 'through' it, and the explanations may be basic in parts. There must be a clear demonstration of knowledge and understanding of the relevant safety documents and their use in the specific sector being studied, for example the aerospace or manufacturing pathway.

Learners will identify all significant hazards and calculate the associated risks. For example, when performing experiments on electrical machines a low likelihood of shock multiplied by high severity of injury would result in a medium risk. Risks should be documented on an agreed risk assessment pro forma. A risk assessment may not identify all the associated hazards, for example a risk assessment should cover the direct risks, such as electrical shock and entrapment in rotating parts, but it might not include manual handling of the machines.

Learning aims B and C

For distinction standard, learners will cover in their reports experiments on three DC and four AC machines. They will evaluate how the machines operate, which will include a justification of the differences between the experimental results and accurate theoretical curves and calculations. For example, differences in the results occur because of stray resistances in the test equipment because of particularly warm or cold conditions when the tests were undertaken, or due to power losses in the machines that are not accounted for in theoretical calculations.

The evaluation should also include evidence on the conditions for optimum machine performance that is backed up by the practical experimentation results and learners' observations.

Overall, the evidence will be logically structured and will use the correct technical engineering terms about the operation of electrical machines.

For merit standard, learners will safely and efficiently set up and carry out the experiments on the electrical machines, specifically on two DC motors, one DC generator, a single-phase transformer, a single-phase motor and a generator and a three-phase induction motor. Circuit diagrams will be followed precisely and learners should choose leads of suitable length to avoid entanglement or trailing leads becoming a hazard. The experimental results will be accurate, neatly tabulated, clearly labelled and graphs will be drawn to scale.

To enhance the explanation of how the machines operate, learners will get at least two other reputable sources of information, which have been correctly referenced. For example, learners will use diagrams from an online source, confirm the test validity using a recommended book, and identify the appropriate components on the tested machine.

Overall, learners will use theoretical calculations and standard data curves to accurately analyse the operation of the DC and AC electrical machines.

For pass standard, learners will select appropriate equipment, connect the equipment in an appropriate way and undertake six experiments safely. Learners will record what they are doing along with their results in a logbook.

Overall, evidence will be logically structured, but there may be some minor inaccuracies in the recording of the results, for example the DC results will tabulate the different starting torques for two different types of DC motors and the proportionality between speed and terminal voltage in a DC generator. The results for the:

- single-phase transformer will include the link between the number of turns and voltage ratio
- single-phase motor will include the phase difference between the current in the start winding and the run winding
- single-phase generator will demonstrate the proportionality between speed and frequency of the terminal voltage
- three-phase induction motor will include the synchronous speed, torque and motor shaft speed.

Learners will prepare evidence on how the machines operate. The evidence will include details on how the machines are constructed and some reference will be made to the underpinning theory and standard curves. For example, the:

- DC shunt motor operates at a relatively constant speed, the experimental results will have been compared with typical curves and an explanation will have been given for why some DC motors contain control circuitry to start
- DC generator should include an explanation of how Faraday's law applies
- single-phase transformer will cover the application of Faraday's and Lenz's laws
- single-phase motor will cover the effect of phase shift in creating a pseudo-rotating magnetic field, the reasons why starting circuitry is needed and an explanation of how the circuitry works
- single-phase generator will cover the link between speed of rotation and frequency of the AC signal and the effect of increasing the number of poles in the machine
- three-phase induction motor will cover synchronous speed and slip as well as determining the torque versus speed characteristic.

Based on the explanation of how the electrical machines operate and from the characteristics observed during experiments, learners should suggest at least two suitable applications for each type of electrical machine.

Overall, the explanations should be logically structured, although they may be basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 16: Three Phase Electrical Systems
- Unit 17: Power and Energy Electronics.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise of electrical machines
- contribution of ideas to unit assignment/project materials.

Unit 19: Electronic Devices and Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the operation of electronic devices and their uses in circuits through simulation and practical exercises to build and test physical analogue and digital circuits.

Unit introduction

Electronic analogue and digital devices and circuits are at the heart of familiar household products and high-speed complex operations in industrial applications. For example, they are fundamental to the operation of television remote controllers and to the control of processes in nuclear power stations.

In this unit, you will cover the simulation, construction, testing and evaluation of analogue electronic circuits based on diodes and transistors and combinational and sequential logic digital circuits. As part of the unit you will use software to simulate circuits and use typical bench instruments to test them, since electronic circuit designers make frequent use of software to simulate design ideas before building prototype circuits. Finally, you will reflect on the skills and understanding you have acquired during the unit and the behaviours you have applied.

A wide range of industries, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation, employs electronic engineers. This unit helps to prepare you for employment, for example as an electrical/electronic technician, for an apprenticeship and for entry to higher education.

Learning aims

In this unit you will:

- A** Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits
- B** Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits
- C** Review the development of analogue and digital electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
<p>A Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits</p>	<p>A1 Safe electronic working practices</p> <p>A2 Diode devices and diode-based circuits</p> <p>A3 Transistor devices and transistor-based circuits</p> <p>A4 Operational amplifier circuits</p> <p>A5 Schematic capture and simulation of analogue circuits</p> <p>A6 Testing physical analogue circuits</p>	<p>A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.</p>
<p>B Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits</p>	<p>B1 Logic gates and Boolean algebra</p> <p>B2 Combinational logic circuits</p> <p>B3 Sequential logic circuits</p> <p>B4 Schematic capture and simulation of digital circuits</p> <p>B5 Testing physical digital circuits</p>	<p>A report containing circuit diagrams, photographs, tables of results, sketches, screenshots, calculations and an evaluation of the physical and simulated circuits, supported by observation records and/or witness statements.</p>
<p>C Review the development of analogue and digital electronic circuits and reflect on own performance</p>	<p>C1 Lessons learned from exploring electronic devices and circuits</p> <p>C2 Personal performance while exploring electronic devices and circuits</p>	<p>The evidence will focus on the skills and knowledge gained when exploring analogue and digital electronic devices and their common applications, reflecting on the ways in which theoretical, simulated and measured values compare.</p> <p>The portfolio of evidence generated while exploring electronic devices and circuits, reflecting on own performance.</p>

Content

Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits

A1 Safe electronic working practices

- Know how to react in an emergency, including:
 - isolate power and/or heat supplies
 - notify the responsible person
 - follow instructions from the responsible person, including raise the alarm, notify first aider, evacuate the area.
- Safe working practices: awareness and compliance with hazard identification, risk assessments and standard operating procedures associated with electronic-based tasks to include:
 - construction of electronic circuits
 - measurement and testing of electronic circuits.

A2 Diode devices and diode-based circuits

- Types of diode to include signal diodes, rectifier diodes, Zener diodes and light-emitting diodes (LED).
- Operation of diodes to include:
 - semiconductors: materials, intrinsic, extrinsic, doping, p-type, n-type
 - type: PN-junction
 - characteristics, e.g. forward and reverse bias.
- Construction of diode-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
 - rectification: half wave, full wave
 - voltage stabilisation
 - voltage regulation.

A3 Transistor devices and transistor-based circuits

- Types of transistor to include:
 - bipolar junction transistors (BJT): NPN, PNP
 - field effect transistors (FET): N channel, P channel.
- Operation of transistors to include:
 - transistor connections: common base, common emitter, common collector
 - transistor action, including no collector current (cut off), some collector current (in the active region) and collector current above the emitter current (in saturation)
 - biasing – operating point of the transistor device.
- Construction of transistor-based physical circuits safely, using e.g. bread board or strip board, for different applications including:
 - switching including function of components, comparator, digital (set point)
 - single stage amplifier, including current and voltage gains, phase inversion, bandwidth.

A4 Operational amplifier circuits

- Construction of operational amplifier-based physical circuits safely, using e.g. bread board or strip board, for different applications, including:
 - voltage comparator
 - inverting and non-inverting amplifier: negative feedback, gain.
- Characteristics of operation of operational amplifiers to include resonant frequency, cut-off frequency, gain, bandwidth, gain-bandwidth product, dependence on component values.

A5 Schematic capture and simulation of analogue circuits

- Schematic capture of analogue circuits to include electrical circuit drawing standards BS 8888, BS 3939 or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation extraction of data/measurements, e.g. voltage, current, power, input and output signals, gain, frequency analysis, e.g. Bode plot.

A6 Testing physical analogue circuits

- The safe use of physical test equipment to include multimeters, function generators, oscilloscopes and more complex equipment, e.g. Bode plotters if available.
- Calculations using measured values to include:

- transistor current gain $h_{fe} = \beta = \frac{I_b}{I_c}$

- circuit voltage gain (transistor amplifier, non-inverting and inverting op-amp circuits)

$$A_v = \frac{V_{out}}{V_{in}}$$

- Cut-off frequency for op-amp filters $f_c = \frac{1}{2\pi RC}$

Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits**B1 Logic gates and Boolean algebra**

- Types of logic gate: AND, OR, NOT, NAND, NOR, XOR.
- Gate symbols, British Standard (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI) or other relevant international equivalents.
- Truth tables for standard logic gates.
- Types of logic family:
 - transistor-transistor logic (TTL)
 - complementary metal oxide semiconductor (CMOS).
- Characteristics of logic families: supply voltage, input and output operating voltages, input and output impedance, propagation delay, power.

B2 Combinational logic circuits

Rules of Boolean algebra, including:

- Boolean expressions e.g. sum of products $(A \bullet B) + (C \bullet \overline{D})$
- truth tables for Boolean expressions
- minimisation of combinational logic circuits containing at least three inputs and five gates:
 - Karnaugh maps for minimisation circuits with at least three inputs
 - De Morgan's theorem.

Construction of physical combinational logic circuits safely, using e.g. bread board or strip board.

B3 Sequential logic circuits

- Bi-stable devices (flip-flops), including R-S, D type including clocked D type and JK including master-slave JK.
- Types of sequential logic circuit, including:
 - three-stage asynchronous counter
 - three-stage synchronous counter
 - three-stage shift register.
- Construction of physical sequential logic circuits safely using, e.g. bread board or strip board and R-S, D-type and/or JK bi-stable devices.
- Practical integrated circuits using flip flops, e.g. binary counter, shift register.

B4 Schematic capture and simulation of digital circuits

- Schematic capture of digital circuits to include electrical circuit drawing standards BS 8888, BS 3939, or other relevant international equivalents.
- Simulation methods and the use of virtual instrumentation, e.g. logic probe, logic pulser, logic 'analyzer'.
- Extraction of data/measurements, e.g. input and output logic states.

B5 Testing physical digital circuits

- The safe use of physical test equipment to include multimeters, logic probes and more complex equipment, e.g. logic 'analyzers'.
- Calculations using Boolean algebraic and truth tables.

Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance**C1 Lessons learned from exploring electronic devices and circuits**

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- electronic skills, e.g. schematic capture, simulation, construction methods, use of measurement and test equipment and techniques and semiconductor theory
- general engineering skills, e.g. mathematics, interpreting drawings and using information technology software packages.

C2 Personal performance while exploring electronic devices and circuits

Understand relevant behaviours for exploring the construction, operation and application of electronic devices in analogue and digital circuits, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- awareness of the ways in which the skills, knowledge and techniques developed in this unit can be used in further study.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits		
<p>A.P1 Simulate, using captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit.</p> <p>A.P2 Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one.</p> <p>A.P3 Explain, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.</p>	<p>A.M1 Simulate, using accurately captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit.</p> <p>A.M2 Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one accurately.</p> <p>A.M3 Analyse, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.</p>	<p>A.D1 Evaluate, using language that is technically correct and of a high standard, the operation of at least one diode, transistor and operational amplifier circuit, comparing the results from safely and accurately conducted simulations and tests.</p>
Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits		
<p>B.P4 Simulate, using captured schematics, the correct operation of at least one combinational logic circuit and two sequential logic circuits.</p> <p>B.P5 Build at least one combinational logic circuit and two sequential logic circuits safely and test the characteristics of each one.</p> <p>B.P6 Explain, using the simulation and test results, the operation of at least three logic circuits.</p>	<p>B.M4 Simulate, using accurately captured schematics, the correct operation of at least one combinational logic circuit minimising the gates and at least two sequential logic circuits.</p> <p>B.M5 Build at least one combinational logic circuit minimising the gates and at least two sequential logic circuits and test the characteristics of each one accurately.</p> <p>B.M6 Analyse, using the simulation and test results, the operation of at least three logic circuits.</p>	<p>B.D2 Evaluate the operation of at least one combinational logic circuit minimising the gates and two sequential logic circuits, comparing the results from safely and accurately conducted simulations and tests.</p>
Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance		
<p>C.P7 Explain how health and safety, electronic and general engineering skills were effectively applied during the development of the circuits.</p> <p>C.P8 Explain how relevant behaviours were effectively applied during the development of the circuits.</p>	<p>C.M7 Recommend improvements to the development of the electronic circuits and to the relevant behaviours applied.</p>	<p>C.D3 Demonstrate consistently good technical understanding and analysis of the electronic circuits, including the application of relevant behaviours and general engineering skills to a professional standard.</p>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.M2, A.M3, A.D1)

Learning aim: B (B.P4, B.P5, B.P6, B.M4, B.M5, B.M6, B.D2)

Learning aim: C (C.P7, C.P8, C.M7, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- electronic laboratory and bench top test equipment, including signal generators, low-voltage DC power supplies, dual trace oscilloscopes and digital multimeters. Spectrum analyser/Bode plotter would be advantageous, but is not essential
- physical components for selection and construction using appropriate prototyping approaches such as protoboard (bread board)
- equipment that can support the verification of digital circuit operation to include at the minimum logic probes and ideally access to logic 'analyzer'
- industry-standard SPICE software. A virtual Bode plotter and logic 'analyzer' may be an acceptable alternative to use of real instruments.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the different types of analogue electronic circuit that they have captured, simulated, constructed and tested. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively. They will include evidence such as circuit schematics and waveform sketches, as well as accurate calculations, from their simulation and testing of physical circuits. For example, the voltage gain of a non-inverting amplifier will be calculated from component values, with estimated upper and lower expected values due to component tolerance.

Learners will compare their results from the simulation and safe construction and testing of physical circuits. The characteristic of device and circuit performance will be more complex than simple output to input ratios in amplifier circuits, for example voltage gain of the amplifier at different frequencies from oscilloscope traces, simulated waveforms and circuit calculations. Small variations may be noted between the results from different sources and attributed to factors such as the simulation using ideal components, but still giving results within acceptable levels considering the preferred values used.

The impact on circuit performance of modifying one criterion will also be evaluated. For example, learners will support their evaluation of changes in bandwidth as a result of increasing or decreasing gain by referring to gain-bandwidth product and its importance in op-amp circuit applications.

Overall the evidence, such as practical and simulation reports, 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, with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will capture a circuit schematic accurately and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. The circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely and accurately, such as instrument controls set to allow the amplitude and frequency of waveforms to be measured accurately, for example time base set to give just over two cycles, and voltage gain to use as much of the vertical scale as possible.

Learners will analyse the operation of the analogue circuits using the simulation and test results from physical circuits, including calculations where appropriate. For example, they will calculate the gain of a non-inverting operational amplifier from measurements and component values at a number of frequencies, but may not make specific reference to the gain-bandwidth product.

Overall, the evidence should be logically structured, technically accurate and easy to understand. For example, schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled, and virtual instruments connected correctly with controls set to realistic values.

For pass standard, learners will capture a circuit schematic and simulate the correct operation of at least one diode-based, one transistor-based and one operational amplifier-based circuit. These circuits must be at least as complex as a full-wave rectifier, a single-stage common emitter amplifier and a non-inverting amplifier respectively.

Learners will construct and test the circuits safely and measure and record the operating characteristics of the circuits safely. For example, they will construct an inverting operational amplifier and measure input and output voltages to calculate the circuit gain.

Using the simulation and test results from physical circuits, learners will explain the operation of at least one diode-based, transistor-based and operational amplifier-based circuit. For example, an explanation and evidence for the dependence of gain of an inverting operational amplifier on component values at a given frequency would be indicative of pass level achievement. Learners will include calculations where appropriate to do so, for example the voltage gain of the amplifier from amplitude measurements of input and output sinusoidal voltages.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example calculating gain and attenuation as ratios rather than in decibel (dB), and may contain minor technical inaccuracies relating to engineering terminology, such as not differentiating between peak and root-mean squared (RMS) voltages, or inconsistent use of units.

Learning aim B

For distinction standard, learners will present a balanced evaluation of combinational and sequential logic circuits that they have captured, simulated, constructed and tested accurately.

They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates needed using one type of gate, for example NAND. They will verify that the minimised circuit functions as required.

Learners will produce a schematic diagram for two different sequential circuits that use D type and/or JK flip-flops and standard logic gates for a stated application. One of the sequential circuits should use a proprietary integrated circuit to carry out the sequential function.

Learners will verify that the circuits function as required, comparing and contrasting simulation and building and testing them accurately.

Overall the evidence, such as practical and simulation reports, 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, learners will capture circuit schematics accurately and simulate the correct operation of at least one combinational and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format and minimise the number of gates using a combination of gate types.

Learners will produce a schematic diagram for two different sequential circuits using D type and/or JK flip-flops and standard logic gates, for example a minimum 3-bit asynchronous counter and a minimum 3-bit shift register. They will verify that the minimised circuits function as required using schematic capture and simulation.

Learners will construct and test the circuits and measure and record the operation of the circuits safely and accurately. For example, they will take suitable precautions when handling integrated circuits and use appropriate instruments such as a logic probe rather than a multimeter.

Overall, the evidence will be logically structured, technically accurate and easy to understand. For example, the schematics will be laid out clearly and logically using standard conventions, with all components appropriately labelled and virtual instruments connected correctly.

For pass standard, learners will capture circuit schematics and simulate the correct operation of at least one combinational logic and two sequential logic circuits. They will analyse a truth table for a combinational logic circuit which requires a minimum of three inputs and five gates when stated in sum of products format. They will verify that the circuit functions as required using schematic capture and building and testing the circuit.

Learners will produce schematic diagrams for two different sequential circuits, for example a 3-bit asynchronous counter and a 3-bit shift counter using D type and/or JK flip-flops. They will verify that the circuits function as required using schematic capture and simulation software.

Learners will construct and test the circuits and record the operation of the circuits safely.

Using the simulation and test results from physical circuits, learners will explain the operation of the circuits, for example an explanation and evidence for the operation of a shift register.

Overall, the evidence will be logically structured. The evidence may be basic in parts, for example not explaining why a shift register shifts in a given direction, and may contain minor technical inaccuracies such as not differentiating between D type and JK flip-flops.

Learning aim C

For distinction standard, learners will demonstrate, during the first two assignments, relevant behaviours and general engineering skills to a professional standard. For example, they will plan all activities in advance and they will meet all deadlines.

Their evidence will show consistently good technical understanding of the analogue and digital electronic circuits during the simulation and construction and testing processes. They will use accurate technical engineering terms and grammar and will clearly differentiate facts from opinion.

The lessons learned evidence, for example a report, will present a good technical understanding of analogue and digital electronic circuits. Overall the evidence will include a balanced view about the actions taken, electronic circuit development (circuit simulation and construction and testing processes), including health and safety compliance, and technical engineering terms used correctly and consistently. The evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will provide in their evidence, such as a logbook, and especially the lessons learned report, examples of where improvements could be made to the:

- development (simulation, construction and testing) of analogue and digital electronic circuits, for example how an understanding of triggering flip-flops can help in deciding whether a shift register will shift left or right
- application of relevant behaviours, for example how listening to instructions has resulted in an activity running smoothly or a circuit operating as intended.

Overall, the suggested improvements should be reasonable and practical. Learners will give professional explanations and use engineering terminology accurately. Some parts of the evidence may have more emphasis than others, making the evidence more difficult for a third party to understand.

For pass standard, learners will give evidence, such as a lessons learned report, that is around 500 words in total and that covers the management of health and safety, analogue and digital electronic skills and general engineering skills, as well as a reflection of personal performance. The evidence will be basic in its approach, with some use of technical language, but it may not be consistent and there may be some errors throughout. The evidence will explain:

- actions taken to manage health and safety in the workplace, for example which personal protective equipment was used and whether any unforeseen issues occurred
- electronic engineering skills, such as identifying components and their characteristics, circuit theory and the skills required to construct and test circuits
- how general engineering skills were used, such as the use of IT to simulate circuits, CAD to capture schematics and interpreting drawings
- the behaviours used, such as time management and planning to ensure the activity was completed within the appropriate time.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 17: Power and Energy Electronics
- Unit 20: Analogue Electronic Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 22: Electronic Printed Circuit Board Design and Manufacture
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics and engineering organisations involved with electronic devices and circuits.
- contribution of ideas to unit assignment/project materials.

Unit 21: Electronic Measurement and Testing of Circuits

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate the operation of common electronic test and measurement devices and measure and test analogue and digital circuits to diagnose faults.

Unit introduction

The majority of industrial and domestic processes are controlled by electronic circuitry, so it is important for engineers in a range of sectors to be proficient with fault finding and testing techniques, even though they may not be an expert in electronics.

In this unit, you will explore the operational features, including the construction of a range of devices used in the testing of analogue and digital electronic circuits, using discrete and integrated circuit components. You will also explore fault finding techniques and prepare a test plan for diagnosing faults. You will go on to measure and test operational circuits to diagnose the location and nature of faults.

The standard fault finding techniques introduced as part of this unit can be applied to a wide range of industries, including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation. This unit will help to prepare you for employment, for example as an electrical/electronic technician, an apprenticeship or for entry to higher education.

Learning aims

In this unit you will:

- A** Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits
- B** Examine fault finding techniques and test plans used when measuring and testing electronic circuits
- C** Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely
- D** Review the measurement and testing of electronic circuits and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits	A1 Operational features of measurement devices A2 Operational features of test devices	A written report exploring the operational features of typical measurement and testing devices. Learners will explore the measurement and test devices in the laboratory and through research.
B Explore fault finding techniques and test plans used when measuring and testing electronic circuits	B1 Fault finding techniques B2 Preparation for testing and test plans	A test plan to analyse each electronic circuit, detailing the fault finding techniques to be used and preparation tasks to be undertaken. It will also explain the rationale behind the application of different techniques.
C Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely	C1 Safe working practice C2 Practical fault finding on analogue and digital circuits	A logbook and fault finding record for the circuits, detailing tests undertaken, symptoms and final identification of the faulty components in analogue and digital circuits. One or more observational witness statements.
D Review the measurement and testing of electronic circuits and reflect on own performance	D1 Lessons learned from measuring and testing electronic circuits D2 Personal performance while measuring and testing electronic circuits	Evidence will focus on what went well and what did not go so well when testing and measuring electronic circuits, reviewing the processes and reflecting on own performance. A portfolio of evidence generated while measuring and testing electronic circuits and reviewing the processes and reflecting on own performance.

Content

Learning aim A: Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits

A1 Operational features of typical measurement devices

- Operational features of multiple range meters (multimeters), to include:
 - input impedance and output impedance for different parameters being measured
 - reading of analogue and digital displays
 - parallax issues with analogue meters
 - correct selection of terminals depending on the characteristics being measured
 - comparisons between analogue and digital meters
 - comparisons between autoranging and manual selection meters.
- Operation of dual beam oscilloscope for accurate measurement of alternating current (AC) waveform, to include:
 - operation of the cathode ray gun
 - how the beam is deflected
 - how to read a graticule.
- Explanation of oscilloscope features, to include:
 - time base
 - amplitude
 - waveform selector
 - trigger selection (internal, external triggering)
 - inbuilt calibration facilities.
- Operation of spectrum analyser, to include:
 - continuous or swept frequency analysis
 - input bandwidth control
 - reading of the cathode ray tube (CRT) output.
- Operation of digital test devices, to include:
 - logic probe and 'logic analyser' for measurement of the output states on digital electronic circuits
 - the points at which logic states change in both complementary metal oxide semiconductor (CMOS) and transistor-transistor logic (TTL) circuits
 - the response the probe gives when in-between the two states.

A2 Operational features of electronic test devices

Operational features of standard test devices, to include:

- stabilised direct current (DC) power supply
- alternating signal generator
- digital pulse generators
- binary word generator.

Learning aim B: Explore fault finding techniques and test plans used when measuring and testing electronic circuits

B1 Fault finding techniques

Applications and process for different fault finding techniques, to include:

- visual examination:
 - generally the first test carried out
 - look for signs of burnt or damaged components or broken connections
 - check values of components against circuit diagrams to identify any errors

- input-to-output and output-to-input technique:
 - efficiently used when the expected output of the electronic system (also referred to as a circuit) is known or can be predicted
 - works forwards from the input until a fault is found or backwards from the output until predicted values are obtained
- half-split technique:
 - used to minimise the number of tests to improve efficiency
 - involves measuring at the mid-point
 - if the signal at the mid-point is faulty then the next step is to test at the midpoint between the input and this first test point
 - repeat the process until there is no fault – the fault then lies between the last two test points
 - if the signal at the mid-point is not faulty then the second test is at the mid-point of the first test point to the output
- symptom-to-cause technique:
 - efficiently used when fault data is systematically recorded
 - uses historical test data to relate symptoms to potential faults
- circuit substitution technique:
 - efficiently used when visual inspection or other analysis indicates that a particular component or circuit is faulty
 - replaces suspect components or circuits with functionally operational ones
 - system is then retested
- top-down technique:
 - efficiently used in complex electronic systems
 - involves testing the complete system, then each subsystem is tested and finally each component in the faulty subsystem (operational subsystems will have been ruled out) will be tested until the fault has been identified.

B2 Preparation for testing and test plans

- Test plan, to include:
 - Fault finding aids, e.g. relevant diagrams (block schematic, circuit wiring diagrams), component and circuit tolerances, functional charts, troubleshooting charts, component data sheets, operation and maintenance manuals, software-based records and data
 - identification of key test nodes and expected signal conditions for analogue and digital circuits
 - production of a test schedule.
- Fault reporting methods, including standardised fault finding report forms that identify the:
 - symptoms of the fault
 - details of test devices used for traceability, e.g. serial numbers
 - checks undertaken
 - proposed solution to the problem.

Learning aim C: Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely

C1 Safe working practice

Safe working practice, to include:

- observation of safety rules
- responsible behaviour at all times in a workshop environment
- identification of risk assessments and controls for the tasks to be carried out
- safe use of devices for their designed purpose
- protection of others and self.

C2 Practical fault finding on analogue and digital circuits

Measurement of signal conditions at key test points for non-faulted analogue and digital circuits to compare with nominal values.

Application of fault finding plans for analogue and digital circuits to:

- identify fault symptoms using appropriate test devices
- select and apply a suitable fault finding technique
- identify faults.

Learning aim D: Review the measurement and testing of electronic circuits and reflect on own performance**D1 Lessons learned from measuring and testing electronic circuits**

Scope of the lessons learned to cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- electronic circuit measurement and testing skills, e.g. selection and correct use of electronic test devices
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while measuring and testing electronic circuits

Understand relevant behaviours for measuring and testing electronic circuits, including:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving and perseverance, e.g. logical approach taken to identify the faults.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits		A.D1 Evaluate, using language that is technically correct and of a high standard, the operational features of at least six different analogue and digital circuit measurement and test devices, identifying how to ensure accurate results.
A.P1 Explain the operational features of at least six analogue and digital circuit measurement and test devices.	A.M1 Compare the operational features of at least six different analogue and digital circuit measurement and test devices.	
Learning aim B: Explore fault finding techniques and test plans used when measuring and testing electronic circuits		BC.D2 Optimise a fault finding test plan and carry out the identification of faults correctly and safely for two analogue circuits and two digital circuits, each with less than four stages, justifying the effectiveness of the test processes and any further improvements to be made.
B.P2 Explain two suitable techniques for testing faults in given analogue and digital circuits.	B.M2 Produce an effective fault finding test plan for two analogue circuits and two digital circuits, each with less than four stages, comparing testing techniques.	
B.P3 Produce a logical fault finding test plan for two analogue circuits and two digital circuits, each with less than four stages.		
Learning aim C: Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely		
C.P4 Identify faults correctly and safely in at least one analogue circuit.	C.M3 Identify faults correctly and effectively in two analogue circuits safely, while recording the results accurately.	
C.P5 Identify faults correctly and safely in at least one combinational and/or one sequential logic circuit, each with less than four stages.	C.M4 Identify faults correctly, safely and effectively in one combinational and one sequential logic circuit, each with less than four stages, while recording the results accurately.	
Learning aim D: Review the measurement and testing of electronic circuits and reflect on own performance		D.D3 Demonstrate consistently good technical understanding and analysis of the measurement and testing of circuits, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Explain how health and safety, measurement, testing and general engineering skills were effectively applied when fault finding circuits.	D.M5 Recommend improvements to the measurement and testing of circuits and to the relevant behaviours applied.	
D.P7 Explain how relevant behaviours were applied effectively during the measurement and testing of circuits.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, C.M3, C.M4, BC.D2)

Learning aim: D (D.P6, D.P7, D.M5, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- an electronic laboratory and bench top test devices, including signal generators, low voltage direct current (DC) power supplies, dual trace oscilloscopes, analogue and digital multimeters, logic probes and logic pulsers
- pre-built analogue and digital circuits with switched faults, for example fixed voltage regulated DC power supply, two-stage class A amplifier with test points accessible, single stage active filter, position controller (servo), a combinational logic circuit such as a 4-bit adder or decision-making circuit, a sequential logic circuit such as a traffic light circuit or ripple counter
- standardised fault finding record sheets, including devices under test, initial symptoms, test devices used (including serial numbers or other identification for traceability), tests carried out, observations and conclusions, identification of root cause
- spectrum analyser/Bode plotter (advantageous)
- electronic computer-aided design (ECAD) facilities, such as MultiSIM, to allow learners to simulate the operation of the rarer test devices (advantageous).

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will present a balanced evaluation of the operational features of common measurement and test devices used in industry. They will cover the operational features of at least four measurement devices, including digital and analogue multimeters, a dual beam oscilloscope and a logic probe, and two test devices, for example a stabilised power supply, and a signal generator identifying applications for each. They will discuss the relative merits of digital and moving coil meters in testing electronic circuits, including accuracy and ease of reading displays/scales.

Learners' evidence will identify inherent problems with accuracy for the different types of device and suggest ways to improve confidence in measurements, for example appropriate calibration.

Overall, 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 use correct technical engineering terms.

For merit standard, learners will compare the use of analogue and digital test devices in producing accurate measurements when testing analogue and digital electronic circuits. For example, they may note the effect of input or output impedance on measurements, or the effect of analogue to digital conversion in digital multimeters. They will compare the ease of reading digital test devices with analogue meters against their accuracy.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the operation of at least three analogue and one digital measurement devices and two testing devices used to identify faults in analogue and digital electronic circuits. They will support their explanations with annotated diagrams to illustrate the correct connection of each of the chosen devices when measuring and testing.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example explanations may omit some detail, such as how to adjust an oscilloscope to display an alternating waveform.

Learning aims B and C

For distinction standard, learners will optimise their fault finding test plans using at least two fault finding techniques. They will justify their choice of technique, making comparisons between the available options as part of the test plan and provide details of preparatory tasks. They will explain how the results will be consistent and accurate, for example identifying the serial numbers of measurement and test equipment and making comparisons using the same equipment for traceability.

Learners will use a range of documentation to produce an efficient fault finding plan, including safe working practice, to identify the cause of a single fault in each circuit. For example, the plan may be in the form of a flow chart and will include accurately validated signal values and waveforms at key test points on unfaulted circuits for comparison purposes. Learners will use their plan to find each fault in at least two complex analogue electronic circuits and two digital logic circuits (one combinational, and one sequential).

Learners will systematically document the steps taken in logical sequence, the devices used and the detailed observations made, reaching insightful conclusions using standardised documentation. The conclusions reached at each stage will lead logically to the next measurement in the sequence, for example a permanently low voltage level on the base of a transistor leading to checking for a short circuit between base and emitter, or a permanently low logic level (stuck-at zero) on a logic gate leading to the search for a short circuit to signal ground.

Overall, 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 use correct technical engineering terms.

For merit standard, learners will use relevant documentation to produce an effective fault finding plan, incorporating safe working practice, to identify the cause of each fault. However, the plan may not necessarily be the most efficient, for example learners may follow an end-to-end approach, measuring accurately and making logical deductions to find the fault, but a half-split method could reach the same outcome in fewer steps. Learners will also compare the advantages and disadvantages of at least two different fault finding techniques for a given circuit.

Learners will find the root cause of the faults in at least two analogue and two digital circuits. They will complete tests effectively, for example in a logical sequence, comparing measured values with those from unfaulted circuits. There may be some deviation from the initial plan as a result of the measurements taken. The conclusions learners reach will reflect the observations made and lead logically to the next test, although this may not be the most obvious alternative and could lead to additional steps being taken.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain at least two techniques for testing faults in analogue electronic circuits and complex digital electronic circuits, for example half-split and output-to-input techniques. The circuits will be sufficiently complex to allow learners to use a range of fault finding techniques, for example a two-stage class A amplifier, a regulated full-wave rectifier or a modulo-7 asynchronous counter using J-K flip-flops.

Learners will focus on the fault finding techniques rather than in-depth understanding of how each component works in the circuit. They will use given documentation to produce a logical test plan for an electronic circuit that incorporates safe working practice and includes preparatory tasks. The fault finding plan may not be the most efficient, for example using an input-to-output technique on a complex circuit. The plan should be logical although it may omit key detail, for example not stating if the expected signal value measured at a test point in an unfaulted analogue circuit is RMS or peak, making it difficult to select an analogue/digital multimeter or an oscilloscope as the most appropriate measurement device, but not preventing learners from finding the fault in a circuit with a single fault.

Learners will find the root cause of at least one analogue and one digital fault, carrying out fault finding procedures on each circuit, although they may deviate from the plan. Conclusions may not be drawn or, if they are, may lack detail or be misinterpreted. The next step in the testing sequence may not relate to the conclusions drawn from the first step, for example measurement of a permanently low voltage level on the base of a transistor being followed by measuring the voltage across an unconnected resistor.

Overall, the evidence will be logically structured. Evidence may be basic in parts, for example observations may lack detail such as whether a signal is sinusoidal and units may be inconsistent. Some outcomes may be inconclusive, or a reading may be misinterpreted resulting in the root cause of a particular fault not being identified correctly.

Learning aim D

For distinction standard, learners will demonstrate relevant behaviours and general engineering skills to a professional standard, for example they will plan all activities in advance and meet all the deadlines.

Their evidence will show consistently good technical understanding of measurement and testing as well as the fault finding processes. They will include accurate technical engineering terms and grammar, and will clearly differentiate facts from opinion.

Overall, the evidence will include a balanced view about the actions taken, electronic circuit fault finding (including measurement, testing, calculations and using devices), including health and safety compliance, and technical engineering terms will have been used correctly and consistently. The evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will give examples, such as their lessons learned report, of where improvements could be made to:

- the fault finding process (including measurement, testing, calculations and using devices) for analogue and digital electronic circuits, for example how a database of previous fault finding results allows the fault symptoms to identify a potential cause
- application of relevant behaviours, for example using deductive reasoning to move from a test result to the next test.

Overall, the suggested improvements will be reasonable and practical, explanations will be professional and engineering terminology will be used accurately. Some parts of the evidence may have more emphasis than others, making the evidence more difficult for a third party to understand.

For pass standard, learners will provide evidence, such as a lessons learned report, around 500 words in total, that covers the management of health and safety, analogue and digital measurement, testing skills, general engineering skills and a reflection on personal performance. The evidence will be basic in its approach with some use of technical language, but this may not be consistent and there may be some errors throughout. The evidence will explain:

- the actions taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- electronic measurement and testing skills, such as consistently selecting and connecting correctly appropriate measurement and testing devices
- how general engineering skills were used, such as reading measurement and test devices accurately and interpreting schematic drawing
- behaviours used, such as problem solving and perseverance to identify the faults.

Links to other units

This unit links to:

- Unit 16: Three Phase Electrical Systems
- Unit 19: Electronic Devices and Circuits
- Unit 20: Analogue Electronic Circuits
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local electronics organisations
- contribution of ideas to unit assignment/project materials.

Unit 22: Electronic Printed Circuit Board Design and Manufacture

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore and develop the design and manufacture of electronic printed circuit boards (PCBs). This unit does not cover the design of circuits.

Unit introduction

Electronic products are everywhere, from toasters to computer tablets, and at the heart of these devices are ever more complex electronic circuits. To make these products function as intended (reliably and safely), the circuits need to be connected effectively; and this is the job of a PCB. As well as making all of the required electrical connections that join the components together, a PCB must also physically support the components. PCBs might also comprise some user controls or a display, and can be designed to help protect the circuit from excess heat or interference.

In this unit, you will understand and explore the industrial processes involved in designing and manufacturing sustainable PCBs. You will gain an understanding of the different types of PCB and the design considerations for an electronic product or system. You will experiment with software tools to design and simulate the PCB, before safely producing a PCB that you will then examine to assess its functionality and build quality. Finally, you will reflect on the skills and understanding you have acquired while designing and manufacturing a PCB, and the behaviours applied.

It is the role of electronic design engineers to examine and analyse the diverse product and system requirements and then to develop effective, efficient and sustainable solutions, ensuring optimal performance. This unit will help to prepare you for employment and apprenticeships in electronic and electrical engineering and, in particular, electronic product design and manufacture. You may also be interested in this unit if you want to progress to higher education to study engineering.

Learning aims

In this unit you will:

- A** Examine the design and manufacture of printed circuit boards that are widely used in industry
- B** Explore how computer software is used for schematic capture and simulation of an electronic circuit
- C** Develop safely a printed circuit board to solve an engineering problem
- D** Review the development of the printed circuit board and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the design and manufacture of printed circuit boards that are widely used in industry	A1 PCB types, technologies and applications A2 Characteristics of printed circuit boards A3 Heat gain and thermal management A4 Manufacturing processes A5 Quality control methods A6 Sustainability and environmental considerations	A written report or formal presentation detailing the PCB technology, characteristics and thermal management techniques employed in electronic products, including a description of the relevant manufacturing processes and quality control methods.
B Explore how computer software is used for schematic capture and simulation of an electronic circuit	B1 Schematic capture B2 Circuit simulation	Evidence of computer-based activities capturing and simulating direct current (DC) and alternating current (AC) circuits, or a complex circuit containing DC and AC elements; witness statements accompanied by annotated screenshots, printouts and data generated.
C Develop safely a printed circuit board to solve an engineering problem	C1 PCB design C2 Health and safety requirements when manufacturing a PCB C3 Risk assessment C4 Manufacture of a single-sided PCB	A reflective developmental log detailing the design, manufacture and testing process undertaken. This should be accompanied by one or more observational witness statements, photographic evidence, a formal assessment of the final circuit board and relevant behaviours applied.
D Review the development of the printed circuit board and reflect on own performance	D1 Lessons learned from developing a PCB D2 Personal performance while developing a PCB	The portfolio of evidence learners' generate while developing a printed circuit board and reviewing the processes and reflecting on own performance

Content

Learning aim A: Examine the design and manufacture of printed circuit boards that are widely used in industry

A1 PCB types, technologies and applications

- Types of PCB and their technology: through hole (THC), surface mount (SMT), mixed-technology boards, single and multiple layer/sided boards, rigid, flexible and membrane PCBs and chip-on-board (COB).
- Typical PCB applications, e.g. multimedia devices, computing, household electrical items/white goods, industrial processes, aerospace, and medical, influence the choice of manufacturing technology and characteristics of the PCB.

A2 Characteristics of PCBs

- Characteristics of the different PCB technologies, including physical size and component density, composition and materials used, ease of mass manufacture, component availability and cost, design complexity, connectivity and interconnection, radio frequency immunity, mechanical characteristics, ease of rework and power handling capability.
- Justification of the technology used for different applications based on design requirements and circuit board characteristics.

A3 Heat gain and thermal management

- Causes of heat generation, e.g. resistance, internal resistance, semiconductor junction.
- Consequences of excess heat gain and thermal cycling, e.g. component failure, reduced product life span, changes to components' electrical characteristics, de-soldering, material property changes, physical stresses, safety, usability issues.
- Thermal management methods:
 - heat dissipation methods, including heat sinks, fins/cavities, heat pipe, air and liquid cooling, Peltier plate, case/enclosure design, and thermal interface efficiency (component mounting and thermal compound)
 - heat efficient PCB design, e.g. component placement (geographic and relative to other components), component density, heat dissipation via board/copper, consideration of enclosure fixtures/features
 - thermal rating conventions and typical values for simple heat dissipation devices.

A4 Manufacturing processes

PCB mass manufacturing processes:

- artwork production (photo/laser)
- drilling (manual/automated)
- chemical processes: exposure, developing, electroplating and etching
- component placement: manual insertion and automated pick and place
- soldering techniques: hand, selective, wave and reflow
- solder mask over bare copper (SMOBC)
- silkscreen
- punching, routing, scoring
- Institute for Printed Circuits (IPC) standards or other relevant international equivalents.

A5 Quality control methods

- Quality control methods used in the batch and mass manufacture of PCBs including: visual inspection techniques (manual/assisted), automated optical inspection (AOI), x-ray, automated test equipment (ATE), electrical testing, flying probe and test fixtures/'bed of nails', functional testing, standards conformity testing, e.g. electromagnetic compatibility (EMC).

- Quality control methods for the one-off and small batch manufacture of PCBs, including:
 - pre-assembly inspection methods, e.g. incomplete or bridged tracks and pads, hole completeness and hole alignment, and finish quality assessment
 - post-assembly inspection methods, e.g. component placement and polarity, quality of soldering and functional testing – test procedures and plans, basic input and output testing, test points and criteria.

A6 Sustainability and environmental considerations

Sustainability and environmental considerations of different PCB technologies, including:

- manufacturing processes:
 - waste particulate, e.g. copper, gold and epoxy/fibreglass
 - liquid effluents, e.g. acids, copper, caustics, fluorides
 - air pollutants, e.g. acid gases, formaldehyde
- leaded and lead-free solder
- materials used in manufacture
- energy usage in manufacture and product operation
- product life cycle/expectancy
- Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC (updated 2009 and 2012) or other relevant international equivalents
- hazardous product waste materials, e.g. lead, cadmium, mercury.

Learning aim B: Explore how computer software is used for schematic capture and simulation of an electronic circuit

B1 Schematic capture

Capturing a schematic circuit in a software package, including:

- selection of correct components, device models and values
- drawing of circuit network connections
- electrical circuit drawing standards BS 8888, BS 3939, or other relevant international equivalents, e.g. organisation, component identification, connections and crossovers.

B2 Circuit simulation

Software simulation of AC and DC circuit(s) prior to physical manufacture:

- Simulation Program with Integrated Circuit Emphasis (SPICE)
- onscreen simulation
- confirmation of desired operation
- extraction of data/measurements, e.g. voltage, current, power (DC analysis)
- input and output signals AC analysis.

Learning aim C: Develop safely a printed circuit board to solve an engineering problem

C1 PCB design

Design of a single-sided PCB, to include:

- schematic capture and simulation
- PCB routing/design:
 - component packages and physical layouts
 - component placement, orientation and organisation
 - layers, tracks, pads, vias
 - track width and isolation gap requirements
 - manual and automated routing
 - mechanical fixtures, mounting points and off-board connections
 - production aids, e.g. silkscreen, component numbering, test points
 - generation of manufacturing information, e.g. PCB artwork, CAD/CAM data, bill of materials (BOM), technical specification and simulation/analysis data.

C2 Health and safety requirements when manufacturing a PCB

Key features of regulations, or other relevant international equivalents, including:

- hazardous materials: storage, handling and disposal of processing chemicals, Control of Substances Hazardous to Health (COSHH) Regulations 2002 and amendments
- Provision and Use of Work Equipment Regulations (PUWER) 1998 and amendments
- Personal Protective Equipment (PPE) at Work Regulations 1992 and amendments, e.g. safety goggles, gloves, apron, fume extraction/displacement.

C3 Risk assessment

Risk assessment and work area preparation and manufacturing planning, to include hazard identification and classification:

- defining a hazard by inspection of the work environment and consideration of specific PCB design and manufacturing processes:
 - electrical, e.g. electric shock, equipment inspection, and PAT testing
 - electrostatic, e.g. grounding, storage and packaging
 - fire safety, e.g. flammable chemicals, and safe working when soldering
- defining a risk by determining how hazards may cause injury, e.g. some chemicals will cause burns
- putting control measures in place to reduce risk, e.g. using rubber gloves when handling some chemicals
- Health and Safety Executive (HSE) guidance on risk assessment, to include the five steps to risk assessment and the use of standard risk assessment pro forma.

C4 Manufacture of a single-sided PCB

- Manufacture of a single-sided PCB to include:
 - manufacturing processes for the substrate, e.g. board preparation, UV exposure, photoresist development, etching, tinning and drilling
 - visual pre-assembly quality control checks, e.g. quality of copper layer reproduction, hole completeness and hole alignment.
- Circuit assembly methods:
 - safe working practices
 - appropriate identification, handling and preparation of components, including:
 - passive components, e.g. resistors, capacitors, inductors and transformers
 - active components, e.g. transistors, diodes and integrated circuits
 - mechanical components, e.g. connectors, sockets and mountings
 - component polarity and placement
 - hand soldering techniques
 - wire preparation, e.g. stripping, tinning, trimming
 - connection of off-board components
 - post-assembly quality control checks, e.g. component placement and polarity, quality of soldering and functional testing.

Learning aim D: Review the development of the printed circuit board and reflect on own performance**D1 Lessons learned from developing a PCB**

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- PCB design and manufacturing skills, e.g. schematic capture, PCB artwork generation, quality control methods and hand soldering methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while developing a PCB

Understand that relevant behaviours cover:

- time planning and management to complete all the different activities in an appropriate time and in an appropriate order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- commercial and customer awareness to ensure the design and manufacture of the PCB is fit for purpose and meets the client brief.

Assessment criteria

Pass	Merit	Distinction	
Learning aim A: Examine the design and manufacture of printed circuit boards that are widely used in industry			
<p>A.P1 Explain the technology used in and characteristics of at least two different PCBs contained in products.</p> <p>A.P2 Explain the causes and consequences of heat gain and thermal management methods used in at least two different PCBs contained in products.</p> <p>A.P3 Explain the manufacturing processes and quality control methods used in at least two different PCBs contained in products.</p>	<p>A.M1 Analyse the design and the manufacture of at least two different PCBs contained in products.</p>	<p>A.D1 Evaluate, using vocational and high-quality written language, the design and manufacture of at least two different printed circuit boards contained in products and consider how they are likely to evolve.</p>	
Learning aim B: Explore how computer software is used for schematic capture and simulation of an electronic circuit			
<p>B.P4 Capture a DC and AC circuit(s) schematic and simulate the correct operation of the DC circuit.</p>	<p>B.M2 Capture accurately and efficiently a DC and AC circuit(s) schematic and simulate the correct operation including the generation of representative circuit(s) data.</p>	<p>B.D2 Capture, following industry conventions, a DC and AC circuit(s) schematic and use simulation data to create a technical specification for the circuit(s)</p>	
Learning aim C: Develop safely a printed circuit board to solve an engineering problem			
<p>C.P5 Design a PCB and generate documentation for manufacture.</p> <p>C.P6 Manufacture safely a PCB and identify any issues with the quality and functionality.</p>	<p>C.M3 Design and manufacture accurately and efficiently a PCB that functions as intended, while documenting alternative solutions.</p>	<p>CD.D3 Refine, during the process, the development of a PCB safely to improve its performance, whilst applying relevant behaviours and general engineering skills to a professional standard.</p>	
Learning aim D: Review the development of the printed circuit board and reflect on own performance			
<p>D.P7 Explain how health and safety, design and manufacturing and general engineering skills were applied effectively during the manufacture of the PCB.</p> <p>D.P8 Explain how relevant behaviours were applied effectively during the design and manufacture of a PCB.</p>	<p>D.M4 Recommend improvements to the design and manufacture of the PCB and to the relevant behaviours applied.</p>		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.P3, A.M1, A.D1)

Learning aim: B (B.P4, B.M2, B.D2)

Learning aims: C and D (C.P5, C.P6, D.P7, D.P8, C.M3, D.M4, CD.D3)

Further information for teachers and assessors

For this unit, learners must have access to:

- electronics design, simulation and PCB creation software, for example Circuit Wizard, Multisim, Eagle, Tina, DesignSpark, Proteus circuit board manufacturing equipment and consumables (depending on centre manufacturing method), for example photosensitive board, photo transfer paper, PCB shear, UV exposure unit, developer (chemical, tray, tongs), etching unit, etch resist stripper, immerse tin solution, mini drills and bits
- electronic components suitable for practice activities and project circuits
- commercial electronic circuit assembly kits, these are widely available and could support teaching and learning activities, for example Rapid Electronics, RK Education, Velleman
- circuit assembly tools, equipment and consumables, for example soldering irons, extractors, sides cutters, pliers, solder, de-solder tools, IC lead setting tools
- electronics reference materials, for example catalogues, data sheets and web-based resources
- small hand assembly tools, for example files, sandpaper, drill, glue gun, junior hacksaw
- a range of electronic products and/or circuit boards that employ various manufacturing techniques and circuit technologies
- a range of health and safety regulations, as stated in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of the design of at least two PCBs contained in different products. For example, learners could cover the complexity of the circuit, power requirements and physical factors, such as product size. They will also cover environmental conditions and manufacturing considerations, such as production quantity, manufacturing cost, and quality. Learners will suggest how the products might evolve for particular applications that require changes to the PCB technology/characteristics or due to advances in technology. Learners will refer to consumer trends and market forces and how they might influence the evolution of the electronic products and the impact of these on the electronics required.

Overall, 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 use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse each board against the other in terms of the technology, characteristics, thermal management, manufacturing processes and quality control methods. They will also analyse why the PCB technology has been used for the intended product application. This might include the requirements of the circuit itself in order to achieve the product functionality.

Overall, the evidence will be logically structured, technically accurate and be easy to understand.

For pass standard, learners will give fully illustrated responses and, as a minimum, provide a sound overview of the technology used, and the physical construction and associated hardware characteristics of the printed circuit. For example, the explanation will cover the size, materials used, component attachment methods and connections, and case mounting.

Learners will explain the causes and consequences of heat gain, and how the effects can be mitigated by thermal management methods.

The individual manufacturing steps from raw substrate board to final assembly and testing will be included. Learners will detail the process effectively and the required hardware and consumables needed, but do not need to cover detailed chemical reactions.

Overall, the evidence will be logically structured, although it may be basic in parts and contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will draw the circuit to a high standard following industry best practice. This will include a neat, well-organised and readable layout with sequential component labels. Components will be fully specified and connected accurately with efficient wiring. The positioning of power lines will be appropriate and labelling will have been used to identify the purpose of terminals or controls.

Data will have been collated and well presented as a formal document, together with circuit schematics to generate a technical specification for the circuit. This will include a table of electrical values at key points in the circuit and/or at key stages in circuit operation. The AC circuit or AC element of a complex DC and AC circuit will include characteristic waveforms.

For merit standard, learners will enter both DC and AC circuits or the complex DC and AC circuit accurately, with all components appropriately selected with accurate values and models specified. The schematic will be efficient, meaning that the components are neat and readable with good organisation, component labelling and layout. The circuit(s) will simulate as intended to confirm the operation and there will be evidence of collecting electronic data from the circuit(s). This might include voltage, current or power readings for the DC circuit or DC element of a complex DC and AC circuit and input/output traces for the AC circuit or DC element of a complex DC and AC circuit.

For pass standard, learners will capture and connect correctly a range of (at least five and up to c. 15) passive and active components in a DC and an AC circuit or in a complex DC and AC circuit. The layout of components and connections in the circuit(s) may not be logical and well organised. There may be minor discrepancies in component values or device model selections that may affect the operation of the circuit(s). As a minimum, when simulated, the DC circuit or DC element of a complex DC and AC circuit will function as intended.

Learning aims C and D

For distinction standard, learners will include justifications for design decisions, records of identification of errors/defects and remedial action taken, and iterations of the circuit board to detail refinements that would improve its performance. For example:

- consideration of the intended application, such as the positioning of fixed components and points for mounting
- a name and other reference text will be included (if applicable)
- the soldering will be of an excellent quality, with no defects
- component density and grouping optimised.

Throughout the activity, learners will demonstrate relevant behaviours and general engineering skills to a professional standard. For example, all assignments will be completed on time, the practical activities will be planned out in advance and the finished PCB will fully meet the requirements of the client brief, hence demonstrating commercial awareness.

The lessons learned report will present a good technical understanding of PCB design and safe manufacturing processes. Overall, the evidence will include a balanced view about the actions taken, and PCB design and manufacture, including health and safety compliance and technical engineering terms, which will have been used correctly. The evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will be accurate and efficient in their PCB design with neat routing of tracks and minimal use of space, and alternative design ideas will have been given. The schematic diagram will be drawn accurately and efficiently, with components aligned, numbered consecutively, labelled appropriately, neat, readable and oriented with connectors at board edges. Few or no links will be required and an appropriate track width, pad size and isolation gap (depending on application) will have been used.

Construction and assembly will be to a high standard, with the board cut to size and holes drilled accurately. Learners will have manufactured the PCB safely and well, with no bridged/broken tracks and clean, sharp traces. The soldering will be of a good quality (little or no bridged, incomplete, dry, excessively soldered or overheated joints) and the leads neatly trimmed. The circuit will function correctly as intended.

Additionally, learners will explain what improvements could be made throughout the processes and to the behaviours applied. There will be a detailed explanation of these improvements and the reasoning for them will be well considered.

For pass standard, learners will include in their circuit a range of passive and active components (around five to 15 components). All components will be selected correctly with values and device models set accordingly. PCB artwork will be generated with all nets routed successfully. Manufacturing documents such as bill of materials and construction reference materials will be produced.

A risk assessment will be written and learners will demonstrate safe working practices while manufacturing, assembling and testing a PCB. The board will contain all the necessary components and the components will have correct position and polarity. The soldering will be adequate, but there may be some dry, excessively soldered or overheated, untidy or uneven joints in places. The board will be complete but may have partial or incorrect functionality.

Learners will present a lessons learned report, of between 500 and 1000 words, covering the management of health and safety, the application of design and manufacturing, general engineering skills and a reflection of personal performance. The evidence will explain what:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- electronic/electrical engineering skills were used, such as identifying components and their characteristics, and electronic circuit theory and using schematic diagrams
- electronic circuit design and manufacture skills were used, such as how accurate and efficient the PCB design was and the skills required to manufacture the PCB
- how general engineering skills were used, such as the use of IT, computer-aided design (CAD) and interpreting drawings
- behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

Overall, the evidence will be well structured and technical language will have been used where appropriate, although there may be some inaccuracies with terms used. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 5: A Specialist Engineering Project
- Unit 10: Computer Aided Design in Engineering
- Unit 19: Electronic Devices and Circuits
- Unit 21: Electronic Measurement and Testing of Circuits
- Unit 23: Digital and Analogue Electronic Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in PCB design and manufacture
- contribution of ideas to unit assignment/project materials.

Unit 24: Maintenance of Mechanical Systems

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will explore the processes and components associated with the maintenance of mechanical systems and undertake maintenance tasks on a mechanical system.

Unit introduction

Mechanical systems are at the heart of many of the machines that we use to carry out work on our behalf, from cars to the escalators that move us between floors in shopping centres. Mechanical systems harness power, for example from an electrical motor, and involve the movement to complete a task. Power transmission is responsible for the movement of energy from a power source to a location where it performs useful work.

In this unit, you will explore the maintenance of different mechanical systems, including the use of lubricants and lubrication systems and the application of seals, bearings and fastenings. You will explore the function of power transmission and mechanical systems in general. Finally, you will complete routine maintenance on a mechanical system safely.

As an engineer you may need to undertake work on mechanical systems competently and efficiently if they are to continue to work properly. This unit will help to prepare you for an engineering apprenticeship, an engineering degree in higher education or for technician-level roles in a variety of engineering specialist areas.

Learning aims

In this unit you will:

- A** Examine the characteristics of lubricants and their application in mechanical systems
- B** Investigate the characteristics and applications of common consumable components used in mechanical systems
- C** Investigate the operation and application of power transmission components used in mechanical systems
- D** Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of lubricants and their application in mechanical systems	A1 Lubricant characteristics A2 Lubrication of mechanical systems	A report about the characteristics of lubricants and their application in two mechanical systems.
B Investigate the characteristics and applications of common consumable components used in mechanical systems	B1 Mechanical seal characteristics and common applications B2 Bearings characteristics and common applications B3 Fastener characteristics and common applications	A report about the characteristics, maintenance considerations and applications of common consumables and the operation and maintenance considerations of power transmission components used in mechanical systems.
C Investigate the operation and application of power transmission components used in mechanical systems	C1 Gear train function and operation in power transmission systems C2 Typical function and operation of other power transmission components	
D Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system	D1 Safe working practices when undertaking routine maintenance D2 Routine maintenance tasks on mechanical systems	Practical activity to complete maintenance tasks safely. Evidence will include a record of the procedures followed, observations records and correctly completed documentation, with witness signatures against each completed task.

Content

Learning aim A: Examine the characteristics of lubricants and their application in mechanical systems

A1 Lubricant characteristics

- Function of lubricants – to keep moving parts separate, transfer heat, reduce friction, remove contaminants and debris, transmit power, protect against wear and corrosion and seal for gases.
- Definition of viscosity – a fluid's resistance to flow at a given temperature and the internal friction of a moving fluid.
- Fluid lubricant types:
 - mineral oils derived from petroleum
 - biolubricants – vegetable oil, e.g. corn, castor and animal oils
 - synthetic lubricants – polyalphaolefins (PAO), polyglycols (PAG), esters, silicones
 - semi-fluid lubricants, e.g. greases.
- Solid lubricant types, e.g. powders, graphite, polytetrafluoroethylene (PTFE), molybdenum disulfide.
- Additives can improve the performance of lubricants, e.g. extreme pressure, oxidation, corrosion inhibitors, foam inhibitors, dispersants, and anti-wear.
- Properties high boiling point, low freezing point, high viscosity index, thermal stability, hydraulic stability, corrosion prevention, high resistance to oxidation.

A2 Lubrication of mechanical systems

- Lubrication processes – gravity feed, forced feed, splash, capillary, grease packing, compressed air.
- Applications in mechanical systems – internal combustion engines, electrical motors, transmissions, machine tools, and pumps.
- Lubricant environment – extremes of temperature, light and heavy loads, low and high speeds, accessible and non-accessible.
- Maintenance considerations – choice of lubrication type, quantity required and replenishment and/or replacement at the correct intervals related to the particular requirement of the mechanical system.

Learning aim B: Investigate the characteristics and applications of common consumable components used in mechanical systems

B1 Mechanical seal characteristics and common applications

- Function of mechanical seals – to prevent contaminants from entering, to prevent lubricants from escaping, contain pressure and/or separate sections of a system.
- Types of seal, including:
 - static seals – O-rings, gaskets
 - dynamic seals – radial shaft seals, piston seal rings
 - non-contact seals – labyrinth, gap
 - bellows and membranes.
- Materials – rubber, e.g. nitrile, silicone, PTFE, tungsten carbide, carbon graphite and ceramics, e.g. aluminium oxide.
- Applications – internal combustion engines, electrical motors, transmissions, machine tools, pumps, turbines, actuators, compressors, clutches, brakes.
- Application parameters, – temperature, pressure, environment, e.g. foreign particles and corrosion, lubricant type, chemical compatibility, surface finish and nature of any moving parts.
- Maintenance considerations – choice of seal type, seating of the seal, operating environment, replacement at the correct intervals.

B2 Bearing characteristics and common applications

- Function of bearings – to assist one surface move with ease over another, which might be in a linear or a rotational movement.
- Types of bearing:
 - contact, including plain, e.g. bush, two-piece, jewel, flexure, e.g. hinge and roller, e.g. ball, spherical and tapered
 - non-contact, including fluid and magnetic
 - applications – internal combustion engines, electrical motors, transmissions, pumps, turbines, actuators, compressors, clutches
 - materials – steels, ceramic composites, bronze, sintered, nylon, PTFE
 - application parameters – low and high speed, continual and intermittent running, small and large loading, high temperature and shock loading
 - maintenance considerations – choice of bearing type, bearing wear, lubrication, vibration.

B3 Fasteners characteristics and common applications

- Characteristics of screwed fasteners, including:
 - head form – flat, hex, round and thread form, e.g. square, triangular
 - terminology – thread pitch, thread type, torque
 - tightening methods – bolts, studs, self-tapping screws
 - locking systems – locking nuts, locking inserts, locking washers, cotter pins, locking washers, wired.
- Other types of mechanical fastener – eye bolts, latches (including snap and compression), detent pins and rivets (solid and hollow).
- Applications – mechanism covering, guarding, assemblies.
- Maintenance considerations – stress concentration, galvanic corrosion and a mismatch of thermal expansion coefficients.

Learning aim C: Investigate the operation and application of power transmission components used in mechanical systems**C1 Gear train function and operation in power transmission systems**

- Function – to provide a mechanical advantage through the gear ratio, changing the speed, torque and direction of a mechanical power source. Gear trains can be fixed or provide manual or automatic transmission to change the gear ratio.
- Types – spur, helical, herring bone, bevel, spiral bevel, hypoid, simple, compound, worm and wheel, combinations, epicyclic.
- Materials – carbon steels, brass, bronze, plastics.
- Maintenance considerations – lubrication type, replenishment and replacement, filter type and replacement, gear material characteristics, e.g. plastic is self-lubricating and low cost, alignment of gears, backlash, overloading, e.g. scoring or scratching of teeth and overheating, e.g. pitting and burning of teeth.

C2 Typical function and operation of other power transmission components

- Cams and cam followers:
 - function – to convert an input motion, either rotary or linear, into a reciprocating motion of the follower, e.g. uniform velocity or acceleration and deceleration
 - types of cams – plate, cylindrical and follower, e.g. knife edge and roller
 - maintenance considerations – the follower is normally allowed to wear and is replaced during maintenance.
- Linkage mechanisms:
 - function – to modify movement and to transfer power
 - types – slider crank and inversion, four-bar linkages and inversions, slotted link quick return motion, Whitworth quick return motion
 - maintenance considerations – failure of parts of the mechanism, failure of bearings, lubrication.

- Belts:
 - function – to transfer power, modify the direction of motion and to provide synchronisation
 - types – flat V-section, synchronous, tensioning devices
 - maintenance considerations – failure of belt and lubrication.
- Transmission shafts and couplings:
 - function – to transfer power and to change the direction of motion
 - types, e.g. sections – solid, hollow, flanged couplings, splined couplings, angle couplings, Hooke universal, constant velocity
 - maintenance considerations, e.g. failure of transmission, coupling and lubrication.
- Clutches:
 - function – to transfer power in a controlled way between the driver and driven parts of mechanical systems
 - types – dog, flat plate, conical, centrifugal, fluid couplings
 - maintenance considerations – wear and failure of clutch and failure of bearings in the clutch.
- Brakes:
 - function – to slow down or to stop mechanical systems
 - types, e.g. friction – internal, external contracting, disc, dynamometers, fluid electromagnetic
 - maintenance considerations – wear and failure of individual parts.
- Applications – internal combustion engines, heat engines, transmissions, machine.

Learning aim D: Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system

D1 Safe working practices when undertaking routine maintenance

Current safe working practices, or other relevant international equivalents, including:

- compliance with the current electricity at work regulations and amendments
- Current Control of substances hazardous to health (COSHH) regulations and amendments – identifying harmful substances, assessing risks of exposure, types of exposure, safety data sheets, using/checking/maintaining control measures/equipment, training/instruction/information
- Current Personal protective equipment (PPE) at work regulations and amendments – 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
- Current Manual handling operations regulations (MHOR) and amendments – 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 aids
- procedures, hazards and precautions when working at height (Work at Height Regulations 2005 and amendments) and working in confined spaces, e.g. under mechanical systems.

D2 Routine maintenance tasks on mechanical systems

- Typical routine maintenance tasks, including replacing filters, changing lubricants, replacing seals, changing bearings, replacing gears, replacing linkages, replacing belts, replacing brake pads, replacing clutches and clutch plates, replacing blades.
- Sustainability considerations, including reusing consumables and components, reducing the use of materials, recovering materials when possible and recycling where possible.

- Completing routine maintenance tasks by following the correct process (using appropriate equipment, components and following procedures), including:
 - disassembly, removal and strip processes – using screwdriver, wrench, spanner, sockets, pliers/grips, keys and draining lubricants
 - manual processes – using snips, cutters, knives, punch, saw, file, hammer
 - components and consumables – lubricants, seals, bearings, fasteners, and belts
 - assembly processes – using soldering iron, mechanical fasteners, cables/connectors, crimping tools, pneumatic tools, clamps
 - inspection and testing processes – using flow meter, calipers, torque meter, pressure sensor or gauge
 - disposal of waste materials in a sustainable way, including fasteners – reusable or non-reusable, disposal of lubricants and filters, disposal of worn bearings, disposal of broken parts.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the characteristics of lubricants and their application in mechanical systems		A.D1 Evaluate, using language that is technically correct and of a high standard, the characteristics of lubricants used and the process of and maintenance considerations for lubrication in two different mechanical systems, suggesting improvements to the lubrication systems.
A.P1 Explain the characteristics of the lubricants used and the process of and maintenance considerations for lubrication in two mechanical systems.	A.M1 Analyse the characteristics of lubricants used and the process of and maintenance considerations for lubrication in two different mechanical systems.	
Learning aim B: Investigate the characteristics and applications of common consumable components used in mechanical systems		BC.D2 Evaluate the characteristics and applications of at least three types of consumable and the operation of at least three types of power transmission components in two mechanical systems, including how they each contribute to the system and their maintenance considerations.
B.P2 Explain the characteristics, applications and maintenance considerations of at least three types of consumable components used in two mechanical systems.	B.M2 Justify the characteristics, applications and maintenance considerations of at least three types of consumable components used in two mechanical systems.	
Learning aim C: Investigate the operation and application of power transmission components used in mechanical systems		
C.P3 Explain the operation of and maintenance considerations for power transmission gears in two mechanical systems.	C.M3 Analyse the operation of and maintenance considerations for power transmission gears and two other power transmission components in two mechanical systems.	
C.P4 Explain the operation of and maintenance considerations for two other power transmission components in two mechanical systems.		
Learning aim D: Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system		D.D3 Refine, while using the correct process, two routine maintenance tasks on a mechanical system safely, sustainably, accurately and efficiently, explaining the safe working practices that apply and inspecting the work.
D.P5 Explain what safe working practices apply when performing two routine maintenance tasks.	D.M4 Complete two routine maintenance tasks, using the correct process, on a mechanical system safely, sustainably and accurately, explaining the safe working practices that apply and inspecting the work.	
D.P6 Complete two routine maintenance tasks, using the correct process, on a mechanical system safely, and sustainably while inspecting the work.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, C.P3, C.P4, B.M2, C.M3, BC.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of mechanical systems containing power transmission components (these could be machines in a standard workshop and might utilise any automotive facility but it is expected that these would be enhanced by further industrial examples)
- a good range of seals, bearings and fastenings
- the required equipment for health and safety, for example PPE
- a number of industrial visits and visiting speakers (arranged through industrial partners to facilitate learners being exposed to a range of suitable enhancing experiences)
- accompanying documentation for the equipment referred to above and relevant health and safety regulations.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced evaluation of the lubrication maintenance requirements, the process of lubrication in the system and the characteristics of the lubricants used. They will compare the lubrication of each system and suggest improvements to the process, characteristics or maintenance requirements. For example, the improvement could suggest a different lubricant for a mechanical system or perhaps a lubrication additive for a lawnmower engine.

Overall, learners' 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 use correct technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling.

For merit standard, learners will analyse the lubricant characteristics, the maintenance requirements and the process of lubrication of the systems. Their analysis will be methodical and cover the interrelationships between the characteristics, maintenance requirements and the system. In addition, learners will compare the systems, for example a comparison of the viscosity of the lubricant in a lawnmower engine and in an electric motor, suggesting a reason for the difference.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the process of lubrication as well as the function, type, additives, properties and sustainability characteristics of the lubricants used in two different mechanical systems. They will also explain the maintenance requirements for the lubrication of the system, for example the requirements to check lubrication levels periodically and replace the oil in a lawnmower engine.

Overall, learners' evidence will be logically structured although it may be basic in parts, brief and lacking in detail. Evidence may also contain technical inaccuracies or omissions, for example referring to the lubricant as 'oil' and not using the actual technical name or description.

Learning aims B and C

For distinction standard, learners will produce evidence of a thorough and consistent investigation of two mechanical systems, evaluating the use of seals, bearings, fastenings, gear trains and two other power transmission components. They will inform their evaluation through independent research based on the internet and other credible sources. Learners will present the advantages and disadvantages of components used in the task and will suggest two alternatives, providing a justification for each. For example, learners may evaluate a solid bronze bearing employed in a system before exploring alternative roller bearings, suggesting why these might be more appropriate.

Learners will evaluate how each component in the system contributes towards the overall operation and maintenance of the system, for example considering the operational requirement of the rotational support that a roller bearing would provide for a system, noting the radial and axial loading and the speed range.

Overall, learners' evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will produce evidence of a thorough investigation and independent research of two mechanical systems. They will justify the use of the seals, bearings, and fastenings used in each system, for example the use of a roller bearing rather than a ball bearing by an analysis of the radial loading before comparing the radial loading capacity of each type of bearing.

Learners will also analyse the operation of and maintenance considerations for the gear trains and two other power transmission components, for example learners may consider the gear ratio employed in both systems and the potential for wear in each, necessitating scrutiny of the bearings.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will investigate at least two mechanical systems, each of which contains power transmission components. Their explanations will cover the applications, characteristics (types, function, materials, application parameters) and maintenance considerations of at least three types of consumable component (seals, bearings and fasteners). For example, learners may investigate the load carrying capability of the bearings employed in the mechanical system and establish the load carrying capability of the bearings in terms of radial and axial loading.

Learners will explain the operation and maintenance considerations for power transmission gear trains, going on to explain the considerations for two other power transmission components, such as belts and transmission shafts. For example, they will explain the operation of the belt drive in a typical machine tool between the electrical drive motor and the gear shaft, which could include an explanation for the number of belts and the type of belt being employed.

Overall, learners' evidence will be logically structured although it may be basic in parts, for example learners may refer to belts rather than specifying the shape and/or the number of belts. Evidence may also contain technical inaccuracies or omissions, such as mixing up the driven and driver aspects of the system or simply not specifying which is driver and which is driven.

Learning aim D

For distinction standard, learners will refine, while using the correct processes, the completion of two different maintenance tasks on an appropriate mechanical system. This will be completed safely, sustainably, accurately and efficiently. Efficiency will be evident in learners who prepare well for the task, for example by gathering the correct consumables and components in advance, walking through the task prior to completing it, outlining who will complete the tasks and what is the most appropriate order (sequence) in which to do this, while keeping the workshop well organised, reasonably clean and ensuring that risks are mitigated. Their inspection checks will be completed during the tasks and appropriate records made. Once complete, the system will work as intended.

Overall, learners' evidence will be presented clearly and in a way that is understood by a third party who may or may not be an engineer. There will be a comprehensive record of the safety procedures followed, together with accurate and correct documentation for each of the maintenance tasks completed.

For merit standard, learners will complete two different maintenance tasks on an appropriate mechanical system. This will be completed using the correct processes safely and accurately, using the correct tools, equipment and following procedures. Accuracy will be evident in learners who ensure that seals and bearings are seated correctly, fastenings are tightened to the correct torque and the correct amount of lubrication is used. Their inspection checks will be completed during the tasks and appropriate records made. Once the maintenance is complete, the system will work as intended.

Overall, learners' evidence will be logically presented, technically accurate and easily understood. This will include learners' explanations of the safe working practice that will have been prepared before starting the tasks and evidence of applying the practices will also be clear.

For pass standard, learners will explain the safe working practices that apply to the two routine maintenance tasks they undertake. For example, having selected appropriate personal protective equipment, learners will isolate the mechanical system.

Learners will complete two routine maintenance tasks on a mechanical system that contains power transmission components. They will apply safe working practices and follow the correct maintenance process, for example using the correct tools, equipment, and following procedures. Learners' evidence will demonstrate that safe working practices were applied and sustainability was considered, for example lubrication and faulty components will be disposed of in the appropriate way. Learners will inspect the quality of their work as they undertake the tasks, although the system may not be operating correctly once the work is finished.

Overall, any supporting evidence may be limited, for example there may be little evidence of preparation tasks and inspection documentation may lack the required detail.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 11: Engineering Maintenance and Condition Monitoring Techniques
- Unit 12: Pneumatic and Hydraulic Systems
- Unit 15: Electrical Machines
- Unit 25: Mechanical Behaviour of Metallic Materials
- Unit 28: Dynamic Mechanical Principles and Practice
- Unit 29: Principles and Applications of Fluid Mechanics
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes
- Unit 50: Aircraft Gas Turbine Engines
- Unit 53: Airframe Mechanical Systems.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations involved with the maintenance of mechanical machines
- contribution of ideas to unit assignment/project materials.

Unit 25: Mechanical Behaviour of Metallic Materials

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners investigate and conduct tests on the mechanical properties of metals, consider suitable applications and explore failure modes to improve component design.

Unit introduction

Selecting the most appropriate material and processing method for an engineered product or system is critical to ensure that it is fit for purpose. The materials used in the airframe of an aeroplane, car body pressings, cast components in domestic appliances and the 'T'-shaped electricity pylons (in the UK) all require careful selection and testing of appropriate metallic materials.

In this unit, you will investigate and research the microstructures of ferrous and non-ferrous metallic materials, some of which will have been processed, for example heat treated. You will inspect the microstructures of the materials you are investigating. You will also undertake destructive and non-destructive tests on the materials and use the results of the experimentation and research to determine the mechanical properties of, and suitable applications for, the materials. Finally, you will examine the reasons why components have failed in service and consider possible design improvements that could prevent failure.

As an engineer it is important to know about and understand the capabilities of a range of metallic materials to create products and systems that are suitable for application. This unit will help to prepare you for an apprenticeship or a technician-level role in industry. It will also help to prepare you for a range of higher education courses, such as a Higher National Diploma (HND) or a degree in any engineering discipline.

Learning aims

In this unit you will:

- A** Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties
- B** Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements
- C** Explore the in-service failure of metallic components and consider improvements to their design.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
<p>A Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties</p>	<p>A1 Types of ferrous metals and alloys</p> <p>A2 Types of non-ferrous metals and alloys</p> <p>A3 Mechanical properties of metallic materials</p> <p>A4 Grain structure of metallic materials</p> <p>A5 Effects of processing on the mechanical properties of metallic materials</p> <p>A6 Microstructure investigation of metallic materials</p>	<p>A report containing investigative research and library images of the microstructures of metallic materials, some of which will have been processed.</p>
<p>B Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements</p>	<p>B1 In-service requirements of metallic materials</p> <p>B2 Destructive test procedures</p> <p>B3 Non-destructive test procedures</p>	<p>A portfolio of results gathered from tests on samples of given metallic materials and an investigation of the materials, supported by a logbook and images. Observation records are essential.</p>
<p>C Explore the in-service failure of metallic components and consider improvements to their design</p>	<p>C1 Ductile and brittle fracture</p> <p>C2 Creep failure</p> <p>C3 Fatigue failure</p> <p>C4 Corrosion mechanisms</p> <p>C5 Design considerations to help prevent component failure</p>	<p>A report containing investigative research into the failure mode of given engineered products or components and possible design solutions. Observation records are essential.</p>

Content

Learning aim A: Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties

A1 Types of ferrous metals and alloys

- Plain carbon steel: low, medium, high carbon.
- Alloy steels: constructional, tool, stainless, heat-resistant.
- Cast iron: grey, white, malleable.
- Wrought iron.
- Identification methods, e.g. BS, EN, DIN and ISO coding, MIL-Spec, American UNS.

A2 Types of non-ferrous metals and alloys

- Types: aluminium, copper, gold, lead, magnesium, silver, tin, titanium, zinc.
- Alloys: aluminium (wrought and cast), copper (brass and bronze), magnesium and titanium.
- Shape memory alloys (SMA), e.g. nickel-titanium, copper-aluminium-nickel.
- Identification methods, e.g. ISO, SAE, MIL-Spec, American UNS, EN 485.

A3 Mechanical properties of metallic materials

- Elastic and plastic behaviour of a metal when subjected to stress.
- Strength: yield, proof, tensile, compressive, shear.
- Specific strength: strength per unit density.
- Surface hardness.
- Fracture toughness.
- Plasticity: ductility, malleability.
- Elastic modulus: Young's (E), shear (G).
- Specific stiffness, resistance to bending: elastic modulus per unit density.
- Fatigue limit.

A4 Grain structure of metallic materials

- Atomic lattice packing: body-centred cubic (BCC), face-centred cubic (FCC), close-packed hexagonal (CPH).
- Features of grain structure: formation, growth, boundary, size.
- Crystal defects: point, line/dislocation, planar.
- Slip planes: elastic and plastic deformation, surface slip bands.
- Metallurgical phase: single substance in an alloy system, e.g. pure metal, solid solution, uniform liquid.
- Alloys: eutectics, interstitial and substitutional solid solutions, intermetallic compounds.
- Iron/carbon thermal equilibrium diagram: ferrite, pearlite, cementite, austenite.
- Aluminium/copper thermal equilibrium diagram: solubility curve for the aluminium-rich end of the diagram, unsaturated and saturated solid solutions of copper in aluminium.
- Effect of grain structure, lattice packing and alloying on a parent metal's mechanical properties, e.g. ductility, brittleness, hardness, tensile and compressive strength.

A5 Effects of processing on the mechanical properties of metallic materials

- A non-processed material is one that has not undergone any subsequent processing from the point of being made as a raw material, e.g. bar stock or billet.
- Recrystallisation: grain growth, structure.
- Hot working: forging, pressing, rolling, extrusion.
- Cold working, e.g. rolling, drawing, pressing, deep drawing, coining, embossing, impact extrusion, spinning, stretch forming.
- Heat treatment of steels through hardening, case hardening, annealing, normalising.
- Heat treatment of aluminium alloys: solution treatment, precipitation hardening, over-ageing.

- Heat treatment of titanium alloys: precipitation hardening.
- Alloying elements in steel, e.g. chromium, manganese, molybdenum, nickel, tungsten, vanadium.
- Alloying elements in aluminium, e.g. copper, silicon, magnesium, manganese, titanium, chromium, lithium.
- Alloying elements in titanium: aluminium, vanadium.

A6 Microstructure investigation of metallic materials

- Macro-investigation and micro-investigation of metals and alloys, including identification of grain structures and boundaries, phases within grains and segregation of impurities at grain boundaries.
- If available, surface examination equipment, including a hand magnifier, optical microscope and a digital imaging system.
- Reference sources, including micrographs.

Learning aim B: Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements

B1 In-service requirements of metallic materials

- High strength requirement, e.g. vehicle suspension components, pressure vessel.
- High strength to weight ratio, e.g. aircraft undercarriage components, high-performance motor vehicles.
- High resistance to impact loading, e.g. impact tool bits.
- Hardness, e.g. drill bit.
- Toughness, resistance to fracture under impact loads, e.g. car body.
- Ductility, e.g. drawn wire.

B2 Destructive test procedures

- Tensile strength testing:
 - British Standard (BS EN ISO 6892-1:2009) or other relevant international equivalents, selection and preparation of test specimens, tensile test machine, extensometer, data recording, pull to destruction, force–extension graph, examination of fractured surface
 - analysis of results: elastic limit/limit of proportionality, yield point, tensile strength, Young’s modulus, percentage elongation and reduction in cross-sectional area.
- Hardness testing:
 - hardness standards relevant to test being performed, including British Standards BS EN ISO 6506-1:1999, BS EN ISO 6508-1:2015 or other relevant international equivalents
 - surface preparation, e.g. cleaning using light abrasion and removal of surface film
 - use of equipment to determine hardness, e.g. Brinell hardness number, Vickers pyramid number (HV), Rockwell (A, B, C) value, Shore scleroscope hardness index.
- Impact testing:
 - British Standard BS EN ISO 148-3:2008 or other relevant international equivalents, selection and preparation of test specimens
 - test specimens: selection, notch preparation
 - use of equipment to measure impact values, e.g. Izod test, Charpy test, Hounsfield balanced impact machine
 - visual inspection of the fractured surface to estimate the crystalline area percentage
 - test reporting, e.g. presentation of results and comparison with reference values taken from accredited data sources.

B3 Non-destructive test procedures

- Surface and sub-surface defect detection, e.g. visual inspection, dye penetrant, magnetic particle, ultrasonic, radiographic, eddy current.
- Test reporting and presentation of results.

Learning aim C: Explore the in-service failure of metallic components and consider improvements to their design

C1 Ductile and brittle fracture

- Effects of gradual and impact loading and grain size.
- Surface appearance: crystalline, torn, cup and cone configuration.

C2 Creep failure

- Primary, secondary, tertiary creep.
- The effect on creep rate of temperature, grain size, applied stress.
- Strain–time graphs and limiting creep stress.

C3 Fatigue failure

- Crack propagation and growth.
- Internal stress concentrations: granular defects, porosity.
- External stress concentration: surface defects, sharp changes of section.
- Stress variation: reversal due to cyclic loading, random loading, vibration.
- Stress and endurance (S/N) curves: fatigue and endurance limits for ferrous and non-ferrous alloys.
- Final, catastrophic failure: reduction in load carrying area, tensile strength exceeded.
- Characteristic appearance of fracture surface: smooth burnished area (crack growth), crystalline area (final tear), ripple-like marks showing crack progression.

C4 Corrosion mechanisms

- Chemical fundamentals, e.g. the corrosion cell, rust reactions, dry corrosion, galvanic action, active and passive materials, electro-chemical series for metals.
- Types of corrosion and their recognition and cause, e.g. hydrogen embrittlement, surface, crevice, exfoliation, inter-granular, bimetallic, pitting, fretting, stress.

C5 Design considerations to help prevent component failure

- Knowledge of the component's operating environment, e.g. static loading, dynamic loading, cyclic stressing, temperatures, wet or dry conditions.
- Correct choice of material based on mechanical properties, consequences of sudden failure, corrosion resistance.
- Design features, e.g. reducing the impact of stress raisers, e.g. sharp corners, sudden changes in cross-sectional areas, poor surface finish.
- Higher quality material, e.g. free from inclusions or porosity.
- Surface treatment and finishes, e.g. painting, polymer coating, plating.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties		A.D1 Evaluate, using an accredited data source, the microstructures of non-processed and processed metallic materials to correctly identify the material, including how the processing history, impurities and grain boundaries affect the mechanical properties of the materials.
A.P1 Explain how the microstructures of non-processed metallic materials affects the mechanical properties of the materials. A.P2 Explain how the microstructures of processed metallic materials affects the mechanical properties of the materials.	A.M1 Analyse, using an accredited data source, the microstructures of non-processed and processed metallic materials to correctly identify the material, including how the processing history affects the mechanical properties of the materials.	
Learning aim B: Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements		B.D2 Evaluate, using the results from safely conducted tests and an accredited data source, how the mechanical properties of processed and non-processed metallic materials affect their behaviour and suitability for different realistic applications, justifying the validity of the test methods used.
B.P3 Conduct destructive tests safely on different non-processed and processed metallic samples. B.P4 Conduct one type of non-destructive test safely on one non-processed and one processed metallic sample. B.P5 Explain, using the test results, how the mechanical properties of metallic materials affect their behaviour and suggest an application.	B.M2 Conduct destructive and non-destructive tests accurately on different non-processed and processed metallic samples. B.M3 Analyse, using the test results and an accredited data source, how the mechanical properties of metallic materials affect their behaviour and suggest a realistic application.	
Learning aim C: Explore the in-service failure of metallic components and consider improvements to their design		C.D3 Evaluate, using language that is technically correct and of a high standard, the results from safely conducted and accurate checks and tests to establish how components failed in service, recommending a design solution from a range of alternatives.
C.P6 Conduct a visual inspection check and at least one test safely on components that have failed in service. C.P7 Explain, using the results, how each component failed and how each component's design could be improved.	C.M4 Conduct a visual inspection check and at least one test safely and accurately on components that have failed in service. C.M5 Analyse, using the results, how each component failed and justify how each component's design could be improved.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.P5, B.M2, B.M3, B.D2)

Learning aim: C (C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- access to data sources, e.g. MatWeb, an online materials information resource, www.matweb.com
- hardware equipment, including:
 - tensile test, hardness and impact testing equipment (essential)
 - non-destructive test equipment
 - creep and fatigue test equipment – preferred, but it can be replicated using simulation software.

Centres may want to provide learners with prepared metallic material samples of known composition and processing history. If physical material samples are inspected then learners will need access to hand magnifiers and a metallurgical microscope.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will investigate the microstructures of at least six unlabelled images of materials, which will comprise a mix of ferrous, non-ferrous and processed metallic materials. Learners' evaluation will involve comparing the material microstructure in each image with examples from an accredited data source and will include the impact that impurities and grain boundaries have on the mechanical properties. For example, for an image of steel learners may have identified impurities at grain boundaries, phases such as pearlite and cementite, equiaxed grains or elongated grains for a material that has been cold worked. Learners' observations will also be linked to the mechanical properties of the material, for example the elongated grain structure of wrought iron and the distribution of impurities, making for a laminated structure that improves the impact resistance. For each examined material learners' evidence will contain an equilibrium diagram marked up with phases, for example eutectic.

Overall the evidence, such as a logbook and report, 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 images of material grain structure with those from an accredited data source, to correctly identify the six or more materials. The images will comprise a mix of ferrous, non-ferrous and processed metallic materials. Learners will analyse how the microstructures affect the mechanical properties of the materials. For example, they may analyse the differences between materials with fine and coarse grains.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will investigate the microstructures of at least six unlabelled images of metallic materials. If available, learners may instead inspect prepared material samples, using a suitable hand magnifier and metallurgical microscope. The images will be of ferrous and non-ferrous metallic materials and at least three will have been processed, for example one heat treated, one alloy and one mechanically worked. Learners will use the images to explain how the microstructures of the metallic materials affect their mechanical properties. For example, fine-grained castings generally have higher toughness and strength properties than those with coarse grains.

Overall, the evidence will be logically structured, although it may be basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology.

Learning aim B

For distinction standard, learners will safely set up and correctly use mechanical tensile, impact and hardness test equipment and gather accurate results when completing destructive tests independently. They will test at least six prepared samples comprising unlabelled ferrous and non-ferrous materials, some of which will have been processed, for example work hardened. Learners will justify why they have selected the correct test for the mechanical property that they are measuring. For example, if they are testing a thin piece of metal it would invalidate the results to use a hardness test that has a high-impact force, because it will distort the metal and the indentation measurements will not be a true indication of surface hardness.

Learners will also complete at least two non-destructive tests safely and accurately on metallic material samples.

Learners will use a combination of the mechanical test results and accredited data sources to evaluate their results. The evaluation for the:

- tensile tests will include plot load–extension plot (stress–strain graphs) and provide key data, for example yield strength, tensile strength, Young’s modulus, percentage elongation and reduction in area
- tensile and impact tests will include the condition of the fracture surface in terms of how crystalline it is
- hardness tests will make comparisons between measured hardness values and what is expected for the material
- non-destructive tests will include a report on the surface or internal condition of the given metallic materials.

Learners will present suitable realistic applications of where the tested materials might be used in service, for example appreciating that while high-strength alloy steel might be good for the passenger shell of a car, lower-strength, more malleable steel would be a better option for the front and rear crumple zones. Learners will also determine that there is often a trade-off between tensile strength, hardness and impact strength of materials.

Overall the evidence, such as a logbook and report, will have been 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 complete accurate and safe mechanical tests using at least six pre-prepared given and unlabelled samples. Limited help may be given in setting up the equipment and learners will independently gather and process their test results, for example finding the yield and tensile strengths and seeing how they compare with published values.

Learners’ analysis will compare the results of destructive testing with accredited data sources and identify the materials that were tested. For example, learners will be able to determine, from the density, colour and surface finish of two samples, that the type of material they are testing is a form of steel. The mechanical tests and data from the accredited source will allow learners to determine what types of steel they are testing and whether these have been processed.

Learners will also complete at least two non-destructive tests safely and accurately on metallic material samples and will draw conclusions from the results, for example a dye penetrant test that reveals surface cracks, with the learner explaining why the cracks have occurred.

Overall, the evidence should be logically structured, technically accurate and easy to understand. Learners’ evidence will include a realistic application for each material sample, for example stainless steel can be used for a high-temperature pressure vessel.

For pass standard, learners will complete mechanical tensile tests (to destruction), impact tests and hardness tests using pre-prepared given ferrous and non-ferrous metal samples, some of which will be processed. In total learners will test at least six samples. For each sample they will carry out a mechanical test and record their results. Throughout the delivery of the tests they will demonstrate safe working practices, for example by completing a risk assessment and checking with the assessor before conducting an impact test. Although help may be given to set up the equipment, learners will gather their test results independently.

Learners' evidence will explain, using the test results, how the mechanical properties of different metallic materials affect their behaviour. For example, a material with good impact resistance (determined, for example, from an Izod test) is better able to withstand shock loading.

Learners will also complete at least one non-destructive test safely and explain the results, for example identifying that there is porosity in a casting by completing an ultrasonic test.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the results and an application for each metallic material sample. The evidence may be basic in parts and may contain minor technical inaccuracies relating to engineering terminology.

Learning aim C

For distinction standard, learners will explore a range of given components that have failed in service after having been in use for significant periods of time. At least two components will have failed due to a mechanical fault and at least one other due to corrosion. Learners will undertake a visual inspection check of the corrosion and complete at least one mechanical test safely. The type of mechanical test(s) undertaken will depend on the components selected. It is expected that most learners will complete a hardness test, although some may also or instead complete a creep test.

Having investigated the various failure modes, learners will evaluate how to eliminate or mitigate the problem by thinking how to redesign the component, for example by specifying a larger fillet radius where there is a change of cross-section and by using a material that has a better operating performance at high temperature and stress levels, such as a titanium alloy.

Overall the evidence, such as a logbook and report, will be presented clearly and in a way that would be understood by a third party who may or may not be an engineer. This means that learners must clearly demonstrate a good understanding of mechanical design principles when evaluating the failure modes of the selected components and suggesting improvements.

For merit standard, learners will examine at least three components that have collectively suffered creep and fatigue failure and surface degradation due to corrosion. This will involve visual inspection checks, a hardness test and/or a creep test and comparison with reference sources, for example images.

Having investigated the various failure modes, learners will justify design modifications to the components so as to eliminate or reduce the impact of the failures, for example changing the design of a product to reduce the impact of electrolytic corrosion by choosing materials that are closer together in the electromagnetic (galvanic) series.

Overall, the evidence should be logically structured, technically accurate and easy to understand.

For pass standard, learners will carry out a visual inspection check and a mechanical hardness and/or creep test on at least three sample components that have failed in service for different reasons. At least two components will have failed due to mechanical faults (fatigue and creep) and at least one other due to corrosion. Throughout the delivery of the tests they will demonstrate safe working practice, for example by completing a risk assessment and checking with the assessor before conducting a test. Although help may be given to set up some of the equipment, learners will gather their test results independently.

Using the visual inspection check and mechanical test results, learners' evidence will explain how the components failed in service. Learners will also give at least one explanation for how the design of the component could be improved, for example by increasing the size of a fillet radius on a stepped shaft.

Overall, the evidence, such as a logbook and report, will be logically structured and will include the results. The evidence may be basic in parts.

Links to other units

This unit links to:

- Unit 3: Engineering Product Design and Manufacture
- Unit 26: Mechanical Behaviour of Non-metallic Materials
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes
- Unit 44: Fabrication Manufacturing Processes
- Unit 45: Additive Manufacturing Processes
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in metallic materials
- contribution of ideas to unit assignment/project materials.

Unit 27: Static Mechanical Principles in Practice

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore the effect of forces acting on structures that are in static equilibrium using theoretical principles, calculations and practical experiments.

Unit introduction

Mechanical structures and their components (sub-parts of a structure) are found in many everyday products, such as bridges, buildings, and as part of systems, such as manufacturing equipment. The design and maintenance of mechanical structures and components can be crucial to prevent injury or loss of life, and to ensure that products are usable and services are available when required. The study of the forces acting on stationary structures and their components is often referred to as 'statics'.

You will investigate the theory that underpins the design of framed structures. You will then explore, through a combination of experimentation and theory, what happens when simply supported and cantilever beams are subjected to forces generated by applied loads. Finally, you will investigate the stresses and strains generated in structural components that carry bending, shear and axial loading. Stresses produced by changes in temperature are also covered. As part of the investigation, you will look at the design of a structure or components and make improvements so that they are fit for purpose.

In our modern economy, consumers and organisations expect ever-increasing standards of safety and fitness for purpose of products, systems and other structures (e.g. buildings). Mechanical engineers will be able to work out if the loaded structure, such as a beam that forms part of a bridge, is in a safe condition. It is their job to understand and design products, systems and other structures that perform as intended. Studying this unit will help learners to progress to mechanical engineering technician job roles and also to higher education to study engineering.

Learning aims

In this unit you will:

- A** Examine how the forces acting in pin-jointed framed structures influence their structural integrity
- B** Explore safely the shear forces and bending moments in simply supported and cantilever beams
- C** Examine how axial, bending and shear loading affect the design of structural components.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine how the forces acting in pin-jointed framed structures influence their structural integrity	A1 Static parameters A2 Analysis of statically determinate framed structures	A report containing graphical and mathematical modelling relating to the analysis of given pin-jointed structures.
B Explore safely the shear forces and bending moments in simply supported and cantilever beams	B1 Beam parameters B2 Theoretical beam analysis B3 Experimental beam analysis	A portfolio of results gathered by experimentation when investigating given beam configurations, supported by a logbook, images, observation records and graphical and mathematical modelling (including differential calculus).
C Examine how axial, bending and shear loading affect the design of structural components	C1 Axial loading C2 Bending loading C3 Shear loading C4 Design considerations	A report containing mathematical modelling relating to the analysis of the stresses and strains in given structural components.

Content

Learning aim A: Examine how the forces acting in pin-jointed framed structures influence their structural integrity

A1 Static parameters

- Framework components: members and pins.
- Conditions for static equilibrium: $\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$
- Two-dimensional framed structures: stable and unstable.
- Statically determinate structures: members (m), joints (j), determinate and indeterminate condition, $(m + 3) <=> 2j$ test, redundancy.
- Loading configurations: vertical force, angled force, gravitational force ($F_g = mg$)
- Fixed (pin) and rolling framework support reactions.
- Pin and rigid framework joints.
- Resolution of forces into horizontal ($F_x = F\cos\theta$) and vertical components ($F_y = F\sin\theta$)
- Primary compressive and tensile forces in structural members.
- Types of member in a framed structure: struts and ties.

A2 Analysis of statically determinate framed structures

- Graphical method, including:
 - graphical analysis method – scale and accuracy
 - space diagram – labelling joints including uppercase lettering to code members and Bow's notation including labelling with uppercase lettering, with spaces separating adjacent forces
 - funicular polygon to determine support reactions
 - reciprocal (vector) diagram – choice of starting point (a joint with no more than two unknown forces), annotation of diagram with lowercase lettering
 - sequential analysis of the framed structure – annotation of a space diagram with arrows to show the direction of forces in a member
 - tabulation of forces – member code, vector code, force including magnitude and type, type of member (strut or tie).
- Analytical method, including:
 - space diagram – labelling joints using uppercase lettering
 - determination of support reactions and choice of starting point, e.g. a joint with no more than two unknown forces
 - resolution of forces into components at first joint and determination of forces
 - sequential joint resolution, including the annotation of a space diagram with arrows to show the direction of forces in members
 - tabulation of forces – member code, forces including magnitude and type, type of member (strut or tie)
 - method of sections – selecting an appropriate cutting plane position, annotation of force directions, coding of cut members, determination and tabulation of forces.

Learning aim B: Explore safely the shear forces and bending moments in simply supported and cantilever beams

B1 Beam parameters

- Reactions, including built-in and simply supported.
- Sign conventions for shear forces, either positive or negative.
- Sign conventions for bending moments, including positive and negative, sagging and hogging.
- Simple loading, including concentrated (perpendicular to beam axis) and effective beam mass.
- Complex loading including concentrated (angled to beam axis), uniformly distributed load (UDL) and distributed beam mass.

B2 Theoretical beam analysis

- Simply supported beams with and without overhang.
- Simple cantilever beams.
- Beam support reactions, graphically by funicular polygon and analytically by taking moments.
- Shear forces, including presentation in diagrammatic form and identification of maximum values.
- Bending moments, including presentation in diagrammatic form and identification of maximum and minimum bending moments, points of contraflexure.
- Applying differential calculus (max/min theory) to the analysis of beams carrying point and uniformly distributed loads to determine the magnitude and position of the maximum bending moment.

B3 Experimental beam analysis

- Function and operation of test equipment for measuring shear forces and bending moments in loaded structures, including loading configurations, force sensing, and resolution.
- Selecting and setting up equipment, including loading configurations, dimensional parameters and force sensing.
- Effects of point loads.
- Effects of uniformly distributed loads.
- Effects of point and uniformly distributed loads on a structure.
- Measurement and recording of shear forces.
- Measurement and recording of bending moment data.
- Presentation of experimental results and comparison against theoretical analysis.

Learning aim C: Examine how axial, bending and shear loading affect the design of structural components

C1 Axial loading

- Elasticity, plasticity, Young's modulus of elasticity, tensile strength, safe working stress, factor of safety.
- Structural components, including simple bars, complex (compound) bars with series configuration, parallel configuration and different materials.
- Effects of axial loading on structural components, including internal stress, strain, and material dimensional change.
- Effects of temperature change on fixed-end structural components, including thermal stress.

C2 Bending loading

- Neutral axis, stress distribution, second moment of area for solid and hollow rectangular sections, bending stress, Young's modulus, radius of curvature.
- Bending equation $\left(\frac{\sigma}{y} = \frac{M}{I} = \frac{E}{R}\right)$, including application to the analysis of simply supported and cantilever beams.
- Determination of bending stresses for given loading configurations and bending moment data.
- Beam efficiency, including width/depth ratio, load carrying ability, factor of safety, beam mass.

C3 Shear loading

- Single and double shear loads for bolted and riveted joints.
- Joint parameters including butt, lap, number of rivets or bolts, shear load, bolt and rivet diameters.
- Shear stress and strain in joints, shear modulus, tensile strength, factor of safety.

C4 Design considerations

- Published reference data including the mechanical and physical properties of engineering materials, second moments of area.
- Design parameters, including tensile and compressive strength, safe working stress, factor of safety.
- Design efficiency, including optimisation of physical parameters to meet load carrying and safety requirements.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine how the forces acting in pin-jointed framed structures influence their structural integrity		
<p>A.P1 Determine graphically the support reactions and primary forces acting in the members of a pin-jointed, statically determinate framed structure.</p> <p>A.P2 Calculate the support reactions and primary forces acting in the components of a pin-jointed, statically determinate framed structure.</p>	<p>A.M1 Determine accurately the magnitude and nature of the primary forces acting in the components of a pin-jointed, statically determinate framed structure.</p>	<p>A.D1 Demonstrate accurately the most appropriate method for finding the forces in the central members of a pin-jointed framed structure, justifying the rationale.</p>
Learning aim B: Explore safely the shear forces and bending moments in simply supported and cantilever beams		
<p>B.P3 Conduct experiments safely to determine the shear forces and bending moments in simply supported and cantilever beams when subjected to simple loading.</p> <p>B.P4 Explain, using experimental results and theoretical calculations, the shear forces and bending moments in simply supported and cantilever beams when subjected to simple loading.</p>	<p>B.M2 Conduct experiments accurately to determine the shear forces and bending moments in simply supported and cantilever beams when subjected to simple and complex loading.</p> <p>B.M3 Analyse, using experimental results and theoretical calculations, the shear forces and bending moments in simply supported and cantilever beams when subjected to simple and complex loading.</p>	<p>B.D2 Evaluate the simple and complex loads acting on simply supported and cantilever beams, comparing the results from safely conducted experiments and theoretical calculations, and suggest improvements to the experimental method used.</p>
Learning aim C: Examine how axial, bending and shear loading affect the design of structural components		
<p>C.P5 Calculate the axial stress produced in a rigidly held simple structural component when subjected to a combination of axial loading and temperature change.</p> <p>C.P6 Calculate the maximum bending stress, the factor of safety in operation and the minimum radius of curvature for a simply supported beam carrying concentrated and uniformly distributed loads.</p> <p>C.P7 Calculate the maximum shear stress for a single shear lap joint and a double shear butt joint for given loading.</p>	<p>C.M4 Analyse accurately the axial stress produced in a rigidly held complex structural component when subjected to a combination of axial loading and temperature change.</p> <p>C.M5 Develop accurately a design for a complex structure that does not fail when subjected to bending and shear loading.</p>	<p>C.D3 Optimise the physical parameters of a structure ensuring that it is fit for purpose when subjected to axial, bending and shear loading.</p>

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.P2, A.M1, A.D1)

Learning aim: B (B.P3, B.P4, B.M2, B.M3, B.D2)

Learning aim: C (C.P5, C.P6, C.P7, C.M4, C.M5, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- framework and beam apparatus, for example from TecQuipment
- published databases of physical and mechanical properties of metallic materials.

The practical activities should take place in a test facility with appropriate equipment, and should take account of health and safety requirements.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will select a suitable cutting plane so that the forces in a small number of internal members can be determined accurately using the 'method of sections'. The values of these forces will be compared with those found by the analysis of the framework and graphical representation (refer to the pass standard for further details). In addition to the mathematical work, learners will evaluate, in a wider context, the reasons for using the method of sections and for the given framework, and comment on the suitability of the method as compared to the analytical and graphical methods.

Overall the evaluation will be easy to read and understand by a third party who may or may not be an engineer. For example, it will be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, evidence will include a graphical and mathematical analysis to a high degree of accuracy. For each member there must be correct tabulation of the force that it carries and designation of whether it is either a tie or a strut.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Figures produced by the two methods will be broadly equivalent and if there are major differences learners will go back through their work, identifying where there are errors, and complete any necessary rework.

For pass standard, the graphical analysis of a pin-jointed framework that has two support reactions (one pinned and one roller) will include a scale drawing that will have been used to generate space, and reciprocal force diagrams that are correctly annotated using the accepted conventions, for example, Bow's notation for labelling the spaces between the external forces, support reactions and structural members. There will be evidence of a check having been carried out to ensure that the framework is statically determinate.

Using the same framework, learners will also carry out a mathematical analysis using the method of joint resolution. The framework will be configured so that for each joint the forces in the members attached to it can be resolved horizontally and vertically. Learners can present a sketched space diagram for the structure which will be marked up with force direction arrows as they work sequentially through the framework.

Overall, in the graphical analysis there may be some minor scaling errors when reading off and determining the tensile or compressive force carried by each member, and in the mathematical analysis there may be minor mathematical errors. Learners will not be penalised for 'carry-through' errors.

Learning aim B

For distinction standard, learners will present a detailed evaluation of the results from safely conducted experiments and theoretical analysis, and justify the differences between them. They will have theoretical calculations and diagrams that are accurate and will use these as a benchmark against which to judge their experimental findings. They will consider aspects such as accuracy of measuring equipment, methods used and ways to improve the experimental methods if repeated. If there are major differences between experimental and theoretical results, there will be a balanced evaluation of why this happened.

Overall, the experimental reports will be logically structured and use the correct technical engineering terms, and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will conduct accurate experimental work, to include selecting measuring equipment that has the appropriate resolution, and will record results methodically. The practical work will involve a combination of simple and complex loading, which will take the form of at least two point loads and one uniformly distributed load.

Overall, the analysis will be logically structured, technically accurate and easy to understand. Theoretical calculations and the annotation of shear force and bending moment diagrams must be accurate and conform to accepted conventions, for example, a positive bending moment indicating sagging.

For pass standard, learners will conduct experimental work on a simply supported beam carrying at least three simple (point) loads and set up in two configurations – with overhang and without overhang. Learners will conduct similar experiments with a cantilever beam carrying at least two simple (point) loads.

Overall, learners' evidence will be logically structured and there may be some minor numerical and diagrammatic errors, and minor inaccuracies relating to the engineering terminology used. The explanation of each experiment will include hand-drawn, to-scale diagrams that are annotated with relevant figures, for example maximum and minimum values. Theoretical calculations will also be included, but there may be minor numerical and diagrammatic errors.

Learning aim C

For distinction standard, learners will present ideas, supported by detailed, accurate calculations, about how to optimise the design of the structure, so that for a given loading condition the best use is made of the available materials, for example, replacing a solid rectangular cross-section beam with a hollow one to reduce mass. In addition, learners will consider features such as strength to weight ratio, factors of safety, and high-strength materials. There may be some repetition of calculations; this can be done using a spreadsheet provided that formulae are visible (printed out) and the use of functions like 'goal seek' are acknowledged. Evidence will include correctly annotated sketches to support the mathematical analysis (modelling) of the structures.

Overall, the evidence will be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will work with load and temperature data (as used throughout the assignment), but applied to different structural design configurations, for example, two flat plates separated with an aluminium tube spacer and held together with a steel bolt passing through the plates and spacer, and tightened with a nut. Calculations will be accurate and correctly presented using appropriate engineering notation and units.

Learners will review the stress data (refer to the pass standard for further details) and improve the accuracy of the design of the given structure, so that it is able to withstand the applied loads safely. For example, the design could include increasing the cross-sectional area of a beam or putting in more pins to withstand shear loading. Learners will demonstrate that the structure is able to withstand the applied loads by recalculating the stresses accurately.

Overall, calculations will be accurate and the evidence logically structured, with appropriate engineering terminology and units.

For pass standard, learners will present two sets of calculations. The first calculations determine the tensile or compressive stress in an axial-loaded simple component, for example a hollow support strut used in a gantry. The second calculations are to consider the effects of temperature change, if the component is assumed to have fixed ends. The analysis will have the correct interpretation of given data, correct use of formulae and presentation of logical steps to a solution.

Learners will undertake bending and shear stress calculations, and demonstrate analysis through correct interpretation of given data, correct use of formulae and presentation of logical steps to a solution. The stress analysis of riveted or pinned joints will be presented as annotated sketches and calculations.

Overall, the analysis will contain correct interpretation of the given data, correct use of formulae and be logically structured. There may be minor mathematical errors and learners will not be penalised for carry through errors.

Links to other units

This unit links to:

- Unit 1: Engineering Principles
- Unit 7: Calculus to Solve Engineering Problems
- Unit 8: Further Engineering Mathematics
- Unit 25: Mechanical Behaviour of Metallic Materials.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and construction organisations with expertise in static mechanical systems
- contribution of ideas to unit assignment/project materials.

Unit 30: Mechanical Measurement and Inspection Technology

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore mechanical measurement equipment and inspection methods, including statistical process control (SPC). Also, learners undertake a process-capability study.

Unit introduction

Many of the products we use daily rely on components being manufactured accurately. The selection of a process to manufacture a product or component is sometimes chosen because of its speed or ability to shape materials, and they are always chosen because of the level of accuracy. Unfortunately, there will always be variation in these processes, and engineers must control the variation to avoid faulty products and/or components being manufactured.

In this unit, you will cover the principles and technology applied to a range of mechanical measurement equipment and inspection methods. You will develop the skills required to use a range of equipment, including comparators and gauges. You will develop and use statistical process control (SPC) charts to inspect components and determine if the process is in control. You will also undertake a process-capability study on a precision-manufacturing process to increase productivity and establish whether the process is capable.

As an engineer, you may need to understand and acquire the practical skills needed to control the manufacture of high-precision components. This unit prepares you for a mechanical or manufacturing engineering apprenticeship or for progression to higher education, and for technician-level roles in industry, such as a quality inspector or a junior production engineer involved in shop-floor machine management.

Learning aims

In this unit you will:

- A** Explore the principles applied to mechanical measurement and inspection methods as used in industry
- B** Carry out mechanical measurement and inspection methods to determine if components are fit for purpose
- C** Explore statistical process control to inspect components and increase productivity
- D** Carry out a process capability study to establish machine suitability for a given application.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Explore the principles applied to mechanical measurement and inspection methods as used in industry	A1 Limits and fits A2 Tolerances A3 Gauge types	<p>A report focusing on gauge design and the principles of tolerancing, including notes about limits and fits.</p> <p>The report to be based on research and to include the design of gauges to inspect four different product features.</p>
B Carry out mechanical measurement and inspection methods to determine if components are fit for purpose	B1 Measuring practice B2 Types of mechanical measurement B3 Comparators B4 Gauging system B5 Component features, types and manufacturing processes	<p>A range of practical measurement and inspection activities recorded in a developmental logbook.</p> <p>Evidence will be a measurement and inspection report, annotated drawings/photographs of the components and observation records/witness statements.</p>
C Explore statistical process control to inspect components and increase productivity	C1 Principles of statistics C2 SPC procedure	<p>A report covering the use of basic statistics and how these can be applied to control procedures during inspection.</p>
D Carry out a process capability study to establish machine suitability for a given application	D1 Pre-process capability study procedure D2 Process capability study	<p>A capability report focusing on the outputs from a particular process, reporting on its suitability.</p> <p>Both reports should include notes and sketches and will be supported by a developmental logbook.</p>

Content

Learning aim A: Explore the principles applied to mechanical measurement and inspection methods as used in industry

A1 Limits and fits

Principles applied to the use of limits and fits:

- concepts of limits and fits
- definitions of the types of fits – clearance, transition, interference
- use of tables, e.g. ISO 286–2:1988, ANSI B32.100–2005.

A2 Tolerances

Principles applied to the use of tolerances:

- standard symbols and interpretation, maximum material condition, least materials condition, maximum variation of form
- grades of tolerance applicable to hole tolerances and shaft tolerances
- reference to British Standards, e.g. BS 969, BS 1134, BS 2634, BS 4500 or other relevant international equivalents
- type of high-precision manufacturing processes, e.g. turning, milling, grinding, honing.

A3 Gauge types

Designing gauges for inspection activities as used in industry:

- limit gauge types, including plug, ring, gap and taper; gauge materials, including high carbon, alloy steel and cemented carbide
- Taylor's principle, principle of go/no-go gauging (limit gauges)
- slip gauges as references for length standards, classification of slip gauges, multiple slip gauge use (wringing), care and maintenance required
- component features including: hole diameter, shaft diameter, other external dimension/size, tapered hole.

Learning aim B: Carry out mechanical measurement and inspection methods to determine if components are fit for purpose

B1 Measuring practice

Principles applied to measuring practice:

- precision – how close measurements are to one another
- accuracy – how close measurements are to the 'true answer'
- uncertainty – the quantification of doubt about the measurement result, tells us something about its quality
- resolution – the smallest difference in dimensions that the measuring equipment can detect or distinguish.

B2 Types of mechanical measurement

- Linear measuring equipment:
 - equipment used for linear accuracy, e.g. verniers, callipers (digital), micrometers including external, internal and depth
 - principles, including scales, sources of error, specific calibration issues.
- Surface-texture measuring equipment:
 - equipment used for surface texture measurement, e.g. Rubert gauges, stylus measuring equipment
 - principles, including surface texture symbols, roughness average, waviness, finish, amplitude parameters, spacing parameters.

- Straightness, squareness and flatness measuring equipment:
 - equipment used for determining straightness, squareness and flatness, e.g. straight edges, engineer's square, autocollimator, carriage and reflector, optical square
 - principles, including wedge method, level method, line or surface datum, optical reflection, focal point.
- Angular measurement equipment:
 - equipment used for determining angular accuracy, e.g. sine bar, angle gauges, angle dekkor, vernier bevel protractor, clinometer
 - principles, including trigonometry functions, optical reflection, focal point.

B3 Comparators

- The application of comparators to inspect manufactured features.
- Types of comparators, including:
 - mechanical type, e.g. dial test indicator (DTI), Sigma, Johansson Mikrokator, Venwick
 - electrical type, e.g. digital, Wheatstone bridge circuit
 - optical type, e.g. Eden-Rolt millionth comparator
 - pneumatic type, e.g. Solex gauge.
- Principles, e.g. magnification, cosine errors, specific calibration issues.

B4 Gauging system

Gauges to inspect manufactured features:

- gauge types, including plug, ring, gap and taper
- principles involving the use of slip gauge as references for length standards, use with ancillary equipment, including DTIs, care and maintenance required, wringing.

B5 Component features, types and manufacturing processes

- Component features, including round (external or internal), linear (length, depth), texture, straightness, 90° angles and flatness.
- Types of component, including the jaw of a toolmaker's clamp, precision dowels, machine bed, vee block, vehicle engine block, piston.
- Typical manufacturing high-precision processes, e.g. grinding, milling, honing or high-volume turning.

Learning aim C: Explore statistical process control to inspect components and increase productivity

C1 Principles of statistics

Statistics used in inspection methods to increase productivity:

- Principles of statistics, including:
 - types of data concerned with precision manufacturing, e.g. variable or continuous, attribute or discrete
 - characteristics, including population, sample, sample size, frequency, mean, mode, median, range, variance, standard deviation
 - non-normal distribution curves, e.g. skewed, bimodal, flat topped
 - characteristics of a normal distribution including interpreting the change in shape, spread and position of the distribution over time.
- Graphical analysis, e.g. bar charts, histograms, stem and leaf diagrams, Pareto diagrams, box plots, run charts, time series charts.
- Variation in manufacturing processes, e.g. between components, within components, machine to machine, batch to batch, time to time.
- Causes of variation, e.g. tool breakage and wear, voltage fluctuations and machine wear.

C2 SPC procedure

SPC in inspection:

- developing SPC procedures involving pre-process control procedures, including product/process selection, identify critical characteristics, determine type of data, define the measurement system, design check sheet/chart, data-collection plan, test procedure
- design of control procedure; calculating sample size, frequency and upper and lower control limits, e.g. variable control charts such as X and R charts, attribute charts such as np, p, c and u
- use of control procedure, and mean and range charts, including plotting data, monitoring charts, interpreting charts and identifying of out-of-control conditions
- outcomes from use, e.g. modify process conditions when necessary, audit process.

Learning aim D: Carry out a process capability study to establish machine suitability for a given application**D1 Pre-process capability study procedure**

Procedures involved in designing a process-capability study:

- suitable process, e.g. grinding, milling, honing, turning
- developing specification limits and control chart limits
- use and consequence of relative precision index, e.g. high, medium, low
- equations, e.g. Cp, Cpk, sigma score (Z)
- modified control chart limits.

D2 Process-capability study

Process-capability study to establish machine suitability:

- graphical process-capability sheet
- determine process-capability and parts per million outside upper and lower specification limits
- analysis of information
- defining improvement activities to improve the process capability
- presenting findings in a process-capability report.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Explore the principles applied to mechanical measurement and inspection methods as used in industry		A.D1 Evaluate, using language that is technically correct and of a high standard, the design of limit gauges that are fit for purpose and rely on the principles of limits and fits, tolerances and the use of slip gauges as a reference to the standard.
A.P1 Apply the principles of limits and fits and tolerances to design a range of limit gauges.	A.M1 Analyse, including the use of slip gauges, how different limit gauges rely on the principles of limits and fits and tolerances.	
Learning aim B: Carry out mechanical measurement and inspection methods to determine if components are fit for purpose		B.D2 Evaluate the resolution and measurement of uncertainty for comparators and/or gauges against the mechanical measurement equipment used to inspect a range of components.
B.P2 Measure, using three different types of mechanical measurement equipment, a range of component features. B.P3 Select two different types of comparator and gauge, and inspect a range of component features.	B.M2 Measure accurately and precisely, using three different types of mechanical measurement equipment, a range of component features B.M3 Compare the capabilities and use of two different types of comparator against different types of gauges used to inspect a range of component features.	
Learning aim C: Explore statistical process control to inspect components and increase productivity		CD.D3 Evaluate how statistics have influenced the design and successful use of process control charts and a capability study to demonstrate where an improvement to the process can be achieved.
C.P4 Explain how the principles of statistics and graphical analysis are applied to represent and display variation found during inspection. C.P5 Design and use a SPC procedure involving variable control and attribute charts.	C.M4 Analyse, an in-control process using a SPC procedure involving variable control and attribute charts in relation to effectiveness of variation control and the outcomes from their use.	
Learning aim D: Carry out a process capability study to establish machine suitability for a given application		
D.P6 Design a process-capability study. D.P7 Perform a process-capability study to establish if a machine is capable of producing components to the required precision.	D.M5 Analyse as part of a process-capability study the accuracy of a process and produce a modified control chart, explaining its use.	

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.M3, B.D2)

Learning aims: C and D (C.P4, C.P5, D.P6, D.P7, C.M4, D.M5, CD.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of gauges (limit, slip), linear measuring equipment, surface-texture measuring equipment, straightness, squareness and flatness measuring equipment, angular measuring equipment, a range of different types of comparators as required by the learning aims and unit content
- components to be measured (such as those listed under key content area B5, 'Component features, types and manufacturing processes')
- a range of British or other relevant international standards, as required by the unit content
- a range of data from different precision processes to allow control charts and process capability to be established.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce evidence that is a balanced evaluation of the gauge and design principles used, with appropriate references to the standards applicable to the design and use of limit gauges. For example, it will make reference to the types of fit and maximum metal condition/least materials condition, and Taylor's principle showing how these have influenced the gauge tolerances found in the relevant standards. The evidence will include a reasoned conclusion about the fitness for purpose of the designed gauges, and the use of slip gauges as a reference to the standard.

Overall, the evidence will be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will be consistent in their analysis applied across all the requirements covering the correct use of slip gauges, and will explain clearly the reliance on the principles of limits and fits and. There will be a clear indication that the designed set of limit gauges are appropriate for the component specifications given and easy to use to inspect four different component features.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will give clear evidence that a set of limit gauges have been designed to inspect four different component features, although there may be some confusion between the use of tolerances. Learners may have applied their position across the gauge sizes incorrectly leading to some inaccuracies within the design of the gauges. For example, they may have used the wrong gauge tolerance and, when using slip gauges, the overall slip gauge size may be incorrect or more slip gauges were used than was necessary.

Overall, the explanations should be logically structured, although basic in parts and they may contain minor technical inaccuracies relating to engineering terminology, such as using the term 'block gauges' instead of 'slip gauges'. Also, the calculations may contain some minor arithmetic errors.

Learning aim B

For distinction standard, learners will produce evidence that includes a balanced evaluation of the resolution and measurement of uncertainty resulting from the measurement of components using comparators, gauges and mechanical measurement equipment. The evidence will contain a reasoned conclusion about the use of different types of inspection and measurement equipment. For example, it should include the correct use of scales during measurement and how sources of error are accommodated and why calibration is important.

Overall, the evidence on the practical activities should be logically structured, use the correct technical engineering terms and contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will select the correct measuring equipment and all measurements taken will be precise and accurate.

The comparison will be consistent across all the requirements of the correct selection and use of comparators and gauges. For example, they will refer to the principles involved for each comparator and gauge, such as the correct use of the focal point being similar when using an autocollimator or an angle dekkor. Also, reference will be made that surface texture measurement can be found by comparison to Rubert gauges or can be measured more accurately arriving at values for roughness and waviness. Learners will provide accurate and precise measurements and correct 'no' and 'no go' decisions throughout on at least three different engineering components.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will record in a logbook their results from using three different types of mechanical measurement equipment to measure at least three different features – for example, linear dimensions, surface texture, straightness, squareness, flatness or angular dimensions.

Learners may not have selected the correct equipment, but will have recorded the measurements taken.

Learners will correctly select two different types of comparator and appropriate gauges. They will record the measurements and 'no' and 'no go' decisions on at least three different components covering, across these components, at least one round, linear, texture and geometric feature.

Overall, the evidence will be logically structured. It may contain some inaccuracies in the use of engineering terminology and there may be some minor inaccuracies in the results. For example, learners may only record one measurement of each feature, and some of the gauge and comparator sizes and inspection decisions may not be accurate.

Learning aims C and D

For distinction standard, learners will have information that clearly demonstrates how statistics have influenced the design of the control charts and their use in the SPC evaluation. For example, how mean and range are used as known variation control, and how the sample sizes set produces statistically sound outcomes. It should be clearly shown how the application of these principles of statistics makes the control procedure effective through the:

- accurate and precise measurement of component features and that it is representative
- use of appropriate limits that do not unnecessarily restrict the process ('over or under control').

The capability report will also demonstrate how to improve the process. This improvement will be realistic, for example a lower material machine feed rate or higher workpiece-machining speed can lead to better accuracy.

Overall, the evidence will be logically structured, use the correct technical engineering terms and contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will draw conclusions about the process being monitored and use statistics to demonstrate that the process is under control. Learners will cover the effectiveness of the control method.

Learners will produce a modified control chart that will be fit for purpose and the capability report will clearly explain the use of the modified control chart.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain clearly how the principles of statistics and graphical analysis can be used to show variation in process outcomes and give confidence to monitor the variation of a process. Also, the design and use of the control charts should contain appropriate limits and the process trends should be correct, and the charts should be appropriate for a machine operator to use.

The capability report will contain evidence of how the data and the capability equations have been used to develop specification and control chart limits for the capability study to be carried out on a suitable process.

Learners will plot the data to explain the process and its capability, and the trends in the plotted data will be correct.

Overall, the evidence should be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology, such as confusion between control limits and component tolerances. Also, there may be some minor numerical errors, for example a control chart entry may have been incorrectly plotted. The evidence should be clear to a third party who is not an engineer.

Links to other units

This unit links to:

- Unit 4: Applied Commercial and Quality Principles in Engineering
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering and manufacturing organisations with expertise in mechanical measurement and inspection technology
- contribution of ideas to unit assignment/project materials.

Unit 35: Computer Programming

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will understand how computer programs are designed and structured. They will develop a computer program to solve an engineering-based problem.

Unit introduction

Computer programming, often referred to as software development in industry, is an integral part of most engineering organisations. The advancements in modern computing have driven the need for more complex and higher functioning software program solutions, automating and facilitating common procedures from inventory control to embedded devices in cars.

In this unit, you will learn how computer programming tasks are performed in engineering organisations, the roles of individuals in typical software projects and the methodologies that can be implemented to support the design and development phases of a project. You will also analyse and design a new software program to solve an engineering-based problem, producing design documentation, user stories and test scripts for a software program. You will develop the software program in a suitable computer programming language, testing and refining the solution throughout the process, and will review and reflect on the process once complete.

An understanding of how computer programs work is an essential task for engineers, and the problem-solving skills developed in software engineering are valuable and transferable across all types of engineering. This unit will help to prepare you for employment, for example as an information technology (IT) engineer or an IT operations technician, for an apprenticeship or for progression to higher education.

Learning aims

In this unit you will:

- A** Examine the project structures and methods used in the development of software programs
- B** Design a software program based on user requirements to solve a problem
- C** Develop a software program to solve a problem
- D** Review and reflect on own performance for the development of a software program.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the project structures and methods used in the development of software programs	A1 User requirements and typical project job roles A2 Software development methodologies A3 Development stages	A case study of the initial development plan of a software project to cover a typical software development life cycle, discussing the stages of development and the key roles of a development team. It will include a comparison of software development methodologies, identifying which areas may benefit from a project and where pitfalls may occur.
B Design a software program based on user requirements to solve a problem	B1 Design documentation and system design diagrams	Design documentation and diagrams of user requirements, user interface mock-ups, other structured tools such as flow charts, and test scripts. The implementation of the designed software program, using two programming paradigms and a wide range of constructs. The testing of the software program, using test scripts to demonstrate functionality and conformance to the brief.
C Develop a software program to solve a problem	C1 Programming standards and constructs C2 Development tools C3 Testing and reporting	
D Review and reflect on own performance for the development of a software program	D1 Lessons learned from developing a software program D2 Personal performance while developing a software program	The evidence will focus on what went well and what did not go so well when developing a software program, reviewing the processes and reflecting on own performance. A portfolio of evidence generated while developing a computer program and reviewing the processes and reflecting on own performance.

Content

Learning aim A: Examine the project structures and methods used in the development of software programs

A1 User requirements and typical project job roles

User requirements and typical project job roles in software development projects.

- User requirements, e.g. functions the software needs to perform, problems with a current system or process that need to be eased.
- Typical job roles in a software development team, including:
 - software developer – design and build computer programs to solve problems
 - testers – ensure functionality and uncover potential problem areas for the user
 - business analysts – provide a communication point of contact between the development team and project manager
 - project managers – ensure the smooth and effective running of a project's development and its resources (people, money and infrastructure)
 - product owners – stakeholders in a project, take responsibility for a project and promote it throughout the organisation.

A2 Software development methodologies

Software development methodologies commonly used to create computer programs, to include:

- waterfall model:
 - process stages – requirements, design, implementation, testing, deployment and maintenance
 - advantages and limitations, e.g. small rigid projects that have little or no outside influence and a linear approach to program development, which can be restrictive and inhibit creativity in a team
- rapid application development:
 - process stages to include requirements, user design, construction, and deployment
 - advantages and limitations, e.g. benefit is to allow customers to interact and feedback on a prototype and limitation is the capacity of the team to adapt to change under short timeframes
- agile:
 - scrum – flexible and iterative development methodology allowing a development team to work together to reach a goal during a set time 'sprint'
 - sprint planning – story points, velocity of a team and burn downs
 - epics – a large feature or function encompassing a set of user stories
 - user stories – functionality described from the perspective of the user
 - tasks – activities carried out by the developer during the implementation stage
 - methods of tracking – web-based tools and card-based boards
 - advantages and limitations, e.g. projects with unclear or unknown user requirements and the complexity of the project methodology.

A3 Development stages

- Quality assurance (QA) – identifying mistakes and potential problem areas in a software solution, raising of bugs (error or a fault within the software program).
- User acceptance testing – a facility to allow a user to test and accept the features provided in a software program.
- Operational test environment(s) – a facility allowing the testing of a pre-release version of software to test for operational readiness of a software program.
- Live deployment – wide release of a software product readily available to the user.

Learning aim B: Design a software program based on user requirements to solve a problem

B1 Design documentation and systems design diagrams

- Project time plan, e.g. Gantt chart, estimated effort and duration for tasks and critical path analysis to set priorities for different tasks.
- Terms of reference and specification documentation, to include:
 - specification and user requirements of the desired program
 - structured design tools – pseudo code, flow chart (to BS4058 or other relevant international equivalent) and decision tables
 - language to be used with the reasons for the choice – interfacing with existing programs, developer preference and skill set, customer limitations on infrastructure
 - target user platform, e.g. desktop, web, mobile, embedded.
- System requirements for development and end use, e.g. minimum and recommended specifications for processor, memory, hard disk space, networking capabilities.
- User interface mock-ups, e.g. screenshots, graphical images and user stories and tasks, including developer subtasks.
- Test scripts for expected and unexpected conditions for the software program in operation.

Learning aim C: Develop a software program to solve a problem

C1 Programming standards and constructs

- Standards, to include:
 - programming paradigms:
 - event driven – a program in which the flow is determined by events, e.g. mouse clicks, key presses, sensors
 - procedural – a program in which the flow is determined by a list of instructions
 - object-orientated – a program built up using objects that contain parameters, giving them unique features, and methods, giving them actions
 - language specific syntax, e.g. annotation, commands
 - advantages and disadvantages of graphical versus text-based user interfaces (TUI)
 - quality of the software program, to include:
 - usability – more intuitive, efficient and enjoyable to use by a human
 - reliability – reduced failures and errors and improved life of the software
 - maintainability – reduced cost of maintaining the software that allows developers to focus on new software projects.
- Constructs, to include:
 - sequence
 - variables – naming conventions, scope of variables, local and global
 - operators including: arithmetic [+ , - , * , / , MOD and DIV], relational logical [= , > , < , => , =< and <>], Boolean [true and false] and logical [AND, OR, NOT, XOR]
 - conditional logic:
 - if statements
 - switch - case
 - iteration:
 - while, do-while
 - for, for each
 - algorithms – sections of code to perform a structured action, to include:
 - complexity – describing the execution time or space used to perform an action
 - reusability – modularised approach to development where common methods and parameters can be reused
 - methods and functions, to include:
 - return types – values to return from functions to the caller statement
 - parameters – passing data and logic into methods to affect the outcome
 - recursion – methods that call themselves with different or modified data

- objects and classes
- multithreading, to include:
 - main thread – the main operating process of the program, controls the flow of the program from start to finish
 - background thread – dynamic, fabricated threads allowing processing to occur ‘off’ the main thread without affecting the user experience, e.g. connecting to a database or a web service, or processing a large amount of data
 - benefits and limitations, e.g. beneficial – responsiveness is increased and effective use of multiple processor cores, limited – ‘misbehaving’ threads that can crash computer processes.

C2 Development tools

- Integrated development environments – source code editor, build tools and debugger.
- Software development kits – a set of tools and software allowing development on a specific system.
- Application programming interfaces – a set of interfaces that allow a developer to use other software without access to source code or original development tools.
- Debuggers – a process to allow a developer to interact and manipulate source code during the execution of the program.
- Source control, to include:
 - branching and merging – division of source code to allow multiple versions of code
 - latest version
 - resolution of conflicts – comparison and resolution of differences in code of the same file or class.

C3 Testing and reporting

Types of testing, to include:

- functionality and usability testing:
 - against user stories
 - against test scripts (under expected and unexpected conditions)
- regression testing and reporting:
 - summary of testing – including pass/fail/skipped details
 - steps to reproduce
 - actual, expected and unexpected scenarios.

Learning aim D: Review and reflect on own performance for the development of a software program

D1 Lessons learned from developing a software program

Scope of the lessons learned should cover:

- computer programming skills, e.g. proper use of constructs and syntax, use of procedures and functions, choice of data types and operations within a process
- general engineering skills, e.g. mathematics and logical thinking.

D2 Personal performance while developing a software program

Understand relevant behaviours for measuring and testing electronic circuits, to include:

- time planning and management to complete all the different activities in an appropriate time and order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving as problems occur, e.g. investigating the source of the problem, breaking it down into manageable chunks and areas for development, solving the problem.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the project structures and methods used in the development of software programs		A.D1 Evaluate, using language that is technically correct and of a high standard, the methodologies and job roles used in two different software development projects, explaining the purpose and importance of user requirements.
A.P1 Explain the methodologies and typical job roles used in two different software development projects and the purpose and importance of user requirements.	A.M1 Compare the methodologies and job roles used in two different software development projects, explaining the purpose and importance of user requirements.	
Learning aim B: Design a software program based on user requirements to solve a problem		BC.D2 Optimise a functional, useable, fully-annotated and efficient software program that operates as intended, with some consideration for unexpected events and using a comprehensive set of design documents, including a project plan and test scripts.
B.P2 Explain the user requirements for a new software program.	B.M2 Analyse the user requirements, identifying areas where potential pitfalls could occur.	
B.P3 Design a new software program with a user interface to meet a client brief, including an outline project plan and test scripts.	B.M3 Design a new software program with an effective user interface to meet a client brief, including a project plan and test scripts.	
Learning aim C: Develop a software program to solve a problem		
C.P4 Build a software program, using the designs and multiple programming paradigms to solve a problem.	C.M4 Build a software program with an effective user interface, using the designs and multiple programming paradigms to solve a problem.	
C.P5 Perform tests on the software program against the user requirements, repairing functional faults.	C.M5 Perform regression tests on the software program, repairing any functional and usability faults.	
Learning aim D: Review and reflect on own performance for the development of a software program		D.D3 Demonstrate consistently good technical understanding and analysis of software development, including the application of relevant behaviours and general engineering skills to a professional standard script.
D.P6 Explain how health and safety, computer programming, and general engineering skills were effectively applied when developing a software program.	D.M6 Recommend improvements to the development of a software program and to the relevant behaviours applied.	
D.P7 Explain how relevant behaviours were effectively applied during the development of a software program.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, B.M3, C.M4, C.M5, BC.D2)

Learning aim: D (D.P6, D.P7, D.M6, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- case study materials on software development projects
- modern, industrial programming, preferably a multi-paradigm language, for example .NET Framework languages (C#, Visual Basic), Pascal or Java
- task planning software (useful but not essential)
- commercial software tools, including free software such as PivotalTracker™
- relevant standards, as listed in the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and appropriately detailed evaluation of the methodologies and job roles relevant to two contrasting software development projects. Learners will describe the characteristics of each methodology, identifying the areas that might benefit a project and individuals in the team, for example a project following the waterfall methodology may be inefficient as a change in user requirements during the development of the software program may result in the development being stopped and restarted. However, the same project following the agile scrum methodology would be able to adapt and change to meet the change in user requirements, making the approach more efficient and flexible.

Overall, learners' evidence, such as a case study, will be easy to read and understand by a third party who may be an apprentice software engineer. It will be logically structured and use technical engineering terms, with a high standard of written language, i.e. consistent use of correct grammar and spelling, and consistent reference to information sources.

For merit standard, learners will compare the methodologies and job roles relevant to at least two different software development projects, explaining the purpose and importance of user requirements in all stages of a project. For example, learners will justify the choice of a methodology for a project with respect to its flexibility due to changing user requirements.

Overall, learners' evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the purpose and importance of user requirements in the stages of a software development project. They will also explain the typical job roles required, outlining the actions and responsibilities they have, for example a project manager following the waterfall methodology would have a duty to ensure developers were meeting their deadlines during the development stage.

Overall, learners' evidence will be logically structured although it may be basic in parts.

Their explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology, for example a developer should not receive user requirements directly from a customer.

Learning aims B and C

For distinction standard, learners will develop a fully functional software program that has been tested for usability, functionality and against user requirements.

Learners will design the new software program with an effective user interface, ensuring the client brief is adhered to. Their project plan will cover all the main activities and the vast majority of time estimates will be reasonable. Their program design will break down key operations into relevant constructs that link logically and coherently together, including the handling of some unexpected events, and their test scripts will confirm a fully functioning software program under expected and some unexpected conditions.

Learners will build an efficient software program, using their designs, and incorporate multiple programming paradigms to produce a functional program with an effective user interface. Their

software program will contain a range of appropriately selected constructs that have been used correctly. Also, the program will be concise, efficient and have the facility to handle some unexpected events, for example the program might use a known sorting algorithm to organise data in an efficient way. Annotation will be consistent and appropriate and will demonstrate a thorough understanding of the key areas of the program and the underpinning constructs. Learners' programs will be well organised, structured and formatted so that a competent third party could efficiently interpret and update them.

Learners will provide a fully detailed regression test, using the test scripts on their software program and producing documentation of the results of the testing process, including testing of some unexpected events. Any functional or usability faults that occur from the testing will be repaired and full testing will be repeated until no new faults arise. A fully supported judgement of conformity will be made by linking test results to the client brief.

Overall, the evidence will be easy to read and understand by a third party who may be a professional software engineer. It will be logically structured and use accurate technical engineering terms appropriately.

For merit standard, learners will analyse the user requirements to identify where potential pitfalls could occur during the design and development stages, for example the user may require data from a source that is not accessible or affordable within the organisation, such as address searches or mapping.

Learners will design the new software with an effective user interface, for example one that is intuitive and efficient to use, ensuring the client brief is adhered to. Their project plan will cover all the main activities and most of the time estimates will be reasonable. Their program design will break down key operations into relevant constructs that link together and their test scripts will confirm a fully functioning software program under expected conditions.

Learners will build a software program, using their designs, and incorporate multiple programming paradigms to produce a functional program with an effective user interface, for example learners could use an object-orientated language such as C#.NET or VB.NET that encompasses event driven and procedural paradigms. Their software program will contain a range of appropriately selected constructs that have been used correctly. Annotation will be present and appropriate and demonstrates understanding of key areas of the program and underpinning constructs. Learners' programs will be well organised and formatted so that a competent third party could interpret and update the program.

Learners will perform a regression test, using the test scripts, on their software program, repairing any functional and usability faults as they arise. A judgement of conformity will be supported by the test results, but they may not all be linked back to the client brief.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will design a new software solution to meet a client brief and prepare an outline project plan. Their design will cover the user interface and use structured tools, for example flow charts, and explain the user requirements. Their program design will break down key operations that link together and their outline test scripts will indicate a limited understanding of the intended software program. If centres are using the agile methodology, then user stories and developer tasks must be included.

Learners will build their software program using their designs and user requirements. Their program will use two programming paradigms and it will contain a range of more basic constructs, which are generally appropriate and have been used correctly. The program may be inefficient, for example by not using 'functions' appropriately, using long algorithms when shorter versions are possible and adding in unnecessary functionality. Annotation will be present but focused on one area of the program and will demonstrate an incomplete understanding of the key areas of the program. Their program structure may have inconsistencies in organisation and/or formatting.

Learners will perform simple tests against the user requirements, using test scripts and repairing any functional faults as they occur. If present, a judgement of conformity is not supported by test results and will not be linked back to the client brief.

Overall, learners' evidence will be logically structured although it may be basic in parts. Their explanation may be limited in places and may contain minor technical inaccuracies relating to engineering terminology, for example tests may not contain steps to reproduce the expected results and the outline project plan may miss out some important tasks.

Learning aim D

For distinction standard, learners will demonstrate relevant behaviours and general engineering skills to a professional standard throughout the activity in assignment 2, for example all assignments will be completed on time and the practical activities will be planned out in advance, with any problems encountered solved.

For lessons learned evidence (for example a report), learners will present a good technical understanding of the software program.

Overall, learners' evidence will include a balanced view about actions taken and the software development process, including health and safety compliance and possible improvements. They will use technical engineering terms correctly and consistently and the evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will provide evidence, such as a lessons learned report, that gives examples of where improvements could be made to the:

- development of the software program, which could cover the program writing methods and include the choice and use of constructs, as well as testing
- application of relevant behaviours, for example regular progress reviews and time management.

Overall, the suggested improvements will be reasonable and practical, explanations will be professional and engineering terminology used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will provide evidence such as a lessons learned report of around 500 words in length. The report will explain:

- which computer programming skills were applied, such as the program constructs, instructions and debugging methods required to develop the program
- how general engineering skills were used, such as numeracy skills and logical thinking
- how behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time, as well as problem solving.

Overall, learners' evidence will be well structured and there will be some use of appropriate technical language, although there may be some inaccuracies with terms used. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 32: Computer System Principles and Practice
- Unit 33: Computer Systems Security
- Unit 36: Programmable Logic Controllers
- Unit 38: Website Production to Control Devices.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local computing organisations and engineering organisations with expertise in computer programming
- contribution of ideas to unit assignment/project materials.

Unit 36: Programmable Logic Controllers

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will apply skills and understanding to develop an industrial Programmable Logic Controller (PLC) system to solve an engineering problem.

Unit introduction

Industrial processes have become increasingly automated. PLCs are widely used to provide the control element in industrial drives. These are systems that include motors, motor control, sequencing and communications functions to optimise the operation of the motor and also the machine or process that it operates, either autonomously or as part of a larger factory automation system.

In this unit, you will understand the use and applications of PLCs, the hardware and software that makes up an industrial PLC control system, and the interaction needed between the component parts. You will gain knowledge of the range of PLCs available and how to select an appropriate one, along with the associated hardware for a given application. You will develop knowledge and practical skills essential to configure and program a PLC and investigate instruction types through writing short programs. You will also gain knowledge and skills in fault-finding and debugging methods. You will demonstrate your knowledge and skills by developing an industrial control PLC system to solve an engineering problem.

Many industries require engineering technicians and engineers with knowledge and skills in automation control. This unit will help you to prepare for employment, for example as a multi-skilled engineering technician, as part of an apprenticeship, or for entry to higher education to study manufacturing engineering.

Learning aims

In this unit you will:

- A** Investigate the technology used in industrial Programmable Logic Controller systems
- B** Explore programming structures and methods to control Programmable Logic Controllers
- C** Develop an industrial Programmable Logic Controller system to solve an engineering problem
- D** Review the development of an industrial control system and reflect on own performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the technology used in industrial Programmable Logic Controller systems	A1 Features and functions of PLCs A2 PLC system hardware A3 Internal operation of Programmable Logic Controllers	A report comparing two contrasting industrial PLC control systems.
B Explore programming structures and methods to control Programmable Logic Controllers	B1 Integrated development environment (IDE) B2 Programming skills for PLCs B3 Test and debug PLC programs	Collated reports and programs demonstrating the use of PLC instructions in increasingly complex situations.
C Develop an industrial Programmable Logic Controller system to solve an engineering problem	C1 Problem definition and identification of hardware requirements C2 Physical system design and assembly C3 Software design tools C4 Program development C5 Testing a PLC system	A portfolio of evidence covering the design and development of a PLC system to solve an engineering problem. This should be accompanied by one or more observational witness statements, photographic evidence, and formal testing of the final system.
D Review the development of an industrial control system and reflect on own performance	D1 Lessons learned from developing an industrial PLC system D2 Personal performance while developing an industrial PLC system	The reflective evidence will focus on what went well and what did not go so well when developing an industrial PLC control system, reflecting on own performance and possible improvements.

Content

Learning aim A: Investigate the technology used in industrial Programmable Logic Controller systems

A1 Features and functions of Programmable Logic Controllers

PLC system requirements, including:

- power supply unit (PSU)
- central processor unit (CPU)
- at least one input/output unit.

Features and functions of PLC architecture, to include:

- CPU block diagram of components and a corresponding description, including:
 - input/output (I/O) interface between the microelectronics of the programmable controller and the real external world, providing all necessary signal conditioning and isolation functions
 - memory, to include:
 - operating system or executive memory – read-only memory (ROM)
 - memory used by the operating system – random-access memory (RAM)
 - I/O status memory mapped to inputs and outputs, giving every input and output module point a unique address (RAM)
 - data memory allocated to timers, counters (RAM)
 - user memory to store, e.g. programs, messages
 - types of memory – RAM, erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), flash
- Types of programmable logic controller, including:
 - unitary (compact), PSU, CPU, memory, (limited) input and output in a single unit
 - modular, to include:
 - small, with PSU, CPU and one or two input and output (I/O) units slotted together or on a backplane
 - medium-sized, with PSU, CPU and several modules (usually) slotted on a backplane
 - large, with PSU, CPU and several modules including more complex functions, such as communications, distributed control, supervisory control and data acquisition (SCADA)
- Choosing a suitable PLC for a given task, to include:
 - number and types of I/O
 - input/output capacity
 - size of memory
 - CPU and instruction set speed and power
 - technical support and backup
 - cost
 - complexity of the problem, e.g. involving communications and distributed control.

A2 Programmable Logic Controller system hardware

- Interfaces including:
 - input interfaces, e.g. direct current (DC) and alternating current (AC) voltage digital input circuits, pulse counters, analogue to digital converters (ADC)
 - output interfaces, e.g. relay, transistor, triac output circuit, digital to analogue converters (DAC).
- Peripheral input devices, to include:
 - digital, e.g. mechanical switches, proximity sensors
 - analogue, e.g. input transducers, including temperature, pressure, flow.

- Peripheral output devices, to include:
 - digital – indicators, electromechanical (e.g. relays and contactors), electro-pneumatic (e.g. control valves)
 - analogue, e.g. motor position and speed.

A3 Internal operation of Programmable Logic Controllers

PLC scan operation, including:

- input scan
- program scan
- output scan.

Learning aim B: Explore programming structures and methods to control Programmable Logic Controllers

B1 Integrated development environment (IDE)

- Overview of the functions of a PLC integrated development environment, including source code editor, build tools and debugger.

B2 Programming skills for Programmable Logic Controllers

- Overview of PLC programming methods, to include:
 - ladder diagrams
 - statement listing
 - functional diagrams
 - graphical programming languages
 - mimic diagrams
 - sequential function charts (SFCs).
- Use and interpretation of number systems, including numeric data types and number conversion between denary, binary, hexadecimal and binary coded decimal (BCD).
- Programming instructions using an appropriate programming method (e.g. ladder logic), to include control of outputs using:
 - input, output and internal value addressing
 - combinational logic where the output is dependent on the combination of inputs at a given instant, e.g. the Boolean expression:

$$Y_2 = (X_1 \cdot Y_1) + X_2$$
 - sequential logic where the output is dependent not only on the actual inputs but on the sequence of the previous inputs and outputs, e.g. extending a pneumatic cylinder on the press of a button until it reaches a limit switch then returning to the original position
 - timers and counters, e.g. extending a pneumatic cylinder on the press of a button until it reaches a limit switch, waiting five seconds then returning to the original position
 - motion step diagrams (MSD) (sometimes called step-action or traverse-time diagrams) to describe the position of sensors and actuators in a sequence.
- Efficiency of a PLC program is programming in a manner that uses a low amount of overall resources when the program is executed. It is influenced by a number of factors, including:
 - the code structure, e.g. use of subroutines or procedures
 - commands selected and combined to create the program, e.g. some instructions use more memory or take more time to complete.

B3 Test and debug Programmable Logic Controller Programs

- Testing, including:
 - unit testing where parts of the program are treated as black box to determine if an expected output is achieved from a known input
 - program simulation and/or onscreen monitoring
 - dry run the program.
- Debugging including syntax errors, logical errors and error correction.

Learning aim C: Develop an industrial Programmable Logic Controller system to solve an engineering problem

C1 Problem definition and identification of hardware requirements

- Analysis of a client brief to select appropriate hardware, including type of PLC and input and output devices.

C2 Physical system design and assembly

- Physical system design, to include:
 - description of the system block diagram
 - wiring diagram including external devices, such as relays or limit switches, that are independent of the PLC system to provide protection for any part of the system that may cause personal injury or damage.
- Assembling the physical PLC system, including:
 - regard to safe operating procedures
 - electrical connections:
 - separation of wiring regions, primary side (power input), secondary or logic side (PLC and input/output interfaces), field side (inputs and outputs)
 - input/output connections (and common connections)
 - cable identification/markers
 - other connections, e.g. pneumatic, hydraulic.

C3 Software design tools

Structured design tools, including:

- develop a list of steps using structured English or a flow chart (using standard symbols) that describe a possible solution to the problem
- identify repeating patterns
- develop a set of instructions to solve the problem using sequence, selection and iteration constructs
- test plan to include expected results and exceptional values.

C4 Program development

- Program structures, to include:
 - sequence of instructions to be carried out
 - selection (if ... then)
 - iteration, e.g. use of a counter or timer.
- Operators, including:
 - arithmetic, e.g. add (ADD), subtract (SUB), negate (NEG), divide (DIV), multiply (MUL), modulus (MOD)
 - comparator, e.g. equal (EQ), less than (LT), greater than (GT)
 - Boolean, e.g. logic functions AND, OR, NOT, XOR give output True or False.
- Subroutines to complete frequently used and repeated instructions.
- Annotated PLC program.
- Results of testing and debugging.
- Operating instructions.

C5 Testing a Programmable Logical Controller system

- Testing and fault finding a PLC system, including checking that:
 - all connections (electrical, pneumatic, and hydraulic) to the PLC and the plant are complete, safe, to the required specification and meeting local standards
 - the incoming power supply matches the voltage setting for which the PLC is set
 - all protective devices are set to their appropriate trip settings
 - all input/output devices are connected to the correct input/output points and give the correct signals
 - the emergency stop button(s) work/s
 - the corresponding indicators on the input module operate when input devices are manipulated to give the open and closed contact conditions.
- Loading and testing the software for function and to debug, using IDE tools and other appropriate techniques.

Learning aim D: Review the development of an industrial control system and reflect on own performance**D1 Lessons learned from developing an industrial Programmable Logical Controller system**

Scope of the lessons learned should cover:

- health and safety skills, including managing electrical hazards, e.g. electric shock and emergency actions, using appropriate personal protective equipment and keeping the work area clean and tidy
- PLC control system skills, including selecting and assembling hardware for an industrial control system and writing computer programs
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while developing an industrial Programmable Logical Controller system

Understand relevant behaviours for developing an industrial PLC control system, including:

- time planning and management to complete all the different activities in an appropriate time and in an appropriate order
- communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
- problem solving issues as they occur, e.g. logical and syntax program errors and hardware assembly faults.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the technology used in industrial Programmable Logic Controller systems		A.D1 Evaluate, using language that is technically correct and of a high standard, the suitability of the technology found in two contrasting industrial PLC systems, suggesting possible improvements.
A.P1 Explain the features and functions of the technology found in two contrasting industrial PLC systems.	A.M1 Analyse the suitability of the technology found in two contrasting industrial PLC systems.	
Learning aim B: Explore programming structures and methods to control Programmable Logic Controllers		B.D2 Critically analyse, using example programs, how PLC instructions including timers and counters are used to efficiently control system outputs.
B.P2 Explain, using example programs, how PLC instructions including timers and counters are used to control system outputs.	B.M2 Discuss accurately, using example programs, how PLC instructions including timers and counters are used to control system outputs.	
Learning aim C: Develop an industrial Programmable Logic Controller system to solve an engineering problem		CD.D3 Optimise a functional, fully-annotated and efficient PLC system safely that operates as intended, whilst recommending improvements and applying relevant behaviours and general engineering skills to a professional standard.
C.P3 Design a PLC system to solve an engineering problem.	C.M3 Develop a functional, annotated PLC system safely that operates as intended.	
C.P4 Build and test a functional PLC system safely to solve an engineering problem.		
Learning aim D: Review the development of an industrial control system and reflect on own performance		
D.P5 Explain how health and safety, PLC system and general engineering skills were effectively applied during the development of a system.	D.M4 Recommend improvements to the development of an industrial PLC system and to the relevant behaviours applied.	
D.P6 Explain how relevant behaviours were effectively applied during the development of an industrial PLC system.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.M2, B.D2)

Learning aims: C and D (C.P3, C.P4, D.P5, D.P6, C.M3, D.M4, CD.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- a range of PLCs and input/output devices
- process rigs
- an integrated design environment to permit programming and implementation of device/applications for circuit performance and debugging
- a range of relevant manuals, reference data and manufacturers' information.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will evaluate two contrasting industrial PLC systems. The evaluation will be detailed, comprehensive and will demonstrate how the systems work and why the technology (hardware components) is suitable for the application. Learners will determine the number of inputs and outputs required and identify specific devices and hardware used in the systems. For example, a PLC system to control a single bidirectional pneumatic cylinder need only be a unitary PLC, with a limited number of inputs and outputs for start/stop buttons, limit switches such as reed switches or rocker switches, and an electro-pneumatic control valve. Learners will also identify potential improvements to the existing systems, for example actuators that are more energy efficient.

Overall, the evidence, such as a report, will be easy to read and understand by a third party who may be an apprentice engineer. It will be logically structured and use correct technical engineering terms with a high standard of written language, i.e. consistent use of correct grammar and spelling, and consistent referencing of information sources.

For merit standard, learners will analyse two contrasting industrial PLC systems with respect to the suitability of the features, the functions of the hardware components and the complexity of each system. For example, learners will justify the selection of PLC type and input/output devices with reference to the system requirements and the devices' technical specifications.

Overall, the evidence will be logically structured, technically accurate and easy to understand.

For pass standard, learners will explain the features and functions of the hardware components found in two contrasting PLC industrial systems. For example, they will determine the generic type of PLC used and other hardware, including switches and motors. Their explanations may lack detail and/or contain omissions, for example they may describe an input as a switch, but not specify whether it is normally open (n.o.) or normally closed (n.c.).

Overall, the evidence will be logically structured although it may be basic in parts. Their explanation may be limited in places and contain minor technical inaccuracies relating to engineering terminology, for example the function of a reed switch may not indicate that it is magnetically operated.

Learning aim B

For distinction standard, learners will critically analyse the operation of PLC instructions, using example programs to demonstrate how each instruction operates, and how data is used. For example, they will explain how a timer can be pre-loaded with a value and decremented on each pass until it reaches zero. They will collate detailed evidence of progressively more complex programs, detailing the purpose. Annotation will be consistent and appropriate and demonstrate a thorough understanding of how key areas of the program work. Learners will include test results showing the program in operation. Learners will debug the code so that it is functional and they will also provide evidence of how they have improved the efficiency of the more complex programs, for example using subroutines for recurring functions.

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 analyse how PLC instructions can be combined to control system outputs. They will demonstrate how counters and timers can be used, but may not explain in detail how a counter or timer can be incremented or decremented to reach zero or a pre-determined value. They will collate detailed evidence of progressively more complex programs, detailing their purpose. Annotation will be present and appropriate and demonstrate how key areas of the program work, and test results showing the program in operation will be given. Learners will debug the code so that it is functional and may provide limited examples of how the more complex programs were made more efficient.

Overall, the evidence will be a well-organised record of the practical work carried out. It will be technically accurate and easy to understand.

For pass standard, learners will explain, using example programs, how PLC instructions, including counters and timers, can be combined to control outputs in industrial systems. They will collate detailed evidence of progressively more complex programs, detailing their purpose. Annotation will be present but it may be focused on a couple of areas of the program and it may demonstrate an incomplete understanding of how key areas of the program work or it may state the obvious, and test results showing the program in operation will be given. Learners will debug the code so that it is functional. The more complex programs may also be inefficient, for example repeating instructions in one long sequence rather than using subroutines.

Overall, the evidence will be an organised record of the practical work carried out. It will be easy to follow, but the descriptions may be basic and the use of technical language may be inconsistent. For example, the difference between normally open (n.o.) and normally closed (n.c.) contacts may not be explained.

Learning aims C and D

For distinction standard, learners will provide an in-depth analysis of an engineering problem and details of the final design solution in terms of the hardware and software. The hardware details will include specific identification of the hardware selected, block diagrams of the schematic and an annotated wiring diagram. The PLC program will be designed using structured tool(s) that break down key operations into relevant constructs that link logically and coherently together, and consideration will be given to the efficiency of the program and operation.

Learners will assemble the system safely and write the program based on their design. The PLC program will comprise a range of appropriate constructs that have been used correctly and the program will be concise and efficient. Annotation will be consistent and appropriate and demonstrate thorough understanding of the key areas of the program and underpinning constructs. The test results will demonstrate how learners' test plan has been used to verify that the system functions as intended and will provide some evidence of optimisation.

Throughout the activity, learners will demonstrate relevant behaviours and general engineering skills to a professional standard. For example, all assignments will be completed on time and the practical activities will be planned out in advance and the finished PLC system will fully function as intended by the client brief, hence demonstrating commercial awareness.

The lessons learned evidence, for example a report, will present a good technical understanding of PLC system development. Overall, the evidence will include a balanced view of the actions taken and of the PLC system's development, including health and safety compliance. Technical engineering terms will have been used correctly and consistently. The evidence will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will provide an analysis of an engineering problem with a final design solution of a PLC system covering the hardware and software. The hardware details will include identification of the hardware selected, block diagram (schematic) and connections used. The PLC program will be designed using structured tool(s) that break down key operations into relevant constructs that link together.

Learners will assemble the system safely and write the program based on their design. The PLC program will comprise a range of appropriately selected constructs that have been used correctly and will be annotated appropriately, demonstrating how key areas of the program work. The test results will demonstrate that the system functions as intended.

The evidence, such as a lessons learned report, will give examples of where improvements could be made to the:

- development of a system, which could cover the choice and use of hardware, program writing methods including the choice and use of constructs, theoretical calculations and testing
- application of relevant behaviours, for example regular progress reviews and time management.

Overall, the suggested improvements should be reasonable and practical, explanations will be professional and engineering terminology used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will provide a design solution covering the hardware and software for a PLC system to solve an engineering problem. The hardware details will include identification of the hardware selected and block diagram schematic, but it may lack detail, for example which devices are connected to which input/output terminals. The PLC program will be designed using structured tool(s) that break down key operations that link together.

Learners will assemble the system safely and write the program based on their design. The program will comprise a range of basic constructs, which are generally appropriate and have been used correctly. Annotation will be present but it may be focused on a couple of areas of the program and it may state the obvious, or demonstrate an incomplete understanding of how key areas of the program work. For example, annotation could say, 'this is a timer'. Learner evidence will demonstrate how the system has been tested, but it may not be evident from the results that the system fully functions as intended.

Learners' evidence will include a lessons learned report, of around 500 words in length. The report will explain what:

- actions were taken to manage health and safety in the workplace, for example whether any unforeseen issues occurred
- PLC electronic engineering skills, such as identifying components, using schematic diagrams and wiring circuits correctly
- program development skills, such as using program constructs, instructions and debugging methods required to develop an industrial control system
- how general engineering skills were used, such as the use of IT and numeracy skills
- how behaviours were used, such as time management and planning to ensure the activity was completed within the appropriate time.

Overall, the evidence will be well structured, and there will be some use of appropriate technical language, although there may be some inaccuracies with terms used. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 6: Microcontroller Systems for Engineers
- Unit 19: Electronic Devices and Circuits
- Unit 33: Computer Systems Security
- Unit 35: Computer Programming.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local organisations with expertise in Programmable Logic Controllers
- contribution of ideas to unit assignment/project materials.

Unit 41: Manufacturing Secondary Machining Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore and carry out secondary machining processes to manufacture shapes by the safe removal of material.

Unit introduction

Many of the products and components we use daily rely on secondary machining processes. These processes are sometimes easy to spot in manufactured components or products, such as a machine bearing or the nut holding a brake shoe in place on a bicycle.

In this unit, you will cover the technology used in, and characteristics of, a range of traditional machining processes such as turning, and specialist machining processes such as broaching. You will develop knowledge of the health and safety requirements for working on secondary machining processes, and gain practical skills and understanding to be able to set up and operate traditional secondary machining processes to manufacture a component. Finally, you will reflect on the skills and understanding of secondary machining processes that you have acquired and the behaviours applied while manufacturing a component.

As an engineer, you need to understand machining processes and have practical skills in using a range of machines. This knowledge and the practical skills gained from the unit will enable you to create feasible solutions to engineering problems. This unit prepares you for a mechanical or manufacturing engineering apprenticeship, for progression to higher education, and for employment in technician-level roles, for example as a machine setter and setter operator.

Learning aims

In this unit you will:

- A** Examine the technology and characteristics of secondary machining processes that are widely used in industry
- B** Set up traditional secondary processing machines to manufacture a component safely
- C** Carry out traditional secondary machining processes to manufacture a component safely
- D** Review the processes used to machine a component and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and characteristics of secondary machining processes that are widely used in industry	A1 Traditional secondary machining processes A2 Specialist secondary machining processes A3 Sustainability characteristics of secondary machining processes	A report focusing on three different traditional processes and an analysis of research case studies on three different specialist processes.
B Set up traditional secondary processing machines to manufacture a component safely	B1 Health and safety requirements when setting up secondary process machines B2 Risk assessment B3 Setting up secondary process machines	<p>A practical activity involving a risk assessment and the setting up of at least two traditional machining processes and the machining of a component.</p> <p>Evidence will include: a developmental logbook, risk assessment, observation records/witness statements, the finished component, annotated photographs and drawings, set up planning notes, and complete quality control documents.</p>
C Carry out traditional secondary machining processes to manufacture a component safely	C1 Features of traditional secondary machining processes C2 Parameters of traditional secondary machining processes C3 Quality control methods	<p>The evidence will focus on what went well and what did not go so well when machining a component, and a conclusion of improvements that could be made.</p> <p>The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.</p>
D Review the processes used to machine a component and reflect on personal performance	D1 Lessons learned from machining a component D2 Personal performance while machining a component	<p>The evidence will focus on what went well and what did not go so well when machining a component, and a conclusion of improvements that could be made.</p> <p>The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.</p>

Content

Learning aim A: Examine the technology and characteristics of secondary machining processes that are widely used in industry

A1 Traditional secondary machining processes

Technology and characteristics of secondary machining processes.

- Drilling:
 - machine type and batch size, including single spindle machines, e.g. pillar (one-off to small batch sizes) and radial (small to medium batch sizes)
 - features of the component, e.g. countersinking, counterboring, spot facing, tapping, holes (including through, blind and reamed holes)
 - accuracy of components – typical dimensional tolerances = ± 0.3 mm to ± 0.05 mm and typical surface texture = 6.3 μm to 1.6 μm .
- Turning:
 - machine type and batch size, including centre lathe (one-off to small batch size) and turret (small to large batch size)
 - features of the component, e.g. flat faces, diameters (including parallel, stepped and tapered diameters), holes (including drilled, bored and reamed holes), profile forms, threads, parting off, chamfers, knurls, undercuts
 - accuracy of components – typical dimensional tolerances = ± 0.05 mm to ± 0.0125 mm and typical surface texture = 3.2 μm to 0.8 μm .
- Milling:
 - machine type and batch size, including horizontal (one-off to small batch size), vertical (one-off to small batch size), universal (one-off to small batch size)
 - features of the component, e.g. faces, steps/shoulders, slots, holes, and profile forms
 - accuracy of components – typical dimensional tolerances = ± 0.1 mm to ± 0.025 mm and typical surface texture = 3.2 μm to 0.8 μm .
- Grinding:
 - machine type and batch size, including surface (one-off to small batch size), cylindrical (one-off to small batch size), centreless (medium to large batch size), universal (one-off to small batch size)
 - features of the component, e.g. faces, slots, diameters and bores
 - accuracy of components – typical dimensional tolerances = ± 0.0125 mm to ± 0.002 mm and typical surface texture = 0.8 μm to 0.2 μm .

A2 Specialist secondary machining processes

Technology and characteristics of specialist machining processes.

- Presswork:
 - machine type and batch size, including single action (small to medium batch size), multiple action (medium batch to mass manufacturing)
 - features of the component, e.g. blanking, notching, piercing, cropping/shearing, bending/forming
 - accuracy of components – typical dimensional tolerances = ± 0.3 mm to ± 0.05 mm.
- Electro discharge:
 - machine type and batch size, including spark erosion (small to large batch size), wire erosion (small to large batch size)
 - features of the component, e.g. holes, faces, forms and other features (including engraving, cavities, radii/arcs, slots)
 - accuracy of components – typical dimensional tolerances = ± 0.1 mm to ± 0.05 mm and typical surface texture = 6.3 μm to 0.4 μm .

- Broaching:
 - machine type and batch size, including horizontal (one-off to medium batch size), vertical (one-off to medium batch size)
 - features of the component, e.g. keyways, holes, and splines
 - accuracy of components – typical dimensional tolerances = $\pm 0.05\text{mm}$ to $\pm 0.01\text{mm}$ and typical surface texture = $6.3\ \mu\text{m}$ to $0.4\ \mu\text{m}$.
- Honing and lapping:
 - machine types and batch size, including horizontal and vertical honing (one-off to medium batch size) and rotary disc and reciprocating lapping (one-off to medium batch size)
 - features of the component, e.g. holes, faces
 - accuracy of components – typical dimensional tolerances = $\pm 0.01\ \text{mm}$ to $\pm 0.005\ \text{mm}$ and typical surface texture = $0.2\ \mu\text{m}$ to $0.03\ \mu\text{m}$.

A3 Sustainability characteristics of secondary machining processes

- Energy consumption to remove material, including power requirements to operate the machine, condition of machine, condition of tooling.
- Use and disposal of cutting fluids/electrolytes and waste materials.

Learning aim B: Set up traditional secondary processing machines to manufacture a component safely

B1 Health and safety requirements when setting up secondary process machines

Key features of regulations or other relevant international equivalents, including:

- Current Personal protective equipment (PPE) at work regulations and amendments, e.g. personal safety, identification of appropriate protective clothing and equipment, work area kept clean and tidy
- Current Manual handling operations regulations and amendments, e.g. safe set up of moving parts, repetitive loading of materials into the machine, setting stops, avoid sharp edges on sheet steel
- Current Control of substances hazardous to health (COSHH) regulations and amendments, e.g. use of barrier cream, choice and handling of cutting fluids/dielectric flow rate, hygiene measures including adequate washing facilities, general ventilation.

B2 Risk assessment

Risk assessment of the working environment and specific secondary machining processes. To include hazard identification and classification.

- Defining a hazard by inspection of the work environment and consideration of specific manufacturing processes, e.g. moving parts of machinery, sharp objects, electricity, slippage and uneven surfaces, dust and fumes, handling and transporting, contaminants and irritation, and unshielded processes.
- Defining risk by determining how hazards may cause injury, e.g. tools, materials or equipment in use, spillages of oil and chemicals, not reporting accidental breakages of tools or equipment, and not following working practices and procedures.
- Putting control measures in place to reduce risk, e.g. issue of eye protection for use when removing material, having guards in place.
- Health and Safety Executive (HSE) guidance on risk assessment to include the five steps to risk assessment and the use of standard pro forma for recording risk assessments.

B3 Setting up secondary process machines

- Tooling, including:
 - materials and form – solid high-speed steel, tungsten carbide, abrasive stone, composite wheels
 - for drilling – drill bit, counterboring tool, centre drill, reamer, tap
 - for turning – turning tools, chamfer tools, centre drills, twist drills, taps

- for milling – face mills, side and face cutters, slotting cutters, end mills, slot drills
- for grinding – straight-sided wheel, recessed and double-recessed wheel and dressing of wheels.
- Workpiece-holding devices, including:
 - chucks – hard three jaw, magnetic
 - for drilling – clamping direct to machine table, machine vice, vee block and clamps
 - for turning – drive plate and centres, faceplates, fixed steadies
 - for milling – clamping direct to machine table, machine vice, angle plate, vee block and clamps
 - for grinding – centres, face plate, machine vices, arbors.
- Speeds and feeds, including:
 - for drilling – tooling revolutions per minute, linear feed rate
 - for turning – workpiece revolutions per minute, linear feed rate, depth of cut for roughing and finishing
 - for milling – linear/table feed rate, milling cutter revolutions per minute, depth of cut for roughing and finishing
 - for grinding – linear/table feed rate, depth of cut for roughing and finishing, cross feed.

Learning aim C: Carry out traditional secondary machining processes to manufacture a component safely

C1 Features of traditional secondary machining processes

- For drilling – through holes, counterboring, tapped hole, reamed hole.
- For turning – parallel diameters, chamfers, drilled and tapped blind hole.
- For milling – flat face, shoulder, slot and profile forms.
- For grinding – parallel diameter, flat surface.

C2 Parameters of traditional secondary machining processes

- Cutting fluid application, swarf removal, workpiece removal.
- For drilling – tool revolutions per minute, feed rate, swarf clearance.
- For turning – workpiece revolutions per minute, tool feed rate, depth of cut for roughing and finishing.
- For milling – linear/table feed rate, tool revolutions per minute, depth of cut for roughing and finishing.
- For grinding – linear/table feed rate, depth of cut for roughing and finishing, cross feed, dressing of wheels.

C3 Quality control methods

Quality control methods, including:

- components to be free from burrs, sharp edges and false cuts
- checks for accuracy:
 - use of equipment to check dimensional tolerance, e.g. external micrometer, gap gauge, slip gauges and comparator
 - use of equipment to check surface texture, e.g. comparators (Rubert gauges), portable surface roughness measuring instruments.

Learning aim D: Review the processes used to machine a component and reflect on personal performance

D1 Lessons learned from machining a component

Scope of the lessons learned should cover:

- health and safety skills, including setting and using machines, using appropriate personal protective equipment, keeping the work area clean and tidy
- traditional secondary machining skills, including the effectiveness and efficiency of setting and operating machines, sustainability considerations, e.g. waste materials and energy usage and the use of quality control methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while machining a component

Understand that relevant behaviours cover:

- taking initiative and responsibility for own actions to monitor, adjust and control the machines continually, often while working independently
- communication and literacy skills to ensure health and safety in the workplace, and to follow and implement instructions appropriately and to explain own intentions
- problem solving as problems occur, e.g. replacing a broken or worn-out tool, deciding which actions to take when setting up and using secondary machining processes.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the technology and characteristics of secondary machining processes that are widely used in industry		A.D1 Evaluate, using language that is technically correct and of a high standard, the use of contrasting traditional and specialist secondary machining processes to sustainably manufacture components in different batch sizes.
A.P1 Explain how different traditional and specialist secondary machining processes are used to manufacture different features on components.	A.M1 Analyse how different traditional and specialist secondary machining processes are used to sustainably manufacture different features on components to the intended accuracy.	
Learning aim B: Set up traditional secondary processing machines to manufacture a component safely		BC.D2 Refine during the process the safe set up and parameters of the traditional secondary processing machines to effectively and efficiently manufacture a component.
B.P2 Explain what health and safety requirements apply when machining a component and conduct a risk assessment of the work environment.	B.M2 Use the correct tooling, work-holding devices and speeds and feeds to set up safely at least two traditional secondary processing machines.	
B.P3 Set up safely at least two traditional secondary processing machines.		
Learning aim C: Carry out traditional secondary machining processes to manufacture a component safely		
C.P4 Manufacture the component safely using at least two different traditional secondary machining processes and containing at least six features.	C.M3 Manufacture accurately the component containing at least six features.	
Learning aim D: Review the processes used to machine a component and reflect on personal performance		D.D3 Demonstrate consistently good technical understanding and analysis of traditional secondary machining processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P5 Explain how health and safety, traditional secondary machining, and general engineering skills were applied effectively during the manufacturing process.	D.M4 Recommend improvements to the set up and use of traditional secondary machining processes and to the relevant behaviours applied.	
D.P6 Explain how relevant behaviours were applied effectively during the manufacturing process.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, B.M2, C.M3, BC.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- pillar and/or radial drills, centre and/or turret lathes, horizontal, vertical and/or universal milling machines, surface, cylindrical, centreless and/or universal grinding machines, as required in the unit content
- auxiliary equipment, such as that listed under 'tooling' and 'workpiece-holding devices' in the content
- a range of equipment suitable for measuring the dimensional accuracy and surface texture of the work pieces to be machined
- a range of health and safety regulations, as required by the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will produce evidence that includes a balanced evaluation of the secondary machining processes, including energy consumption, disposal of fluids and waste material for different batch sizes and why particular processes were chosen. The evidence will detail how each process will accommodate different tolerances and batch sizes and how they relate to sustainable manufacture of components.

Overall, 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 use correct technical engineering terms, and will be of a high standard of written language, for example using correct grammar.

For merit standard, learners will analyse consistently across all the processes covered and include details about energy consumption, disposal of fluids and waste material, and the tolerances achievable.

Overall, the analysis should be logically structured, technically accurate and easy to understand.

For pass standard, learners will be clear in their explanation that three traditional and three specialist processes have been covered.

Overall, the explanations should be logically structured, although basic in parts. They may contain minor technical inaccuracies relating to engineering terminology, such as mentioning 'smoothness' instead of 'surface texture' and making 'edges' instead of 'chamfers'.

Learning aims B and C

For distinction standard, learners will refine throughout the process the machine set-up and parameters. For example, the application of cutting fluid, the tool feed rate and the position of tools, such as correct tool overhang, to ensure the process continues to operate efficiently and effectively, and produces a component that is accurate. Other parameters should be considered to control:

- effectiveness, for example optimising the order of tools and distance travelled by the tools, and machining the component in a realistic time
- efficiency, for example replacing worn tools, using correct cutting fluid and monitoring the machining processes.

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 use the correct tooling and workpiece-holding devices, and select appropriate speeds and feeds to machine a component, involving at least two traditional machining processes. Learners will show which measurements were taken for each of the features and which adjustments were made to ensure dimensional and surface texture accuracy. Additionally, evidence such as observation records will show clearly how working accurately was considered by learners.

For pass standard, learners will explain how health and safety is managed for the machines they intend to use and what regulations should be met. They will also produce a risk assessment, which will include consideration of all significant hazards, be laid out on in an appropriate template and include suitable control measures.

Learners will ensure the safe set-up of processes, including workpiece-holding devices and machine parameters. The vast majority of the speeds and feeds, tooling and workpiece-holding devices will be set up correctly. Learners will use traditional machining processes safely to manufacture a component and will apply cutting fluid (where relevant), remove swarf, and remove the workpiece from the machine correctly. The six features on the component must be free from burrs, sharp edges and false cuts.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results. They may make limited reference to accuracy and the finished components, which may not be completely to the desired tolerance or surface texture.

Learning aim D

For distinction standard, learners will give a balanced evaluation about the actions taken, traditional machining skills and the general engineering skills applied. Relevant behaviours will be consistently applied to a professional standard. For example, learners will take the initiative and responsibility for their own actions, such as when they are setting and adjusting the machines.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. For example, learners will consistently demonstrate a good technical understanding of machining processes that includes correct technical engineering terms and information about improvements.

For merit standard, learners will give in their notes or a logbook, and especially in their lessons learned evidence, detailed examples of where improvements could be made to the:

- set-up and use of the machining processes and equipment to make manufacture of the components more efficient, accurate and/or sustainable
- application of the relevant behaviours, for example, how listening to instructions has resulted in a worn tool being replaced and an activity running smoothly.

Overall, the suggested improvements will be reasonable and practical, and explanations will be professional and engineering terminology will be used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will write a technical report around 500 words in length, detailing the lessons learned during the manufacture of a machined component. The report will explain which:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- traditional secondary machining skills were used, for example how the intended surface texture was achieved, how dimensional accuracy was achieved and how holes were centred accurately
- general engineering skills were used, for example understanding Cartesian coordinates, interpreting drawings and recognising technical parts of machines
- behaviours were used, with an analysis of how successfully they were applied.

Overall, the evidence should be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology and with spelling and grammar.

Links to other units

This unit links to:

- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 42: Manufacturing Primary Forming Processes
- Unit 43: Manufacturing Computer Numerical Control Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local manufacturing organisations with expertise in machining
- contribution of ideas to unit assignment/project materials.

Unit 43: Manufacturing Computer Numerical Control Machining Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners examine the principles of Computer Numerical Control (CNC) machining, and develop a computer part program and manufacture a component using a CNC machine.

Unit introduction

Many of the products and components we use daily rely on CNC machining processes. Manufacturers use CNC for highly complex components difficult to manufacture by traditional methods, for example mould manufacture, valves, and automotive and aerospace components. CNC machines are also used for the batch production of components, where it is more economical than traditional methods.

You will examine how CNC control systems work and the computer programming methods used to create products and components. You will investigate a range of theoretical and practical activities to plan and program a CNC machine tool to manufacture a product or component. As part of the process, you will edit and modify part programs, and use simulation software to safely determine if the program is fit for purpose. Finally, you will reflect on the skills and understanding you have acquired while building, modifying and testing analogue circuits, and the behaviours you have applied.

As an engineer, it is important to understand the manufacturing systems and mechanisms of planning and creating products and components through programming CNC machine tools. This unit helps to prepare you for employment, for example as a manufacturing technician, for an apprenticeship and for entry to higher education to study engineering.

Learning aims

In this unit you will:

- A** Examine the control systems used in Computer Numerical Control machines and different computer programming methods
- B** Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely
- C** Carry out Computer Numerical Control machining processes to manufacture a component safely
- D** Review the processes used to machine a component and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the control systems used in Computer Numerical Control machines and different computer programming methods	A1 CNC machine tool control systems A2 Open and closed loop feedback systems A3 Part programming methods and program efficiency	A written report to investigate the control mechanism of a typical industrial CNC machine, based around open loop and closed loop systems, and its relationship to achieving accuracy via a computer program.
B Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely	B1 CNC processes for milling and turning B2 Tooling parameters B3 Component parameters B4 Machine set-up parameters B5 Development of a CNC part program B6 Sustainability considerations	<p>Preparation activities and documents prior to CNC machining a product or component, to include: machine tool set-up sheet and a computer part program, and simulation of the program.</p> <p>Input the part program and set up the CNC machine, to produce a component, using multiple tooling. Carry out quality control checks to verify that the component meets the specification and is fit for the intended purpose.</p>
C Carry out Computer Numerical Control machining processes to manufacture a component safely	C1 Manufacture of a component using a CNC machine C2 Safe working practices C3 Component quality checks	<p>The evidence will focus on what went well and what did not go so well when programming and machining a component, and a conclusion of improvements that could be made.</p> <p>The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.</p>
D Review the processes used to machine a component and reflect on personal performance	D1 Lessons learned from programming and machining a component D2 Personal performance while machining a component	<p>The evidence will focus on what went well and what did not go so well when programming and machining a component, and a conclusion of improvements that could be made.</p> <p>The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.</p>

Content

Learning aim A: Examine the control systems used in Computer Numerical Control machines and different computer programming methods

A1 CNC machine tool control systems

The role and function of key components and devices in a CNC machine tool control system, including:

- machine control unit
- drive mechanisms, including: lead screw, ball screw, stepper motors, alternating current servomotors and direct current servomotors
- transducers, including: linear, rotary and optical encoders.

A2 Open and closed loop feedback systems

- Understand the process of open and closed loop systems used in a CNC machine tools including: feedback, correction and error detection.

A3 Part-programming methods and program efficiency

- The two types of CNC part programming methods are:
 - non-conversational or manual programming – a program written in the same language and code that a CNC machine will execute it in
 - conversational programming – a system where parameters are input into pre-defined fields and the software typically interprets the information into code that a CNC machine can execute.
- Efficiency of the CNC program is influenced by a number of factors, including:
 - the quality of the product or component determined by the desired surface texture and tolerance
 - code structure and commands selected and combined to create the part program
 - material type and the complexity of the product/component form data interface, e.g. manual data input (MDI), data exchange format (DXF), and CAD/CAM link.

Learning aim B: Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely

B1 CNC processes for milling and turning

- Complex milling processes include: drilling cycle, peck drilling, tool offsets, boring, part radii, tapers, blended radii, tool diameter compensation, pocket cycles, polar coordinates, slots, holes on a PCD, and curved profiles.
- Complex turning processes include: part radii, radii blended to a taper, tool nose radius compensation, tool offsets, roughing cycle and turning cycle, boring, external threading cycle, internal threading cycle, drilling cycles, undercuts, grooves, and parting off.

B2 Tooling parameters

- Feed rates for the material to be machined, e.g. aluminium.
- Cutting speeds for the material to be machined, e.g. aluminium.
- Roughing operations.
- Finishing operations.
- Cutter compensation for the required code, e.g. G40, G41, G42.

B3 Component parameters

Calculations, including:

- cutter path coordinates for intersections that require the use of calculations, e.g. trigonometric functions, sine, cosine, tangent
- arc centres use of required calculations, e.g. trigonometric functions, sine, cosine, tangent

- work (product or component) holding, e.g. machine vice, fixtures, chucks, pneumatic or magnetic table, direct clamping to machine table
- canned cycles, and the selection and use of the correct canned cycles for efficient programming, e.g. G70 or G71 for a roughing cycle
- component materials, preparation of the material, e.g. blank sizes, pre-machining
- suitability of the machine and program to achieve the required tolerance and surface texture.

B4 Machine set-up parameters

- Work holding, and selection of the correct work-holding device.
- Tool change positions, and selection of a safe tool change position.
- Tool mounting, and use of optimal positions in turrets for efficiency and safety.
- Machine datum, and relationship to the program datum.
- Program datum, and safe positioning for machining and tool change activities.

B5 Development of a CNC part program

- Auxiliary functions, including:
 - metric/imperial unit selection for appropriate computer programming system
 - tool selection to meet the specification
 - cutting fluids selection depending on the material to be machined
 - workpiece loading and holding, and billet sizes and locations
 - tool changing sequences and safe machine operation
 - safety block to reset the coding, e.g. cancel compensation
 - edit a part program for coding errors, including logical errors, syntax errors.
- CNC codes, including:
 - G and M codes, e.g. G00, G01, M06
 - axis coordinates, e.g. milling X, Y, Z and secondary axis if available, and turning X, Z and secondary axis if available
 - absolute, incremental programming use of G90, and G91
 - preparatory commands, modal linear interpolation, circular interpolation, e.g. G02 and G03 with cutter compensation and non-modal, e.g. G04 dwell, inch and metric programming
 - program structure and efficiency, e.g. sub-routines/sub-programs, do loops.
- Simulate the CNC part program to check the tool cutter paths and for logical errors, e.g. graphical software simulation or a dry run.

B6 Sustainability considerations

- Disposal of materials, e.g. cutting fluids and swarf.
- Use of resources, e.g. paperless, coding and editing on screen, use of graphics for proving purposes, correct tool life parameters in use, re-using material to test program operation, e.g. wax.

Learning aim C: Carry out Computer Numerical Control machining processes to manufacture a component safely

C1 Manufacture of a component using a CNC machine

- Entry of datums into the program and set them on the machine tool.
- Secure work-holding devices.
- Program tool offsets or enter them into the MCU.
- Tooling prepared and located in the respective turrets, check tooling is in good condition and correct tooling selected or compensation allowed if not available.
- Check tool-change positions are safe.

- Simulate a CNC machining process using the machine control unit (MCU), and using suitable approaches, including:
 - graphical software simulation of the machining process to check the tool cutter paths
 - step through the program single block by single block with or without a component in situ
 - run the program at reduced feed rates
 - machine the component using a foam or wax material
 - machining of the component using the intended material.

C2 Safe working practices

Safe working practices include:

- use of personal protective equipment (PPE), e.g. overalls, safety glasses, safety boots, ear defenders
- in place and secure machine guards
- operational interlocks
- speed and feed over-rides set correctly
- speed and feeds are programmed or set correctly for manual data input (MDI)
- appropriate coolant is available.

C3 Component quality checks

- Dimensional tolerance equivalent to BS 4500, BS 1916 or other relevant international equivalent.
- Surface texture Grade 7 63 μin or 1.6 μm .
- Reamed and bored holes within H8.
- Angles within $\pm 0.5^\circ$.
- Screw threads BS medium fit or other relevant international equivalent.

Learning aim D: Review the processes used to machine a component and reflect on personal performance

D1 Lessons learned from programming and machining a component

The scope of the lessons learned and improvements could be:

- health and safety skills including setting and using machines, using appropriate personal protective equipment and keeping the work area clean and tidy
- programming and machining skills, including the effectiveness and efficiency of programming, setting and operating machines, sustainability considerations, e.g. waste materials and energy usage and the use of quality control methods
- general engineering skills, e.g. mathematics and interpreting drawings.

D2 Personal performance while machining a component

Understand that relevant behaviours for machining a component include:

- taking initiative and responsibility for own actions to monitor, adjust and control the machines continually, while often working independently
- communication and literacy skills to ensure health and safety in the workplace, to follow and implement instructions appropriately and to explain own intentions to others
- problem solving of issues as they occur, for example to re-code or compensate for unavailable tooling or deciding actions to take when setting up and using the CNC machining processes.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the control systems used in Computer Numerical Control machines and different computer programming methods		A.D1 Justify the selection of the control system, feedback system and programming methods for different CNC machining applications.
A.P1 Explain the control system, feedback system and programming methods used in CNC machines.	A.M1 Analyse how the interaction of the control system, feedback system and programming methods influence the CNC machining process.	
Learning aim B: Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely		BC.D2 Optimise the processes to effectively and efficiently develop and manufacture safely a component using at least six complex CNC processes and at least three different cutting tools.
B.P2 Create a machine tool set-up sheet for a component using at least six complex CNC processes and at least three different cutting tools.	B.M2 Produce an accurate machine tool set-up sheet for a component using at least six complex CNC processes and at least three different cutting tools.	
B.P3 Create a part program to machine a component safely using at least six complex CNC processes and at least three different cutting tools and simulate for any syntax and logical errors.	B.M3 Create a part program to machine a component safely and efficiently, using at least six complex CNC processes and at least three different cutting tools and simulate for any syntax and logical errors.	
Learning aim C: Carry out Computer Numerical Control machining processes to manufacture a component safely		
C.P4 Simulate the CNC machining of a component safely, correcting any syntax and logical errors.	C.M4 Manufacture accurately a component using at least six complex CNC processes and at least three different cutting tools, incorporating improvements from the simulation.	
C.P5 Manufacture a component safely using at least six complex CNC processes and at least three different cutting tools.		
Learning aim D: Review the processes used to machine a component and reflect on personal performance		D.D3 Demonstrate consistently good technical understanding and analysis of CNC programming and machining processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Explain how health and safety, CNC programming, machining and general engineering skills were applied effectively during the manufacturing process.	D.M5 Recommend improvements to the set up and use of CNC programming and machining processes and to the relevant behaviours applied.	
D.P7 Explain how relevant behaviours were applied effectively during the manufacturing process.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, B.M3, C.M4, BC.D2)

Learning aim: D (D.P6, D.P7, D.M5, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- CNC lathes, or CNC milling machines, or a machining centre, as required by the learning aims and unit content
- auxiliary equipment (such as that listed in the content under 'tooling' and 'workpiece-holding devices')
- a range of equipment suitable for measuring the dimensional accuracy and surface texture of the work pieces to be machined
- access to a range of health and safety legislation and regulations, as required by the learning aims and unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide in their evidence a balanced evaluation of a CNC control system. For example, the evidence may cover why some manufacturers fit a linear system and some adopt a rotary control system, and what the consequences of a broken lead screw are. The evaluation will also cover different types of feedback system. For example, they may cover the consequences of a CNC machine hunting while locating a tool position in a closed-loop control system. Learners will detail how each system will accommodate accuracy and how it is applicable to different machine systems and programming methodologies.

Overall, 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 use correct technical engineering terms, and will be of a high standard of written language using, for example, correct grammar.

For merit standard, learners will analyse in their evidence the CNC control system, feedback system and programming methodologies consistently. For example, they might observe that programming using the conversational method is easier, requires less skill and is quicker to complete, but it may not be as efficient once interpreted, compared to the non-conversational method. The evidence will demonstrate how the system can influence the machining process, for example stepper motors are often found in open-loop systems, and these devices move in discrete steps resulting in a possible lack of positional accuracy.

Overall, the analysis should be logically structured, be technically accurate and easy to understand.

For pass standard, learners will explain in their evidence how CNC machine control, feedback and programming methodology are used to manufacture products and components. For example, they might explain that the CNC machine's hardware safety system will stop over travel, and the software package has over-travel limits built in to ensure safe operation. This mitigates against possible programming errors.

Overall, the evidence, such as a report, will be structured logically although basic in parts. It may contain minor technical inaccuracies relating to engineering terminology, such as mentioning 'stepper motor' instead of 'servo motor'.

Learning aims B and C

For distinction standard, learners will produce an accurate and concise machine tool set-up sheet. The part program will be graphically simulated using software and physically simulated on the CNC machine, and as a result the program will be edited and optimised. The work-holding and machining parameters will also be refined during the set-up and CNC manufacture of the component. For example, the correct cutting speed and tool feed rates will be used throughout the machining process to ensure the component is safely, efficiently and effectively manufactured. Also, the tools should be checked for the correct location in the turret and all tool offsets correctly set. Other parameters should be refined to optimise the:

- effectiveness, for example by considering the order of tool selection and the distance travelled by the tools
- efficiency, for example by replacing worn tools or providing suitable tool compensation, using correct cutting fluid and monitoring the machining processes.

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 produce an accurate machine tool set-up sheet containing correct data, tooling parameters, feeds and speeds and work-holding parameters required to manufacture a component sustainably on a CNC machine.

Learners will create an efficient part program considering alternative approaches to machine the component using at least six complex processes and at least three tools. For example, to achieve this learners could produce the program using a conversational language and manually insert sub-routines to improve the efficiency.

Learners will accurately manufacture the component, incorporating improvements from the simulation. They will take measurements for each of the machining processes and record any adjustments required to ensure dimensional and surface texture accuracy, for example compensation is correctly applied to allow for tool wear.

Overall, the evidence, including observation records, will clearly demonstrate how working accurately and safely was considered by learners throughout the machining process.

For pass standard, learners will create a machine tool set-up sheet, containing data, tooling parameters, feeds and speeds, work-holding parameters and will consider sustainability for the manufacture of a component on a CNC machine. For example, the machine tool set-up will identify the tooling parameters of tool diameters, tooling material (high speed steel (HSS)/carbide) and tool number. Also, learners will identify the separation and correct disposal of the ferrous and non-ferrous swarf. Tool calculations for speed in revolutions per minute (RPM) may be inaccurate, but are safe to run.

Learners will create a part program for a component containing at least six complex CNC processes and using at least three different tools. During the process, learners will simulate the part program using graphical software for syntax and logical errors. The program will be modified as required. For example, the programmer may see an error of a linear interpolation (G01) in the XY axes without the tooling being lowered previously in Z, thus creating an angular cut.

Learners will set up safely the CNC machine, including work-holding devices and machine parameters. They will simulate the physical machining of a component using a CNC machine and the part program. As required, they will correct any syntax and logical errors. Consequently, the vast majority of the coding, speeds and feeds, tooling and workpiece-holding devices will be set up correctly. However, the part program may not be as efficient as it could be. For example, code G01 (linear interpolation) may have been used when a code G00 (rapid traverse) would be more appropriate.

Learners will manufacture a component safely using the CNC machine and will apply cutting fluid (where relevant), remove swarf, and remove the workpiece from the machine correctly.

Overall, learners' evidence, such as a logbook, will record the activities they have completed, along with the results. They may make limited reference to accuracy, and the finished components may not be completely to the desired tolerance or surface texture.

Learning aim D

For distinction standard, learners will consistently demonstrate a good technical understanding of CNC processes. Evidence, such as notes or a logbook, and especially the lessons learned report, including information about improvements, will consistently contain concise and high-quality written language that includes correct technical engineering terms. The narrative will differentiate facts from opinion.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. A balanced view and evaluation will be given about the actions taken, CNC programming, machining skills and general engineering skills. Also, relevant behaviours will be consistently applied to a professional standard, for example taking initiative and responsibility for their own actions including setting and adjusting the machines and submitting work on time.

For merit standard, learners should show in their evidence, such as notes or a logbook and especially in their lessons learned report, detailed examples of where improvements could be made to the:

- set-up documentation, programming and use of the machining processes and equipment to manufacture the component more efficiently and accurately while considering sustainability
- application of the relevant behaviours.

Overall, improvements suggested should be reasonable and practical and the explanations will be professional and easy to understand using engineering terminology accurately. Some parts of the evidence may have more emphasis than others, creating an unbalanced viewpoint, and making it more difficult for a third party to understand and implement any improvements.

For pass standard, the evidence, such as notes or a logbook, and especially the lessons learnt report, which should be around 500 words in length, will detail the lessons learnt during the manufacture of a CNC-machined component. It will explain which:

- actions were taken to manage health and safety in the workplace, for example what personal protective equipment was used and whether any unforeseen issues occurred
- CNC machining skills were used, for example that the tooling was set correctly for their datum position, offsets and compensation
- general engineering skills were used, for example understanding Cartesian coordinates, interpreting drawings and recognising technical parts of machines
- behaviours were used, with an analysis of how successfully they were applied.

Overall, the evidence, such as a lessons learned report, will be logically structured, although basic in parts, and it may contain minor technical inaccuracies relating to engineering terminology and spelling and grammar.

Links to other units

This unit links to:

- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes
- Unit 45: Additive Machining Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in Computer Numerical Control machining processes
- contribution of ideas to unit assignment/project materials.

Unit 44: Fabrication Manufacturing Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners explore and carry out fabrication processes to safely manufacture products from sheet metal.

Unit introduction

Fabrication processes are used to manufacture sheet metal products and components in a wide range of industries and applications. For example, sheet metal products and components are found in oil rigs, ships and aircraft, desktop computer cases, fridges and filing cabinets.

In this unit, you will cover the four main stages of manufacturing a sheet metal product: preparation, cutting out blank components, forming up the components and joining them into an assembled product. You will learn the safe use of a range of industrial hand tools, machinery and other equipment associated with fabrication processes. You will apply this knowledge in the manufacture of a sheet product, for example tool box, desktop computer or console casing, or a portable wood-burning stove. Finally, you will reflect on how your skills, knowledge, behaviours and organisational skills were applied during the fabrication of a product.

It is important that engineers have an appreciation of the materials and processes involved in manufacturing sheet metal products, and are capable of creating solutions to engineering-based problems. This unit will help prepare you for a mechanical or manufacturing engineering apprenticeship, higher education and for employment in a technician-level role in the sheet metal fabrication industry.

Learning aims

In this unit you will:

- A** Examine the processes and technology used in sheet metal fabrication that are widely used in industry
- B** Carry out the preparation necessary to manufacture a fabricated product safely
- C** Carry out fabrication processes to manufacture a fabricated product safely
- D** Review the processes used to manufacture a fabricated product and reflect on personal performance.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the processes and technology used in sheet metal fabrication that are widely used in industry	A1 Fabricated products A2 Sheet materials A3 Cutting processes A4 Forming processes A5 Joining processes A6 Finishing processes	A written report on at least two different types of fabrication processes and how these might be applied, based on the requirements of researched case studies.
B Carry out the preparation necessary to manufacture a fabricated product safely	B1 Health and safety requirements B2 Risk assessment B3 Interpreting design specifications	A series of practical activities to fabricate a product. Evidence will include: a developmental logbook, the physical fabricated product, risk assessments, forming gauges, observation records/witness statements, annotated drawings, inspection records and notes explaining health and safety requirements.
C Carry out fabrication processes to manufacture a fabricated product safely	C1 Using fabrication manufacturing processes C2 Alignment and clamping C3 Quality control procedures	
D Review the processes used to manufacture a fabricated product and reflect on personal performance	D1 Lessons learned from manufacturing a fabricated product D2 Personal performance while manufacturing a fabricated product	<p>The evidence will focus on what went well and what did not go so well when carrying out fabrication processes, and a conclusion discussing improvements that could be made.</p> <p>The portfolio of evidence will be generated while fabricating a product, and reviewing the processes and reflecting on personal performance.</p>

Content

Learning aim A: Examine the processes and technology used in sheet metal fabrication that are widely used in industry

A1 Fabricated products

- Examples of fabricated products, e.g. desktop computer case, washing machine, tool box, industrial lighting.

A2 Sheet materials

- Sheet materials in common usage, including mild steel, hot dipped galvanised mild steel, Zintec, aluminium and stainless steel.
- Common grades of mild steel, e.g. CR4, stainless steel, e.g. 304, 316, and sheet thicknesses, e.g. 0.5 mm, 0.7 mm, 0.9 mm, 1.2 mm.
- Factors governing material choice, including density, ductility, stiffness, cost, corrosion resistance and environmental considerations.

A3 Cutting processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal cutting processes, including:

- nibbling, e.g. hand, power
- shearing, e.g. hand, bench, power
- presswork, including blanking, piercing, tool design, e.g. punch, die and stripper
- sawing, e.g. bandsaw, hacksaw, reciprocating saw
- material removal, e.g. drilling, filing, grinding
- non-traditional cutting processes, including laser cutting and computer numerical control (CNC) punch press.

A4 Forming processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal forming processes, including:

- principles of sheet metal forming, including minimum bend radii as a function of material thickness, consideration of springback, use of forming gauges
- manual forming methods, including bar folder, bench-mounted forming brakes, e.g. straight, box, finger, fly press with V-block tooling, hammer and former, and bench-mounted bending rolls
- press brake forming, including V-block and blade tooling, e.g. standard, swan neck, letterbox, air bending and bottoming dies
- non-traditional forming processes, including CNC press brake (with V-block and blade tooling) and CNC bending rolls.

A5 Joining processes

Applications, limitations, accuracy, applicable batch size and principles of operation of sheet metal joining processes, including:

- permanent joining processes, including spot welding, metal inert gas (MIG) welding, and brazing
- mechanical fixings, including nuts, bolts, self-tapping screws, pop rivets
- non-traditional joining processes, including CNC robotic spot welding.

A6 Finishing processes

- Applications, limitations, and principles of operation of sheet metal finishing processes, including galvanising, powder coating, painting, plating, e.g. chromium.

Learning aim B: Carry out the preparation necessary to manufacture a fabricated product safely

B1 Health and safety requirements

Key features of regulations, or other relevant international equivalents, including:

- Current Provision and use of work equipment regulations (PUWER) and amendments, e.g. maintaining and inspecting work equipment, provision of training to employees, clearly marked machine controls, use of appropriate guarding
- Current Manual handling operations regulations (MHOR) and amendments, e.g. training in manual handling methods to avoid personal injury, provision of a suitable working environment and appropriate equipment
- Current Control of noise at work regulations, e.g. elimination and/or reduction of noise, acceptable limits, signage, upper exposure action value, hearing protection
- Current Personal protective equipment (PPE) at work regulations and amendments, e.g. employers responsibility to provide appropriate equipment, types of equipment.

B2 Risk assessment

Risk assessment of the general working environment and specific fabrication manufacturing processes, including hazard identification and classification:

- defining a hazard by inspection of the work environment and consideration of specific manufacturing processes, e.g. entrapment in press brakes, manual handling of tooling and sheet material, noise, sheet material sharp edges and corners
- defining risk by determining how hazards may cause injury, e.g. sharp edges likely to cause cuts
- putting control measures in place to reduce risk, e.g. using leather gloves when handling sheet material
- Health and Safety Executive (HSE) guidance on risk assessment, including the five steps to risk assessment and the use of a standard pro forma for recording risk assessments.

B3 Interpreting design specifications

- Interpreting engineering drawings, including reading and understanding individual component, sub-assembly and general assembly drawings to BS8888 or other international equivalents.
- Developing blanks, including bend allowance calculations using standard approximation formulae and drawing out accurately developed blanks.
- Use of bend relief holes or slots to prevent material tearing when forming close to an edge.
- Preparing forming gauges.
- Modelling, including verifying accuracy of blanks by modelling components and creating mock-ups.
- Marking out accurately with appropriate equipment, e.g. steel rule, protractor, set square, compasses, dividers, scribe, engineer's blue, marker pen.
- Nesting multiple component blanks by careful positioning and marking out on stock sheet material to ensure efficient and sustainable use of each sheet, minimising waste.

Learning aim C: Carry out fabrication processes to manufacture a fabricated product safely

C1 Using fabrication manufacturing processes

- Use of workshop equipment, including cutting component blanks, forming sheet metal components, joining formed components into a fabricated product.

C2 Alignment and clamping

- Trial assembly, e.g. offering up, alignment, clamping, dimensional checks, adjustment.
- Work holding, e.g. mitre clamps, toggle clamps, jigs, G-clamps, magnetic clamping devices, fixtures.

C3 Quality control procedures

- Checks for accuracy using measuring equipment to check dimensional tolerance, e.g. ruler, vernier or digital callipers, vernier or digital protractor, templates, forming gauges.
- Identifying critical dimensions as indicated on given engineering drawings. These are component specific and critical to the correct assembly, form and function of a product. These specific dimensions must be checked during inspection.
- Visual checks, e.g. finish, visual appearance, joint quality.
- Design and use of pro forma inspection record sheets.

Learning aim D: Review the processes used to manufacture a fabricated product and reflect on personal performance**D1 Lessons learned from manufacturing a fabricated product**

Scope of the lessons learned and improvements could be:

- health and safety skills, including assessing risk, using appropriate personal protective equipment and keeping the work area clean and tidy
- fabrication manufacturing skills, including the effectiveness and efficiency of using hand tools and machines, sustainability considerations, e.g. efficient use of materials, energy usage, and waste products
- general engineering skills, e.g. mathematics applied when developing blanks, interpreting engineering drawings.

D2 Personal performance while manufacturing a fabricated product

Understand that relevant behaviours cover:

- taking initiative and responsibility for own actions when applying the knowledge and practical skills required to manufacture sheet metal components safely, efficiently and independently, e.g. selecting and using appropriate processes
- communication and literacy skills to ensure health and safety in the workplace and to follow and implement instructions appropriately, and to explain own intentions to others
- problem solving of issues as they occur, e.g. adjusting press settings when forming bends to compensate for material springback.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the processes and technology used in sheet metal fabrication that are widely used in industry		A.D1 Evaluate, using language that is technically correct and of a high standard, the use of contrasting fabrication processes to sustainably manufacture sheet metal components in different batch sizes.
A.P1 Explain how different fabrication processes are used to manufacture sheet metal components.	A.M1 Analyse how different fabrication processes are used to sustainably manufacture sheet metal components to the intended accuracy.	
Learning aim B: Carry out the preparation necessary to manufacture a fabricated product safely		BC.D2 Refine, during the process, the blank design, set-up and parameters of the fabrication equipment to safely, effectively and efficiently manufacture a fabricated product.
B.P2 Explain which health and safety requirements apply when using fabrication processes and conduct a risk assessment of the work environment.	B.M2 Analyse component blanks through modelling and safely and accurately mark components out.	
B.P3 Set up safely at least two cutting, two forming and two joining processes.		
Learning aim C: Carry out fabrication processes to manufacture a fabricated product safely		
C.P4 Manufacture at least four fabricated formed components safely using at least two cutting processes and at least one forming process.	C.M3 Manufacture a fabricated product accurately containing at least four formed components joined using at least two processes.	
C.P5 Manufacture a fabricated product safely containing at least four formed components joined using at least two processes.		
Learning aim D: Review the processes used to manufacture a fabricated product and reflect on personal performance		D.D3 Demonstrate consistently good technical understanding and analysis of fabrication processes, including the application of relevant behaviours and general engineering skills to a professional standard.
D.P6 Review the processes used to manufacture a fabricated product and reflect on personal performance.	D.M4 Recommend improvements to the set up and use of fabrication processes and the relevant behaviours applied.	
D.P7 Explain how relevant behaviours were applied effectively during the manufacturing process.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aims: B and C (B.P2, B.P3, C.P4, C.P5, B.M2, C.M3, BC.D2)

Learning aim: D (D.P6, D.P7, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- shear (bench or powered) machine(s), forming press (fly press, box former and/or press brake with appropriate tooling), and welding equipment (spot or MIG welding)
- general fabrication workshop facilities, including tools and equipment as required by the learning aims and unit content
- a range of equipment suitable for measuring the dimensional accuracy of the components manufactured
- a range of health and safety regulations, as required by the unit content.

Essential information for assessment decisions

Learning aim A

For distinction standard, learners will provide a balanced and well-thought-through evaluation (probably between 500 and 1000 words maximum) of different fabrication processes as applied to different batch sizes. The criteria used as the basis of discussion will include sustainability, cost, accuracy and overall suitability. For example, it may be appropriate to produce a single component blank using only hand tools, small batches by laser cutting or large numbers using a dedicated hard tool. Each scenario will be explored in detail. For at least one of the example products, learners must demonstrate the ability to compare and contrast alternative processes.

Overall, the evidence will be easy to read and understand by a third party who may or may not be an engineer. For example, it will be logically structured, use the correct technical engineering terms and will contain high-quality written language, for example it will be grammatically clear.

For merit standard, learners will highlight in their analysis the preparation, set-up and use of each process according to best practice, to minimise waste and ensure the maximum possible accuracy. The analysis will consider consistent criteria for each process and will include suitable batch size, energy consumption, waste materials and achievable tolerances.

Overall, the analysis will be logically structured, technically accurate and easy to understand.

For pass standard, learners will demonstrate an understanding of how three types of hand/bench equipment and three larger pieces of industrial equipment operate and are used to fabricate sheet metal products.

Overall, the explanations will be logically structured, although may be basic in parts. They may contain minor technical inaccuracies or omissions relating to engineering terminology, such as mistakes when labelling equipment diagrams or perhaps using non-technical language like 'making holes' when 'punching' or 'piercing' would be more appropriate.

Learning aims B and C

For distinction standard, learners will refine throughout the process the blank design, set-up and parameters of the fabrication equipment to safely, effectively and efficiently manufacture the product. For example, learners will:

- demonstrate how the modelling process helped to confirm the calculated blank dimensions and fully explain any adjustments or changes made
- add stress-relieving features, such as bend relief slots to prevent components tearing or distorting during forming
- adjust stops on a power shear to give required blank size
- adjust the power setting and wire feed to optimise the weld quality.

Overall, the evidence should be presented clearly and in a manner that would be understood by a third party who may or may not be an engineer.

For merit standard, learners will determine the blank dimensions through calculation and should be verified by the production of neat and accurate component models. Any issues with the initial calculations will be addressed at the modelling stage and any necessary alterations made. Learners will then work safely, clearly and accurately using appropriate equipment and techniques to mark out the components on sheet steel stock. When marking out, appropriate tolerances for linear dimensions are ± 0.5 mm and for angular dimensions $\pm 1^\circ$.

The component and joined assembly will be manufactured safely and accurately with dimensions recorded in a table, and compared with the required critical dimensions and associated tolerances given on the engineering drawings. In each case and throughout the manufacturing process, it will be stated if a critical dimension is within the required tolerance and, if not, what corrective actions will be taken.

For pass standard, learners will explain how health and safety is managed for the machines they intend to use and what regulations will be met. They will produce a risk assessment for two cutting, two forming and two joining processes, which will include consideration of all significant hazards, be laid out on in an appropriate template and include suitable control measures.

Component blanks will be developed and card templates will be made for each component and the assembled product. Where appropriate, manufacturing aids like forming or rolling gauges will be retained and notes made on their use. Learners will ensure the safe set up of processes, including work-holding devices and machine parameters, with evidence of actions taken.

Learners will cut, using two different processes, and form, using two different processes, at least four components safely. They will safely join together at least four components using at least two joining processes, for example by using spot welding and pop riveting.

Learners will record what they are doing and their results in a logbook. Overall, there may be limited reference to accuracy and only some of the critical dimensions will be measured and recorded by marking up copies of component drawings. Although the finished components and products may not be completely within the desired tolerance, the finished product must be functional and be fit for purpose. For example, a tool box that includes a hinged lid must still close.

Learning aim D

For distinction standard, learners will give a balanced evaluation about the actions taken, fabrication skills and general engineering skills applied. Also, relevant behaviours will be consistently applied to a professional standard. For example, learners will take initiative and responsibility for their own actions, such as when they are setting and adjusting the machines, and by submitting work on time.

Overall, learners will consistently demonstrate a good technical understanding of fabrication processes. Evidence, such as a logbook and reports, will consistently contain concise and high-quality written language that includes correct technical engineering terms and information about improvements. It will be easy to read and understand by a third party who may or may not be an engineer.

For merit standard, learners will recommend where improvements could be made to the:

- set-up and use of the fabrication processes and equipment to make manufacture of the components more efficient, accurate and sustainable
- management of health and safety to decrease the risk of harm to self and others when carrying out workshop activities
- application of relevant behaviours, for example adjusting press settings when forming bends to compensate for material springback.

Overall improvements suggested will be reasonable and practical, explanations will be professional and engineering terminology will be used accurately. Some parts of the evidence may have more emphasis than others, making it more difficult for a third party to understand.

For pass standard, learners will have evidence, typically a report of between circa 500 and 1000 words, detailing the lessons learned during the manufacture of a fabricated product.

The evidence will explain the:

- actions taken to manage health and safety in the workplace, such as conducting risk assessments, use of PPE and how any unforeseen safety issues were dealt with
- fabrication skills applied, such as using specialised equipment and how the intended accuracy was achieved when marking out blanks, performing cutting operations and forming components
- general engineering skills applied, such as interpreting engineering drawings, working with tolerances and using workshop equipment appropriately
- relevant behaviours that were applied when working in a fabrication workshop, such as time management to ensure completion of work to deadlines.

Overall, the explanations will be logically structured, although basic in parts, and they may contain minor technical inaccuracies relating to engineering terminology. Also, some parts of the evidence may be considered in greater depth than others.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 13: Welding Technology
- Unit 39: Modern Manufacturing Systems
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 46: Manufacturing Joining, Finishing and Assembly Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local engineering organisations with expertise in fabrication
- contribution of ideas to unit assignment/project materials.

Unit 45: Additive Manufacturing Processes

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners cover the principles and practical methods used in additive manufacturing (AM) and develop a component using additive processes.

Unit introduction

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 63 000 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.

Learning aims

In this unit you will:

- A** Examine the technology and characteristics of additive manufacturing processes as used in industry
- B** Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes
- C** Develop a component using additive manufacturing processes safely.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and characteristics of additive manufacturing processes as used in industry	A1 AM processes A2 Safe working practices for AM processes	A report examining the technology and characteristics of AM processes, including sustainability and safe working practices.
B Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes	B1 Design considerations for AM processes B2 Component finishing processes post-additive manufacturing	A report focusing on the product or component design considerations and finishing processes required to manufacture a component effectively using additive processes.
C Develop a component using additive manufacturing processes safely	C1 Component design for additive manufacture C2 Manufacture of a component using an AM process	Design and manufacturing evidence for the development of a product or component using additive processes. To include: a developmental logbook, observation records/witness statements, the finished component, annotated photographs and/or drawings, set-up planning notes, and complete quality control documents.

Content

Learning aim A: Examine the technology and characteristics of additive manufacturing processes as used in industry

A1 AM processes

- Technology and characteristics, such as complexity, surface texture, and tolerances, of AM processes, including:
 - material extrusion – fused deposition modelling (FDM)
 - powder bed fusion – electron beam melting, laser powder bed, plasma powder bed, laser sintering
 - photo polymerization – Selective Laser Sintering (LS), stereolithography (SLA), Digital Light Processing (DLP)
 - material jetting – binder jetting
 - wire deposition (wire arc manufacturing), including plasma, electron beam and laser.
- Capacity of AM processes, including:
 - component size is limited by the capacity of the AM machine, including physical machine footprints and base size and working area and swept volume
 - 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:
 - the recycling of metallic powder and polymer-based materials as part of the powder bed fusion process
 - limited waste material is produced as a result of the process
 - less energy is required to manufacture components
 - localisation of manufacturing reduces the need for transportation.
- Applications of AM processes, including:
 - manufacture of aerospace and automotive components – using powder bed technologies and wire deposition processes
 - rapid prototyping of products and components – using FDM and LS processes
 - moulds and tooling, e.g. moulds – for casting near net shapes, patterns, jigs – using FDM and LS
 - digital manufacturing, e.g. industrial components, consumer products – using powder bed technologies and wire deposition
 - personalised fabrication, e.g. customisation, personal products, home and machine repairs – using FDM
 - biomedical, e.g. dental, prosthetics, hearing aids and human tissue – using FDM.
- Typical materials, including:
 - polymers, e.g. Acrylonitrile Butadiene Styrene (ABS), polylactic acid (PLA), polyamides
 - metals, e.g. titanium (Ti), aluminium (Al), steel, gold, silver
 - composites, e.g.: glass fillers within polymers, cermets, carbon fibre, epoxy resins.

A2 Safe working practices for AM processes

- Key features of health and safety regulations, or other relevant international equivalents, including:
 - 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
 - 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.
- 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.

Learning aim B: Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes**B1 Design considerations for AM processes**

- Advantages of AM processes over traditional manufacturing processes, e.g. machining and casting, including:
 - 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
 - further reduction in mass and an improvement in part performance can be achieved by using a mathematical approach called topology optimisation
 - the integration of parts, the ability to manufacture assembled items together that cannot be manufactured together using traditional processes without multiple operations
 - reduced time to manufacture as specialist tooling, e.g. moulds, are typically not required
 - reduced costs as there is typically no need for expensive tooling, e.g. moulds
 - design freedom comes at no extra cost
 - 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:
 - products and components need to be redesigned to realise the advantages
 - materials choice can be limited
 - the process is currently only suitable for jobbing or small batch manufacturing volumes (unless the product or component is high value)
 - the initial capital cost is quite high
 - 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:
 - distortion, including warping, shrinkage
 - surface finish considerations, including aliasing (stepping), creation of edges, effect on radii, and sharp corners
 - 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.

B2 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 aim C: Develop a component using additive manufacturing processes safely**C1 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
 - cooling of the finished product
 - support of overhanging surfaces
 - functionality of the product, e.g. moving parts operate as intended
 - 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
 - transfer of data, e.g. Wi-Fi, direct link, SD card, program file size
 - multiple components.
- Creation of a component drawing suitable for transfer to an AM system, including:
 - 3D model created on a CAD software package
 - image created in a photo-editing software package
 - a component scanned in three dimensions and uploaded into a CAD or photo-editing software package
 - process the CAD or photo-edited image into a file suitable for manufacturing on an additive system.

C2 Manufacture of a component using an AM process

- Manufacturing process set up and implemented, including:
 - data transfer – CAD to a programming language (standard tessellation language, STL), resolution within machine parameters, transfer rate and memory size
 - component set-up to include physical size, swept volume, scale, orientation and datum
 - safe working practices, including:
 - use of personal protective equipment (PPE), e.g. overalls, safety glasses, safety boots
 - in place and secure machine guards
 - additive machine set-up, to include single or multiple materials, binders, fillers and support structures
 - additive machine parameters during operation, e.g. infill, layer height, feed rate, travel feed rate, temperature, resolution
 - finishing processes, e.g. chemically treated, sanded, and shot blasted.
- Quality control checks, including:
 - components to be free from burrs, and sharp edges
 - checks for accuracy, e.g. external micrometer.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Examine the technology and characteristics of additive manufacturing processes as used in industry		A.D1 Justify, using vocational and high-quality written language, the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably.
A.P1 Explain the technology and characteristics of at least two additive processes used to manufacture components safely and sustainably.	A.M1 Compare the technology and characteristics of at least two additive processes used to manufacture components safely and sustainability.	
Learning aim B: Investigate component design considerations and finishing processes required to effectively use additive manufacturing processes		B.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.
B.P2 Explain how the design of at least two components manufactured using traditional processes could be improved and adapted for additive processes.	B.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.	
B.P3 Explain what finishing processes could be applied to two components if they were manufactured using additive processes instead of traditional manufacturing processes.		
Learning aim C: Develop a component using additive manufacturing processes safely		C.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.
C.P4 Design a component encompassing a hollow section and/or a support that can be manufactured safely using an additive process.	C.M3 Design a component encompassing a hollow section and/or a support that can be manufactured safely and effectively using an additive process.	
C.P5 Manufacture a component encompassing a hollow section and/or a support, safely using an additive and suitable finishing process.	C.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.	
C.P6 Check the finished component for dimensional accuracy against the original design.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aim: A (A.P1, A.M1, A.D1)

Learning aim: B (B.P2, B.P3, B.M2, B.D2)

Learning aim: C (C.P4, C.P5, C.P6, C.M3, C.M4, C.D3)

Further information for teachers and assessors

Resource requirements

For this unit, learners must have access to:

- 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.

Essential information for assessment decisions

Learning aim A

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 × 500 mm 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 aim B

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 aim C

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, learners' 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.

Links to other units

This unit links to:

- Unit 2: Delivery of Engineering Processes Safely as a Team
- Unit 10: Computer Aided Design in Engineering
- Unit 39: Modern Manufacturing Systems
- Unit 40: Computer Aided Manufacturing and Planning
- Unit 41: Manufacturing Secondary Machining Processes
- Unit 42: Manufacturing Primary Forming Processes.

Employer involvement

This unit would benefit from employer involvement in the form of:

- guest speakers
- technical workshops involving staff from local manufacturing organisations with expertise in AM processes
- contribution of ideas to unit assignment/project materials.

Unit 57: Sustainable Transport

Level: **3**

Unit type: **Internal**

Guided learning hours: **60**

Unit in brief

Learners will investigate alternative forms of transport that do not rely on the use of petroleum-based fuels. They will examine the impact on the environment, the economy and the general population.

Unit introduction

Transport is important and matters to everyone. In addition to people needing to travel by vehicle for business, leisure or personal needs, most things we use or consume every day will have been moved by a freight operator. As well as the need to meet these demands in an economically viable way, there is an environmental and social cost in terms of noise, congestion, air pollution and safety. Most transport vehicles still rely on petroleum-based, with significant effects on individuals, the community and the environment.

In this unit you will develop your understanding of the necessity to balance the demand for efficient transport services with the long-term effects on sustainability. You will explore sustainable alternatives to petroleum-based fuel powered vehicles as well as ways to access goods and services that could help to reduce the distanced travelled by transport vehicles. The unit introduces toolkits and instruments for conducting an emissions comparison, and you will be able to use these resources in a practical way. You then go on to investigate the barriers to adopting sustainable transport as well as possible incentives and penalties to influence the adoption of sustainable modes of transport. Finally you will also gain knowledge and understanding in exercising judgement as to the suitability of alternatives for transport needs and develop a campaign tool.

This unit will help to prepare you for an engineering apprenticeship, a higher education engineering degree or for a technician-level role in a wide range of specialist engineering areas.

Learning aims

In this unit you will:

- A** Investigate the sustainability of alternative power sources for transport vehicles
- B** Investigate the wider benefits of reducing the distance travelled by transport vehicles
- C** Investigate how barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport
- D** Investigate ways to improve the sustainability of leisure travel.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Investigate the sustainability of alternative power sources for transport vehicles	A1 Alternative power sources for different modes of transport A2 Assessing sustainable options A3 Sustainability	An individually prepared presentation on alternative power sources to petroleum-based fuels for transport vehicles and on the benefits of reducing the use of transport vehicles in a given location, for example a small town.
B Investigate the wider benefits of reducing the distance travelled by transport vehicles	B1 Economic benefits B2 Environmental benefits B3 Social benefits	
C Investigate how barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport	C1 Barriers to use C2 Incentives to encourage demand C3 Penalties to reduce demand	Report, backed up by research, detailing how barriers, incentives and penalties could affect the demand for and use of sustainable transport at a given location.
D Investigate ways to improve the sustainability of leisure travel	D1 Leisure travel D2 More sustainable options D3 Investigation D3 Campaign tools	A campaign tool to encourage people to reduce their private car use to a specific leisure destination and primary research used to refine the campaign tool.

Content

Learning aim A: Investigate the sustainability of alternative power sources for transport vehicles

A1 Alternative power sources for different modes of transport

- Modes of transport, e.g. cars, lorries, trains, planes and boats.
- Alternative power sources than petroleum, e.g. biodiesel, biogas, ethanol, hydrogen fuel cell, solar, battery.

A2 Assessing sustainable options

- Options:
 - holistic approach to sustainability
 - the effect on the environment, local and wider, current and future
 - the economic cost and benefit to how the social fabric of society will be enhanced
 - considering detrimental effect to the social fabric, local and extended, current and future.
- Sustainability assessment tools, e.g. Brundtland sustainability portal, environmental audit, ecological footprint, social impact assessment, sustainability indicators.

A3 Sustainability

- Economic.
- Environmental.
- Social.
- Meeting the needs of the present without compromising the ability of future generations to meet their own needs.

Learning aim B: Investigate the wider benefits of reducing the distance travelled by transport vehicles

B1 Economic benefits

- Increased use of public transport by paying passengers makes routes more viable.
- Walking, cycling, liftshare schemes reduce personal expenditure on fuel costs.

B2 Environmental benefits

- Reduced drain on the Earth's resources, e.g. petroleum-based fuels.
- Less need for highways maintenance.
- Reduction in wildlife deaths due to collision with vehicles.

B3 Social benefits

- Health and wellbeing.
- Improved air quality.
- Reduced traffic congestion in built-up areas.
- Ease of movement for pedestrians.
- Reduced incidences of traffic accident.
- Increase in social interaction, e.g. walking, bus, park and ride, community minibus, walk to school week, liftshare schemes.

Learning aim C: Investigate how the barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport

C1 Barriers to use

- Barriers, including:
 - cost
 - availability of public transport
 - safety, e.g. travelling late at night
 - communication of timetables
 - service reliability, e.g. not knowing when or whether the transport will arrive
 - efficiency of vehicle
 - storage, e.g. places to put accessories, laptops, luggage, shopping
 - support and assistance, e.g. few staff on buses or trains, help for people with disabilities, the elderly or people with children.

C2 Incentives to encourage demand

- For individual members of the public, including:
 - bus passes
 - free or reduced travel
 - shopper buses
 - coupons in media or with sponsorship
 - cycling, e.g. racks, paths, showers at work, purchase loans and cycle training
 - car share scheme.
- For transport providers including travel plan grants, freight grant for taking freight from road and encouraging rail or water use, bus company subsidies.

C3 Penalties to reduce demand

- Schemes, e.g. car parking tickets, clamping towaway zone.
- Congestion zone charges, toll roads, high car park prices, shorter time allowances for town centre car parks, tax on fuel.

Learning aim D: Investigate ways to improve the sustainability of leisure travel

D1 Leisure travel

- Holidays, social activity, non-essential trips, by transport vehicles, e.g. private car, aeroplane.

D2 More sustainable options

- Alternatives to using car or plane, e.g. train, walking, cycling, public transport.
- Comparing the carbon dioxide emissions of the four main modes of transport (car, rail, bus/coach, plane) for a journey using web-based toolkits.
- Case studies, e.g. Department for Transport Sustainable Travel Towns Study.

D3 Investigation

- Case studies, surveys, press articles, advertising literature.
- Using assessment toolkits to measure carbon dioxide (CO₂) impact of various modes of transport.
- Primary research into the effectiveness of campaign tools, e.g. surveys and interviews.

D4 Campaign tools

- Leaflets, posters, websites, advertisements.
- Social networking.
- Incentives, e.g. competitions, loyalty cards (rail user cards, discounted travel).
- Awareness campaigns, promoting wider benefits.
- Effectiveness of campaign tools, e.g. target audience, message, accuracy, visual impact.

Assessment criteria

Pass	Merit	Distinction
Learning aim A: Investigate the sustainability of alternative power sources for transport vehicles		AB.D1 Evaluate alternative power sources to petroleum-based fuels for transport vehicles and the benefits of reducing transport vehicle use at a given geographical location.
A.P1 Describe alternative power sources to petroleum-based fuels for transport vehicles, in terms of their economic, environmental and social sustainability.	A.M1 Compare alternative power sources to petroleum-based fuels for transport vehicles, in terms of their economic, environmental and social sustainability.	
Learning aim B: Investigate the wider benefits of reducing the distance travelled by transport vehicles		
B.P2 Describe the economic, environmental and social benefits of reducing transport vehicle use at a given geographical location.	B.M2 Explain the economic, environmental and social benefits of reducing transport vehicle use at a given geographical location.	
Learning aim C: Investigate how the barriers to use, incentives and penalties could affect the demand for sustainable vehicle transport		C.D2 Evaluate the barriers to use and the effectiveness of incentives and penalties that affect the demand for sustainable vehicle transport at a specific location.
C.P3 Explain the barriers to use and incentives for an individual that could affect the demand for sustainable vehicle transport at a specific location.	C.M3 Discuss the barriers to use, incentives and penalties that affect the demand for sustainable vehicle transport at a specific location.	
C.P4 Explain the incentives and penalties for a given transport provider that could affect the use of sustainable vehicle transport at a specific location.		
Learning aim D: Investigate ways to improve the sustainability of leisure travel		D.D3 Develop an effective campaign tool that compares the benefits and drawbacks of alternative sustainable modes of transport to a leisure destination, making justified refinements based on primary research.
D.P5 Create a campaign tool for an alternative sustainable mode of transport to a leisure destination.	D.M4 Develop a campaign tool that compares the benefits of alternative sustainable modes of transport to a leisure destination, making refinements based on primary research.	
D.P6 Conduct primary research into the effectiveness of the campaign tool.		

Essential information for assignments

The recommended structure of assessment is shown in the unit summary along with suitable forms of evidence. *Section 6* gives information on setting assignments and there is further information on our website.

There is a maximum number of three summative assignments for this unit. The relationship of the learning aims and criteria is:

Learning aims: A and B (A.P1, B.P2, A.M1, B.M2, AB.D1)

Learning aim: C (C.P3, C.P4, C.M3, C.D2)

Learning aim: D (D.P5, D.P6, D.M4, D.D3)

Further information for teachers and assessors

Resource requirements

Learners need access to computers to research information on the internet and through the media. Access to video footage of real-life schemes would be beneficial. Transport will be required for site visits to organisations that have promoted or implemented sustainable transport use.

Access to case studies would also be beneficial. For example, how individuals, groups of people or organisations have implemented sustainable transport or travel initiatives.

Essential information for assessment decisions

Learning aims A and B

For distinction standard, learners will evaluate alternative power sources to petroleum-based fuels by considering the advantages and disadvantages of each for use at a given geographical location. They will use sustainability assessment tools and provide a justified conclusion for the most appropriate power source.

Learners will also evaluate the economic, environmental and social benefits of reducing the use of transport vehicles in a specific geographical location. They will provide a justified conclusion that identifies the most important actions that are likely to produce the biggest benefits in terms of sustainability. All three wider benefits must be covered and relevant examples given.

For merit standard, learners will compare alternative power sources to petroleum-based fuels and use sustainability assessment tools and other sources of information to make the economic, environmental and social comparison. The comparison will be for a mode of transport at a given geographical location.

Learners will also explain, for a given geographical location, what the economic, environmental and social benefits are for reducing the use of transport vehicles. The explanation must cover all three different types of wider benefit and be explicitly focused on the locality, with specific relevant examples evident. Learners' explanations will need to link many of the points being made with appropriate reasoning.

For pass standard, learners need to describe appropriate alternative power sources to petroleum-fuels for different types of transport vehicle used at a given geographical location. At least three different alternative power sources must be covered in terms of their economic, environmental and social sustainability.

Learners will also need to describe the benefits of reducing the use of transport vehicles at a given geographical location. All three types of wider benefit (economic, environmental and social) must be covered with some relevant examples given.

Learning aim C

For distinction standard, learners must evaluate the barriers as well as the effectiveness of incentives and penalties that affect the demand for and use of sustainable transport at a given location. For example, the barriers, incentives and penalties related to the use of the London Congestion Charge Zone, commenting on its effectiveness to increase the demand for sustainable transport. The evaluation must cover intended and unintended impacts and a justified conclusion, with appropriate data, must be given, and the response must cover individuals and private transport providers.

For merit standard, learners need to discuss the barriers as well as incentives and penalties that affect the demand for and use of sustainable transport at a given location. Where appropriate, learners should cover how the points being made interrelate and provide data (where possible) about the size of the impact that they may have. The response must cover individuals and private transport providers, but a conclusion is not required.

For pass standard, learners need to explain about appropriate barriers as well as incentives and penalties that affect the demand for and use of sustainable transport at a given location. They will need to clearly state which are for an individual and which are for the given private transport provider. Learners will need to show they are aware of incentives and penalties currently in existence, such as free or subsidised public transport and car share schemes to encourage reduced car use.

Learning aim D

For distinction standard, learners will develop an effective campaign tool that compares the benefits and drawbacks of at least two alternative sustainable modes of travel to a leisure destination. The information provided in the campaign tool will be supported by appropriate and referenced research. In addition, primary research/peer review will be completed once an appropriate outline idea has been selected. It will focus on the effectiveness of the outline idea in terms of target audience, message, accuracy and visual impact and will be used to justify the need for refining the campaign tool further during its development.

For merit standard, learners will develop a campaign tool that compares at least two alternative sustainable modes of travel to a leisure destination. Learners will need to cover and compare the wider benefits of choosing the sustainable transportation alternatives, for example social, health and wellbeing benefits, in addition to the more obvious environmental benefits. Primary research/peer review will have been completed to inform any further refinement of the campaign tool during its development but changes may not be justified.

For pass standard, learners will create a campaign tool for an alternative sustainable mode of transport to a leisure destination. For example, a learner may select train travel as an alternative mode of transport to using a private car for a domestic or close foreign holiday. Learners will support their decisions with evidence about the sustainability of the mode of transport chosen, but are likely to focus on the environmental benefits rather than other wider benefits. Learners will also conduct primary research/peer review into the effectiveness of the campaign tool, but it may not have been used to justify any further refinement to the campaign tool during development and it may lack detail.

Links to other units

This unit links to:

- Unit 58: Energy Management.

Employer involvement

This unit would benefit from employer involvement in the form of:

- educational visits to manufacturing plants or transport offices
- guest speakers
- technical workshops involving staff from local transportation specialists
- contribution of ideas to unit assignment/project materials.

4 Planning your programme

How do I choose the right BTEC National qualification for my learners?

BTEC Nationals come in a range of sizes, each with a specific purpose. You will need to assess learners very carefully to ensure that they start on the right size of qualification to fit into their 16–19 study programme, and that they take the right pathways or optional units that allow them to progress to the next stage.

If a learner is clear that they want to progress to the workplace they should be directed towards an occupationally-specific qualification, such as a BTEC National Diploma, from the outset.

Some learners may want to take a number of complementary qualifications or keep their progression options open. These learners may be suited to taking a BTEC National Certificate or Extended Certificate. Learners who then decide to continue with a fuller vocational programme can transfer to a BTEC National Diploma or Extended Diploma, for example for their second year.

Some learners are sure of the sector they want to work in and are aiming for progression into that sector via higher education. These learners should be directed to the two-year BTEC National Extended Diploma as the most suitable qualification.

As a centre, you may want to teach learners who are taking different qualifications together. You may also wish to transfer learners between programmes to meet changes in their progression needs. You should check the qualification structures and unit combinations carefully as there is no exact match among the different sizes. You may find that learners need to complete more than the minimum number of units when transferring.

When learners are recruited, you need to give them accurate information on the title and focus of the qualification for which they are studying.

Is there a learner entry requirement?

As a centre it is your responsibility to ensure that learners who are recruited have a reasonable expectation of success on the programme. There are no formal entry requirements but we expect learners to have qualifications at or equivalent to Level 2.

Learners are most likely to succeed if they have:

- five GCSEs at good grades and/or
- BTEC qualification(s) at Level 2
- achievement in English and mathematics through GCSE or Functional Skills.

Learners may demonstrate ability to succeed in various ways. For example, learners may have relevant work experience or specific aptitude shown through diagnostic tests or non-educational experience.

What is involved in becoming an approved centre?

All centres must be approved before they can offer these qualifications – so that they are ready to assess learners and so that we can provide the support that is needed. Further information is given in *Section 8*.

What level of sector knowledge is needed to teach these qualifications?

We do not set any requirements for teachers but recommend that centres assess the overall skills and knowledge of the teaching team to ensure that they are relevant and up to date. This will give learners a rich programme to prepare them for employment in the sector.

What resources are required to deliver these qualifications?

As part of your centre approval you will need to show that the necessary material resources and work spaces are available to deliver BTEC Nationals. For some units, specific resources are required. This is indicated in the units.

Which modes of delivery can be used for these qualifications?

You are free to deliver BTEC Nationals using any form of delivery that meets the needs of your learners. We recommend making use of a wide variety of modes, including direct instruction in classrooms or work environments, investigative and practical work, group and peer work, private study and e-learning.

What are the recommendations for employer involvement?

BTEC Nationals are vocational qualifications and, as an approved centre, you are encouraged to work with employers on the design, delivery and assessment of the course to ensure that learners have a programme of study that is engaging and relevant and that equips them for progression. There are suggestions in many of the units about how employers could become involved in delivery and/or assessment but these are not intended to be exhaustive and there will be other possibilities at local level.

What support is available?

We provide a wealth of support materials, including curriculum plans, delivery guides, authorised assignment briefs, additional papers for external assessments and examples of marked learner work.

You will be allocated a Standards Verifier early on in the planning stage to support you with planning your assessments. There will be extensive training programmes as well as support from our Subject Advisor team.

For further details see *Section 10*.

How will my learners become more employable through these qualifications?

All BTEC Nationals are mapped to relevant occupational standards (see *Appendix 1*).

Employability skills, such as team working and entrepreneurialism, and practical hands-on skills have been built into the design of the learning aims and content. This gives you the opportunity to use relevant contexts, scenarios and materials to enable learners to develop a portfolio of evidence that demonstrates the breadth of their skills and knowledge in a way that equips them for employment.

5 Assessment structure and external assessment

Introduction

BTEC Nationals are assessed using a combination of *internal assessments*, which are set and marked by teachers, and *external assessments* which are set and marked by Pearson:

- mandatory units have a combination of internal and external assessments
- all optional units are internally assessed.

We have taken great care to ensure that the assessment method chosen is appropriate to the content of the unit and in line with requirements from employers and higher education.

In developing an overall plan for delivery and assessment for the programme, you will need to consider the order in which you deliver units, whether delivery is over short or long periods and when assessment can take place. Some units are defined as synoptic units (see *Section 2*). Normally, a synoptic assessment is one that a learner would take later in a programme and in which they will be expected to apply learning from a range of units. Synoptic units may be internally or externally assessed. Where a unit is externally assessed you should refer to the sample assessment materials (SAMs) to identify where there is an expectation that learners draw on their wider learning. For internally-assessed units, you must plan the assignments so that learners can demonstrate learning from across their programme. A unit may be synoptic in one qualification and not another because of the relationship it has to the rest of the qualification.

We have addressed the need to ensure that the time allocated to final assessment of internal and external units is reasonable so that there is sufficient time for teaching and learning, formative assessment and development of transferable skills.

In administering internal and external assessment, the centre needs to be aware of the specific procedures and policies that apply, for example to registration, entries and results. An overview with signposting to relevant documents is given in *Section 7*.

Internal assessment

Our approach to internal assessment for these qualifications will be broadly familiar to experienced centres. It offers flexibility in how and when you assess learners, provided that you meet assessment and quality assurance requirements. You will need to take account of the requirements of the unit format, which we explain in *Section 3*, and the requirements for delivering assessment given in *Section 6*.

External assessment

A summary of the external assessment for this qualification is given in *Section 2*. You should check this information carefully, together with the unit specification and the sample assessment materials, so that you can timetable learning and assessment periods appropriately.

Learners must be prepared for external assessment by the time they undertake it. In preparing learners for assessment you will want to take account of required learning time, the relationship with other external assessments and opportunities for retaking. You should ensure that learners are not entered for unreasonable amounts of external assessment in one session. Learners may resit an external assessment to obtain a higher grade of near pass or above. If a learner has more than one attempt, then the best result will be used for qualification grading, up to the permitted maximum. It is unlikely that learners will need to or benefit from taking all assessments twice so you are advised to plan appropriately. Some assessments are synoptic and learners are likely to perform best if these assessments are taken towards the end of the programme.

Key features of external assessment in engineering

In engineering, after consultation with stakeholders, we have developed the following:

- *Unit 1: Engineering Principles*, the knowledge and understanding contained in the unit can be reliably and validly assessed through an external exam and covers both mechanical and electrical/electronic principles. Learners are expected to solve a range of problems as multi-skilled engineers. The range of content covered and the rigor of this assessment approach is approved by industry and higher education.
- *Unit 3: Engineering Product Design and Manufacture*, the assessment task simulates the work environment where design activities involve research, working to a client brief and improving the design of a product. This is completed in a set time period as in industry.

Units

The externally-assessed units have a specific format which we explain in *Section 3*. The content of units will be sampled across external assessments over time through appropriate papers and tasks. The ways in which learners are assessed are shown through the assessment outcomes and grading descriptors. External assessments are marked and awarded using the grade descriptors. The grades available are Distinction (D), Merit (M), Pass (P) and Near Pass (N). The Near Pass (N) grade gives learners credit below a Pass, where they have demonstrated evidence of positive performance which is worth more than an unclassified result but not yet at the Pass standard.

Sample assessment materials

Each externally-assessed unit has a set of sample assessment materials (SAMs) that accompanies this specification. The SAMs are there to give you an example of what the external assessment will look like in terms of the feel and level of demand of the assessment. In the case of units containing synoptic assessment, the SAMs will also show where learners are expected to select and apply from across the programme.

The SAMs show the range of possible question types that may appear in the actual assessments and give you a good indication of how the assessments will be structured. While SAMs can be used for practice with learners, as with any assessment the content covered and specific details of the questions asked will change in each assessment.

A copy of each of these assessments can be downloaded from our website. An additional sample of each of the Pearson-set units will be available before the first sitting of the assessment to allow your learners further opportunities for practice.

6 Internal assessment

This section gives an overview of the key features of internal assessment and how you, as an approved centre, can offer it effectively. The full requirements and operational information are given in the *Pearson Quality Assurance Handbook*. All members of the assessment team need to refer to this document.

For BTEC Nationals it is important that you can meet the expectations of stakeholders and the needs of learners by providing a programme that is practical and applied. Centres can tailor programmes to meet local needs and use links with local employers and the wider vocational sector.

When internal assessment is operated effectively it is challenging, engaging, practical and up to date. It must also be fair to all learners and meet national standards.

Principles of internal assessment

Assessment through assignments

For internally-assessed units, the format of assessment is an assignment taken after the content of the unit, or part of the unit if several assignments are used, has been delivered. An assignment may take a variety of forms, including practical and written types. An assignment is a distinct activity completed independently by learners that is separate from teaching, practice, exploration and other activities that learners complete with direction from, and formative assessment by, teachers.

An assignment is issued to learners as an assignment brief with a defined start date, a completion date and clear requirements for the evidence that they need to provide. There may be specific observed practical components during the assignment period. Assignments can be divided into tasks and may require several forms of evidence. A valid assignment will enable a clear and formal assessment outcome based on the assessment criteria.

Assessment decisions through applying unit-based criteria

Assessment decisions for BTEC Nationals are based on the specific criteria given in each unit and set at each grade level. To ensure that standards are consistent in the qualification and across the suite as a whole, the criteria for each unit have been defined according to a framework. The way in which individual units are written provides a balance of assessment of understanding, practical skills and vocational attributes appropriate to the purpose of qualifications.

The assessment criteria for a unit are hierarchical and holistic. For example, if an M criterion requires the learner to show 'analysis' and the related P criterion requires the learner to 'explain', then to satisfy the M criterion a learner will need to cover both 'explain' and 'analyse'. The unit assessment grid shows the relationships among the criteria so that assessors can apply all the criteria to the learner's evidence at the same time. In *Appendix 2* we have set out a definition of terms that assessors need to understand.

Assessors must show how they have reached their decisions using the criteria in the assessment records. When a learner has completed all the assessment for a unit then the assessment team will give a grade for the unit. This is given simply according to the highest level for which the learner is judged to have met all the criteria. Therefore:

- to achieve a Distinction, a learner must have satisfied all the Distinction criteria (and therefore the Pass and Merit criteria); these define outstanding performance across the unit as a whole
- to achieve a Merit, a learner must have satisfied all the Merit criteria (and therefore the Pass criteria) through high performance in each learning aim
- to achieve a Pass, a learner must have satisfied all the Pass criteria for the learning aims, showing coverage of the unit content and therefore attainment at Level 3 of the national framework.

The award of a Pass is a defined level of performance and cannot be given solely on the basis of a learner completing assignments. Learners who do not satisfy the Pass criteria should be reported as Unclassified.

The assessment team

It is important that there is an effective team for internal assessment. There are three key roles involved in implementing assessment processes in your centre, each with different interrelated responsibilities, the roles are listed below. Full information is given in the *Pearson Quality Assurance Handbook*.

- The Lead Internal Verifier (the Lead IV) has overall responsibility for the programme, its assessment and internal verification to meet our requirements, record keeping and liaison with the Standards Verifier. The Lead IV registers with Pearson annually. The Lead IV acts as an assessor, supports the rest of the assessment team, makes sure that they have the information they need about our assessment requirements and organises training, making use of our guidance and support materials.
- Internal Verifiers (IVs) oversee all assessment activity in consultation with the Lead IV. They check that assignments and assessment decisions are valid and that they meet our requirements. IVs will be standardised by working with the Lead IV. Normally, IVs are also assessors but they do not verify their own assessments.
- Assessors set or use assignments to assess learners to national standards. Before taking any assessment decisions, assessors participate in standardisation activities led by the Lead IV. They work with the Lead IV and IVs to ensure that the assessment is planned and carried out in line with our requirements.

Effective organisation

Internal assessment needs to be well organised so that the progress of learners can be tracked and so that we can monitor that assessment is being carried out in line with national standards. We support you through, for example, providing training materials and sample documentation.

It is particularly important that you manage the overall assignment programme and deadlines to make sure that learners are able to complete assignments on time.

Learner preparation

To ensure that you provide effective assessment for your learners, you need to make sure that they understand their responsibilities for assessment and the centre's arrangements.

From induction onwards, you will want to ensure that learners are motivated to work consistently and independently to achieve the requirements of the qualifications. Learners need to understand how assignments are used, the importance of meeting assignment deadlines, and that all the work submitted for assessment must be their own.

You will need to give learners a guide that explains how assignments are used for assessment, how assignments relate to the teaching programme, and how learners should use and reference source materials, including what would constitute plagiarism. The guide should also set out your approach to operating assessment, such as how learners must submit work and request extensions.

Setting effective assignments

Setting the number and structure of assignments

In setting your assignments, you need to work with the structure of assignments shown in the *Essential information for assignments* section of a unit. This shows the structure of the learning aims and criteria that you must follow and the recommended number of assignments that you should use. For some units we provide authorised assignment briefs, for all the units we give you suggestions on how to create suitable assignments. You can find these materials along with this specification on our website. In designing your own assignment briefs you should bear in mind the following points.

- The number of assignments for a unit must not exceed the number shown in *Essential information for assignments*. However, you may choose to combine assignments, for example to create a single assignment for the whole unit.
- You may also choose to combine all or parts of different units into single assignments, provided that all units and all their associated learning aims are fully addressed in the programme overall. If you choose to take this approach, you need to make sure that learners are fully prepared so that they can provide all the required evidence for assessment and that you are able to track achievement in the records.
- A learning aim must always be assessed as a whole and must not be split into two or more tasks.
- The assignment must be targeted to the learning aims but the learning aims and their associated criteria are not tasks in themselves. Criteria are expressed in terms of the outcome shown in the evidence.
- You do not have to follow the order of the learning aims of a unit in setting assignments but later learning aims often require learners to apply the content of earlier learning aims and they may require learners to draw their learning together.
- Assignments must be structured to allow learners to demonstrate the full range of achievement at all grade levels. Learners need to be treated fairly by being given the opportunity to achieve a higher grade if they have the ability.
- As assignments provide a final assessment, they will draw on the specified range of teaching content for the learning aims. The specified content is compulsory. The evidence for assessment need not cover every aspect of the teaching content as learners will normally be given particular examples, case studies or contexts in their assignments. For example, if a learner is carrying out one practical performance, or an investigation of one organisation, then they will address all the relevant range of content that applies in that instance.

Providing an assignment brief

A good assignment brief is one that, through providing challenging and realistic tasks, motivates learners to provide appropriate evidence of what they have learned.

An assignment brief should have:

- a vocational scenario, this could be a simple situation or a full, detailed set of vocational requirements that motivates the learner to apply their learning through the assignment
- clear instructions to the learner about what they are required to do, normally set out through a series of tasks
- an audience or purpose for which the evidence is being provided
- an explanation of how the assignment relates to the unit(s) being assessed.

Forms of evidence

BTEC Nationals have always allowed for a variety of forms of evidence to be used, provided that they are suited to the type of learning aim being assessed. For many units, the practical demonstration of skills is necessary and for others, learners will need to carry out their own research and analysis. The units give you information on what would be suitable forms of evidence to provide learners with the opportunity to apply a range of employability or transferable skills. Centres may choose to use different suitable forms for evidence to those proposed. Overall, learners should be assessed using varied forms of evidence.

Full definitions of types of assessment are given in *Appendix 2*. These are some of the main types of assessment:

- written reports
- projects
- time-constrained practical assessments with observation records and supporting evidence
- recordings of performance
- sketchbooks, working logbooks, reflective journals
- presentations with assessor questioning.

The form(s) of evidence selected must:

- allow the learner to provide all the evidence required for the learning aim(s) and the associated assessment criteria at all grade levels
- allow the learner to produce evidence that is their own independent work
- allow a verifier to independently reassess the learner to check the assessor's decisions.

For example, when you are using performance evidence, you need to think about how supporting evidence can be captured through recordings, photographs or task sheets.

Centres need to take particular care that learners are enabled to produce independent work.

For example, if learners are asked to use real examples, then best practice would be to encourage them to use their own or to give the group a number of examples that can be used in varied combinations.

Making valid assessment decisions

Authenticity of learner work

Once an assessment has begun, learners must not be given feedback on progress towards fulfilling the targeted criteria.

An assessor must assess only learner work that is authentic, i.e. learners' own independent work. Learners must authenticate the evidence that they provide for assessment through signing a declaration stating that it is their own work.

Assessors must ensure that evidence is authentic to a learner through setting valid assignments and supervising them during the assessment period. Assessors must take care not to provide direct input, instructions or specific feedback that may compromise authenticity.

Assessors must complete a declaration that:

- the evidence submitted for this assignment is the learner's own
- the learner has clearly referenced any sources used in the work
- they understand that false declaration is a form of malpractice.

Centres can use Pearson templates or their own templates to document authentication.

During assessment, an assessor may suspect that some or all of the evidence from a learner is not authentic. The assessor must then take appropriate action using the centre's policies for malpractice. Further information is given in *Section 7*.

Making assessment decisions using criteria

Assessors make judgements using the criteria. The evidence from a learner can be judged using all the relevant criteria at the same time. The assessor needs to make a judgement against each criterion that evidence is present and sufficiently comprehensive. For example, the inclusion of a concluding section may be insufficient to satisfy a criterion requiring 'evaluation'.

Assessors should use the following information and support in reaching assessment decisions:

- the *Essential information for assessment decisions* section in each unit gives examples and definitions related to terms used in the criteria
- the explanation of key terms in *Appendix 2*
- examples of assessed work provided by Pearson
- your Lead IV and assessment team's collective experience, supported by the standardisation materials we provide.

Pass and Merit criteria relate to individual learning aims. The Distinction criteria as a whole relate to outstanding performance across the unit. Therefore, criteria may relate to more than one learning aim (for example A.D1) or to several learning aims (for example DE.D3). Distinction criteria make sure that learners have shown that they can perform consistently at an outstanding level across the unit and/or that they are able to draw learning together across learning aims.

Dealing with late completion of assignments

Learners must have a clear understanding of the centre policy on completing assignments by the deadlines that you give them. Learners may be given authorised extensions for legitimate reasons, such as illness at the time of submission, in line with your centre policies.

For assessment to be fair, it is important that learners are all assessed in the same way and that some learners are not advantaged by having additional time or the opportunity to learn from others. Therefore, learners who do not complete assignments by your planned deadline or the authorised extension deadline may not have the opportunity to subsequently resubmit.

If you accept a late completion by a learner, then the assignment should be assessed normally when it is submitted using the relevant assessment criteria.

Issuing assessment decisions and feedback

Once the assessment team has completed the assessment process for an assignment, the outcome is a formal assessment decision. This is recorded formally and reported to learners.

The information given to the learner:

- must show the formal decision and how it has been reached, indicating how or where criteria have been met
- may show why attainment against criteria has not been demonstrated
- must not provide feedback on how to improve evidence
- must be validated by an IV before it is given to the learner.

Resubmission of improved evidence

An assignment provides the final assessment for the relevant learning aims and is normally a final assessment decision, except where the Lead IV approves one opportunity to resubmit improved evidence based on the completed assignment brief.

The Lead IV has the responsibility to make sure that resubmission is operated fairly. This means:

- checking that a learner can be reasonably expected to perform better through a second submission, for example that the learner has not performed as expected
- making sure that giving a further opportunity can be done in such a way that it does not give an unfair advantage over other learners, for example through the opportunity to take account of feedback given to other learners
- checking that the assessor considers that the learner will be able to provide improved evidence without further guidance and that the original evidence submitted remains valid.

Once an assessment decision has been given to the learner, the resubmission opportunity must have a deadline within 15 working days in the same academic year.

A resubmission opportunity must not be provided where learners:

- have not completed the assignment by the deadline without the centre's agreement
- have submitted work that is not authentic.

Retake of internal assessment

A learner who has not achieved the level of performance required to pass the relevant learning aims after resubmission of an assignment may be offered a single retake opportunity using a new assignment. The retake may only be achieved at a pass.

The Lead Internal Verifier must only authorise a retake of an assignment in exceptional circumstances where they believe it is necessary, appropriate and fair to do so. For further information on offering a retake opportunity, you should refer to the *BTEC Centre Guide to Assessment*. We provide information on writing assignments for retakes on our website (www.btec.co.uk/keydocuments).

Planning and record keeping

For internal processes to be effective, an assessment team needs to be well organised and keep effective records. The centre will also work closely with us so that we can quality assure that national standards are being satisfied. This process gives stakeholders confidence in the assessment approach.

The Lead IV must have an assessment plan, produced as a spreadsheet. When producing a plan, the assessment team may wish to consider:

- the time required for training and standardisation of the assessment team
- the time available to undertake teaching and carry out assessment, taking account of when learners may complete external assessments and when quality assurance will take place
- the completion dates for different assignments
- who is acting as IV for each assignment and the date by which the assignment needs to be verified
- setting an approach to sampling assessor decisions through internal verification that covers all assignments, assessors and a range of learners
- how to manage the assessment and verification of learners' work so that they can be given formal decisions promptly
- how resubmission opportunities can be scheduled.

The Lead IV will also maintain records of assessment undertaken. The key records are:

- verification of assignment briefs
- learner authentication declarations
- assessor decisions on assignments, with feedback given to learners
- verification of assessment decisions.

Examples of records and further information are given in the *Pearson Quality Assurance Handbook*.

7 Administrative arrangements

Introduction

This section focuses on the administrative requirements for delivering a BTEC qualification. It will be of value to Quality Nominees, Lead IVs, Programme Leaders and Examinations Officers.

Learner registration and entry

Shortly after learners start the programme of learning, you need to make sure that they are registered for the qualification and that appropriate arrangements are made for internal and external assessment. You need to refer to the *Information Manual* for information on making registrations for the qualification and entries for external assessments.

Learners can be formally assessed only for a qualification on which they are registered. If learners' intended qualifications change, for example if a learner decides to choose a different pathway specialism, then the centre must transfer the learner appropriately.

Access to assessment

Both internal and external assessments need to be administered carefully to ensure that all learners are treated fairly, and that results and certification are issued on time to allow learners to progress to chosen progression opportunities.

Our equality policy requires that all learners should 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 are not, when they are undertaking one of our qualifications, disadvantaged in comparison to learners who do not share that characteristic
- all learners achieve the recognition they deserve for undertaking a qualification and that this achievement can be compared fairly to the achievement of their peers.

Further information on access arrangements can be found in the Joint Council for Qualifications (JCQ) document *Access Arrangements, Reasonable Adjustments and Special Consideration for General and Vocational Qualifications*.

Administrative arrangements for internal assessment

Records

You are required to retain records of assessment for each learner. Records should include assessments taken, decisions reached and any adjustments or appeals. Further information can be found in the *Information Manual*. We may ask to audit your records so they must be retained as specified.

Reasonable adjustments to assessment

A reasonable adjustment is one that is made before a learner takes an assessment to ensure that they have fair access to demonstrate the requirements of the assessments. You are able to make adjustments to internal assessments to take account of the needs of individual learners. In most cases this can be achieved through a defined time extension or by adjusting the format of evidence. We can advise you if you are uncertain as to whether an adjustment is fair and reasonable. You need to plan for time to make adjustments if necessary.

Further details on how to make adjustments for learners with protected characteristics are given on our website in the document *Supplementary guidance for reasonable adjustment and special consideration in vocational internally-assessed units*.

Special consideration

Special consideration is given after an assessment has taken place for learners who have been affected by adverse circumstances, such as illness. You must operate special consideration in line with our policy (see previous paragraph). You can provide special consideration related to the period of time given for evidence to be provided or for the format of the assessment if it is equally valid. You may not substitute alternative forms of evidence to that required in a unit, or omit the application of any assessment criteria to judge attainment. Pearson can consider applications for special consideration in line with the policy.

Appeals against assessment

Your centre must have a policy for dealing with appeals from learners. These appeals may relate to assessment decisions being incorrect or assessment not being conducted fairly. The first step in such a policy could be a consideration of the evidence by a Lead IV or other member of the programme team. The assessment plan should allow time for potential appeals after assessment decisions have been given to learners. If there is an appeal by a learner, you must document the appeal and its resolution. Learners have a final right of appeal to Pearson but only if the procedures that you have put in place have not been followed. Further details are given in the document *Enquiries and appeals about Pearson vocational qualifications and end point assessment policy*.

Administrative arrangements for external assessment

Entries and resits

For information on the timing of assessment and entries, please refer to the annual examinations timetable on our website.

Access arrangements requests

Access arrangements are agreed with Pearson before an assessment. They allow students with special educational needs, disabilities or temporary injuries to:

- access the assessment
- show what they know and can do without changing the demands of the assessment.

Access arrangements should always be processed at the time of registration. Learners will then know what type of arrangements are available in place for them.

Granting reasonable adjustments

For external assessment, a reasonable adjustment is one that we agree to make for an individual learner. A reasonable adjustment is defined for the individual learner and informed by the list of available access arrangements.

Whether an adjustment will be considered reasonable will depend on a number of factors, to include:

- the needs of the learner with the disability
- the effectiveness of the adjustment
- the cost of the adjustment; and
- the likely impact of the adjustment on the learner with the disability and other learners.

Adjustment may be judged unreasonable and not approved if it involves unreasonable costs, timeframes or affects the integrity of the assessment.

Special consideration requests

Special consideration is an adjustment made to a student's mark or grade after an external assessment to reflect temporary injury, illness or other indisposition at the time of the assessment. An adjustment is made only if the impact on the learner is such that it is reasonably likely to have had a material effect on that learner being able to demonstrate attainment in the assessment.

Centres are required to notify us promptly of any learners who they believe have been adversely affected and request that we give special consideration. Further information can be found in the special requirements section on our website.

Conducting external assessments

Centres must make arrangements for the secure delivery of external assessments. External assessments for BTEC qualifications include examinations, set tasks and performance.

Each external assessment has a defined degree of control under which it must take place. Some external assessments may have more than one part and each part may have a different degree of control. We define degrees of control as follows.

High control

This is the completion of assessment in formal invigilated examination conditions.

Medium control

This is completion of assessment, usually over a longer period of time, which may include a period of controlled conditions. The controlled conditions may allow learners to access resources, prepared notes or the internet to help them complete the task.

Low control

These are activities completed without direct supervision. They may include research, preparation of materials and practice. The materials produced by learners under low control will not be directly assessed.

Further information on responsibilities for conducting external assessment is given in the document *Instructions for Conducting External Assessments*, available on our website.

Dealing with malpractice in assessment

Malpractice means acts that undermine the integrity and validity of assessment, the certification of qualifications, and/or that may damage the authority of those responsible for delivering the assessment and certification.

Pearson does not tolerate actions (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 incidents (or attempted incidents) of malpractice have been proven.

Malpractice may arise or be suspected in relation to any unit or type of assessment within the qualification. For further details regarding malpractice and advice on preventing malpractice by learners, please see Pearson's *Centre guidance: Dealing with malpractice and maladministration in vocational qualifications*, available on our website.

The procedures we ask you to adopt vary between units that are internally-assessed and those that are externally assessed.

Internally-assessed units

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 that a centre is failing to conduct internal assessment according to our policies. The above document gives further information, examples and 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.

Externally-assessed units

External assessment means all aspects of units that are designated as external in this specification, including preparation for tasks and performance. For these assessments centres must follow the JCQ procedures set out in the latest version of *JCQ Suspected Malpractice in Examinations and Assessments Policies and Procedures* (www.jcq.org.uk).

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

Heads of Centres are required to report incidents of any suspected learner malpractice that occur during Pearson external assessments. We ask that centres do so by completing a *JCQ Form M1* (available at www.jcq.org.uk/exams-office/malpractice) and emailing it and any accompanying documents (signed statements from the learner, invigilator, copies of evidence, etc.) to the Investigations 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.

Teacher/centre malpractice

Heads of Centres are required to inform Pearson's Investigations Team of any incident of suspected malpractice by centre staff, before any investigation is undertaken. Heads of centres are requested to inform the Investigations Team by submitting a *JCQ Form M2(a)* (available at www.jcq.org.uk/exams-office/malpractice) with supporting documentation to pqsmalpractice@pearson.com. Where Pearson receives allegations of malpractice from other sources (for example Pearson staff or anonymous informants), the Investigations Team will conduct the investigation directly or may ask the head of centre to assist.

Incidents of maladministration (accidental errors in the delivery of Pearson qualifications that may affect the assessment of learners) should also be reported to the Investigations Team using the same method.

Heads of Centres/Principals/Chief Executive Officers or their nominees are required to inform learners and centre staff suspected of malpractice of their responsibilities and rights; see Section 6.15 of the *JCQ Suspected Malpractice in Examinations and Assessments Policies and Procedures* document.

Pearson reserves the right in cases of suspected malpractice to withhold the issuing of results and/or certificates while an investigation is in progress. Depending on the outcome of the investigation results and/or certificates may be released or 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.

Where learner malpractice is evidenced, penalties may be imposed such as:

- mark reduction for external assessments
- disqualification from the qualification
- being barred 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 you to create an improvement action plan
- requiring staff members to receive further training
- placing temporary blocks on your certificates
- placing temporary blocks 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 centres that are considering appeals against penalties and sanctions arising from malpractice. Appeals against a decision made by Pearson will normally be accepted only from Heads of Centres (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 our *Enquiries and appeals about Pearson vocational qualifications and end point assessment policy*, which is on our website. In the initial stage of any aspect of malpractice, please notify the Investigations Team by email via pqsmalpractice@pearson.com who will inform you of the next steps.

Certification and results

Once a learner has completed all the required components for a qualification, even if final results for external assessments have not been issued, then the centre can claim certification for the learner, provided that quality assurance has been successfully completed. For the relevant procedures please refer to our *Information Manual*. You can use the information provided on qualification grading to check overall qualification grades.

Results issue

After the external assessment session, learner results will be issued to centres. The result will be in the form of a grade. You should be prepared to discuss performance with learners, making use of the information we provide and post-results services.

Post-assessment services

Once results for external assessments are issued, you may find that the learner has failed to achieve the qualification or to attain an anticipated grade. It is possible to transfer or reopen registration in some circumstances. The *Information Manual* gives further information.

Changes to qualification requests

Where a learner who has taken a qualification wants to resit an externally-assessed unit to improve their qualification grade, you firstly need to decline their overall qualification grade. You may decline the grade before the certificate is issued. For a learner receiving their results in August, you should decline the grade by the end of September if the learner intends to resit an external assessment.

Additional documents to support centre administration

As an approved centre you must ensure that all staff delivering, assessing and administering the qualifications have access to this documentation. These documents are reviewed annually and are reissued if updates are required.

- *Pearson Quality Assurance Handbook*: this sets out how we will carry out quality assurance of standards and how you need to work with us to achieve successful outcomes.
- *Information Manual*: this gives procedures for registering learners for qualifications, transferring registrations, entering for external assessments and claiming certificates.
- *Lead Examiners' Reports*: these are produced after each series for each external assessment and give feedback on the overall performance of learners in response to tasks or questions set.
- *Instructions for the Conduct of External Assessments (ICEA)*: this explains our requirements for the effective administration of external assessments, such as invigilation and submission of materials.
- *Regulatory policies*: our regulatory policies are integral to our approach and explain how we meet internal and regulatory requirements. We review the regulated policies annually to ensure that they remain fit for purpose. Policies related to this qualification include:
 - adjustments for candidates with disabilities and learning difficulties, access arrangements and reasonable adjustments for general and vocational qualifications
 - age of learners
 - centre guidance for dealing with malpractice
 - recognition of prior learning and process.

This list is not exhaustive and a full list of our regulatory policies can be found on our website.

8 Quality assurance

Centre and qualification approval

As part of the approval process, your centre must make sure that the resource requirements listed below are in place before offering the qualification.

- Centres must have appropriate physical resources (for example, equipment, IT, learning materials, teaching rooms) to support the delivery and assessment of the qualification.
- Staff involved in the assessment process must have relevant expertise and/or occupational experience.
- There must be systems in place to ensure continuing professional development for staff delivering the qualification.
- Centres must have in place appropriate health and safety policies relating to the use of equipment by learners.
- Centres must deliver the qualification in accordance with current equality legislation.
- Centres should refer to the teacher guidance section in individual units to check for any specific resources required.

Continuing quality assurance and standards verification

On an annual basis, we produce the *Pearson Quality Assurance Handbook*. It contains detailed guidance on the quality processes required to underpin robust assessment and internal verification.

The key principles of quality assurance are that:

- a centre delivering BTEC programmes must be an approved centre, and must have approval for the programmes or groups of programmes that it is delivering
- the centre agrees, as part of gaining approval, to abide by specific terms and conditions around the effective delivery and quality assurance of assessment; it must abide by these conditions throughout the period of delivery
- Pearson makes available to approved centres a range of materials and opportunities, through online standardisation, intended to exemplify the processes required for effective assessment, and examples of effective standards. Approved centres must use the materials and services to ensure that all staff delivering BTEC qualifications keep up to date with the guidance on assessment
- an approved centre must follow agreed protocols for standardisation of assessors and verifiers, for the planning, monitoring and recording of assessment processes, and for dealing with special circumstances, appeals and malpractice.

The approach of quality-assured assessment is through a partnership between an approved centre and Pearson. We will make sure that each centre follows best practice and employs appropriate technology to support quality-assurance processes, where practicable. We work to support centres and seek to make sure that our quality-assurance processes do not place undue bureaucratic processes on centres. We monitor and support centres in the effective operation of assessment and quality assurance.

The methods we use to do this for BTEC Level 3 include:

- making sure that all centres complete appropriate declarations at the time of approval
- undertaking approval visits to centres
- making sure that centres have effective teams of assessors and verifiers who are trained to undertake assessment
- assessment sampling and verification, through requested samples of assessments, completed assessed learner work and associated documentation
- an overarching review and assessment of a centre's strategy for delivering and quality assuring its BTEC programmes, for example making sure that synoptic units are placed appropriately in the order of delivery of the programme.

Centres that do not fully address and maintain rigorous approaches to delivering, assessing and quality assurance cannot seek certification for individual programmes or for all BTEC Level 3 programmes. An approved centre must make certification claims only when authorised by us and strictly in accordance with requirements for reporting.

Centres that do not comply with remedial action plans may have their approval to deliver qualifications removed.

9 Understanding the qualification grade

Awarding and reporting for the qualification

This section explains the rules that we apply in awarding a qualification and in providing an overall qualification grade for each learner. It shows how all the qualifications in this sector are graded.

The awarding and certification of these qualifications will comply with regulatory requirements.

Eligibility for an award

In order to be awarded a qualification, a learner must complete all units, achieve a Near Pass (N) or above in all external units and a pass or above in all mandatory units unless otherwise specified. Refer to the structure in *Section 2*.

To achieve any qualification grade, learners must:

- complete and **have an outcome** (D, M, P, N or U) for all units within a valid combination
- achieve the **required units at Pass or above** shown in *Section 2*, and for the Extended Diploma achieve a minimum 900 GLH at Pass or above (or N or above in external units)
- achieve the **minimum number of points** at a grade threshold.

It is the responsibility of a centre to ensure that a correct unit combination is adhered to.

Learners who do not achieve the required minimum grade (N or P) in units shown in the structure will not achieve a qualification.

Learners who do not achieve sufficient points for a qualification or who do not achieve all the required units may be eligible to achieve a smaller qualification in the same suite provided they have completed and achieved the correct combination of units and met the appropriate qualification grade points threshold.

Calculation of the qualification grade

The final grade awarded for a qualification represents an aggregation of a learner's performance across 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 may 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.

BTEC Nationals are Level 3 qualifications and are awarded at the grade ranges shown in the table below.

Qualification	Available grade range
Certificate, Extended Certificate, Foundation Diploma	P to D*
Diploma	PP to D*D*
Extended Diploma	PPP to D*D*D*

The *Calculation of qualification grade* table, shown further on in this section, shows the minimum thresholds for calculating these grades. The table will be kept under review over the lifetime of the qualification. The most up to date table will be issued on our website.

Pearson will monitor the qualification standard and reserves the right to make appropriate adjustments.

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. The *Information Manual* gives full 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	90 GLH
U	0	0
Pass	6	9
Merit	10	15
Distinction	16	24

Points available for external units

Raw marks from the external units will be awarded **points** based on performance in the assessment. The table below shows the **minimum number of points** available for each grade in the external units.

	Unit size	
	90 GLH	120 GLH
U	0	0
Near Pass	6	8
Pass	9	12
Merit	15	20
Distinction	24	32

Pearson will automatically calculate the points for each external unit once the external assessment has been marked and grade boundaries have been set. For more details about how we set grade boundaries in the external assessment please go to our website.

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 relevant *Calculation of qualification grade* table for the cohort.

Calculation of qualification grade

Applicable for registration from 1 September 2016.

Certificate		Extended Certificate		Foundation Diploma		Diploma		Extended Diploma	
180 GLH		360 GLH		540 GLH		720 GLH		1080 GLH	
Grade	Points threshold	Grade	Points threshold	Grade	Points threshold	Grade	Points threshold	Grade	Points threshold
U	0	U	0	U	0	U	0	U	0
Pass	18	P	36	P	54	PP	72	PPP	108
						MP	88	MPP	124
								MMP	140
Merit	26	M	52	M	78	MM	104	MMM	156
						DM	124	DMM	176
								DDM	196
Distinction	42	D	74	D	108	DD	144	DDD	216
						D*D	162	D*DD	234
								D*D*D	252
Distinction*	48	D*	90	D*	138	D*D*	180	D*D*D*	270

The table is subject to review over the lifetime of the qualification.

Examples of grade calculations based on table applicable to registrations from September 2016

Example 1: Achievement of a Foundation Diploma with a P grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Pass	12
Unit 2	60	Int	Pass	6
Unit 3	120	Ext	Pass	12
Unit 4	60	Int	Pass	6
Unit 9	60	Int	Unclassified	0
Unit 10	60	Int	Distinction	16
Unit 11	60	Int	Merit	10
Totals	540		P	62

The learner has achieved N or higher in Units 1 and 3, and P or higher in Units 2 and 4.

The learner has sufficient points for a P grade

Example 2: Achievement of a Foundation Diploma with a M grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Near Pass	8
Unit 2	60	Int	Distinction	16
Unit 3	120	Ext	Merit	20
Unit 4	60	Int	Distinction	16
Unit 9	60	Int	Distinction	16
Unit 10	60	Int	Merit	10
Unit 11	60	Int	Merit	10
Totals	540		M	96

The learner has sufficient points for a M grade

Example 3: An Unclassified result for a Foundation Diploma

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Merit	20
Unit 2	60	Int	U	0
Unit 3	120	Ext	Pass	12
Unit 4	60	Int	Distinction	16
Unit 9	60	Int	Distinction	16
Unit 10	60	Int	Pass	6
Unit 11	60	Int	Pass	6
Totals	540		U	76

The learner has a U in Unit 2.

The learner has sufficient points for an M grade but has not met the minimum requirement for N or higher in Units 1 and 3, and P or higher in Units 2 and 4.

10 Resources and support

Our aim is to give you a wealth of resources and support to enable you to deliver BTEC National qualifications with confidence. On our website you will find a list of resources to support teaching and learning, and professional development.

Support for setting up your course and preparing to teach

Specification

This **specification** (for teaching from September 2016) includes details on the administration of qualifications and information on all the units for the qualification.

Delivery Guide

This free guide gives you important advice on how to choose the right course for your learners and how to ensure you are fully prepared to deliver the course. It explains the key features of BTEC Nationals (for example employer involvement and employability skills). It also covers guidance on assessment (internal and external) and quality assurance. The guide tells you where you can find further support and gives detailed unit-by-unit delivery guidance. It includes teaching tips and ideas, assessment preparation and suggestions for further resources.

Schemes of work

Free sample schemes of work are provided for each mandatory unit. These are available in Word™ format for ease of customisation.

Curriculum models

These show how the BTECs in the suite fit into a 16–19 study programme, depending on their size and purpose. The models also show where other parts of the programme, such as work experience, maths and English, tutorial time and wider study, fit alongside the programme.

Study skills activities

A range of case studies and activities is provided; they are designed to help learners develop the study skills they need to successfully complete their BTEC course. The case studies and activities are provided in Word™ format for easy customisation.

Support for teaching and learning

Pearson Learning Services provides a range of engaging resources to support BTEC Nationals, including:

- textbooks in e-book and print formats
- revision guides and revision workbooks in e-book and print formats
- teaching and assessment packs, including e-learning materials via the Active Learn Digital Service.

Teaching and learning resources are also available from a number of other publishers. Details of Pearson's own resources and of all endorsed resources can be found on our website.

Support for assessment

Sample assessment materials for externally-assessed units

Sample assessments are available for the Pearson-set units. One copy of each of these assessments can be downloaded from the website/available in print. For each suite an additional sample for one of the Pearson-set units is also available, allowing your learners further opportunities for practice.

Further sample assessments will be made available through our website on an ongoing basis.

Sample assessment materials for internally-assessed units

We do not prescribe the assessments for the internally-assessed units. Rather, we allow you to set your own, according to your learners' preferences and to link with your local employment profile.

We do provide a service in the form of Authorised Assignment Briefs, which are approved by Pearson Standards Verifiers. They are available via our website.

Sample marked learner work

To support you in understanding the expectation of the standard at each grade, examples of marked learner work at PM/MD grades are linked to the Authorised Assignment Briefs.

Training and support from Pearson

People to talk to

There are many people who are available to support you and provide advice and guidance on delivery of your BTEC Nationals. These include:

- Subject Advisors – available for all sectors. They understand all Pearson qualifications in their sector and so can answer sector-specific queries on planning, teaching, learning and assessment
- Standards Verifiers – they can support you with preparing your assignments, ensuring that your assessment plan is set up correctly, and support you in preparing learner work and providing quality assurance through sampling
- Curriculum Development Managers (CDMs) – they are regionally based and have a full overview of the BTEC qualifications and of the support and resources that Pearson provides. CDMs often run network events
- Customer Services – the ‘Support for You’ section of our website gives the different ways in which you can contact us for general queries. For specific queries, our service operators can direct you to the relevant person or department.

Training and professional development

Pearson provides a range of training and professional development events to support the introduction, delivery, assessment and administration of BTEC National qualifications. These sector-specific events, developed and delivered by specialists, are available both face to face and online.

‘Getting Ready to Teach’

These events are designed to get teachers ready for delivery of the BTEC Nationals. They include an overview of the qualifications’ structures, planning and preparation for internal and external assessment, and quality assurance.

Teaching and learning

Beyond the ‘Getting Ready to Teach’ professional development events, there are opportunities for teachers to attend sector- and role-specific events. These events are designed to connect practice to theory; they provide teacher support and networking opportunities with delivery, learning and assessment methodology.

Details of our training and professional development programme can be found on our website.

Appendix 1 Links to industry standards

BTEC Nationals have been developed in consultation with industry and appropriate sector bodies to ensure that the qualification content and approach to assessment aligns closely to the needs of employers. Where they exist, and are appropriate, National Occupational Standards (NOS) and professional body standards have been used to establish unit content.

In the engineering sector, the following approaches have been used.

- The qualifications have been aligned to employer requirements as identified as part of the Apprenticeship Reform process.
- Content has been mapped to the requirements stated for EngTech registration as stated in UK-SPEC along with the output standards identified in the Approval of Qualifications and Apprenticeships Handbook produced by the Engineering Council.

A detailed mapping to the UK-SPEC can be found on our website.

Appendix 2 Glossary of terms used for internally-assessed units

This is a summary of the key terms used to define the requirements within units.

Term	Definition
Carry out (when used in learning aim)	Learners demonstrate skills through practical activities.
Design (when used in learning aim)	The process of deciding on the look and functioning of a product or process.
Develop (when used in learning aim)	Learners acquire and apply skills through practical activities.
Examine (when used in learning aim)	Learners are expected to select and apply knowledge to less familiar contexts.
Explore (when used in learning aim)	Learners apply their skills and/or knowledge to practical testing or trialling.
Implement (when used in learning aim)	Learners put a plan or decision into effect/execution.
Interpret (when used in learning aim)	Learners demonstrate and apply understanding of something to convey a particular meaning.
Investigate (when used in learning aim)	Learners' knowledge is based on personal research and development.
Modify	Learners make partial or minor changes to something.
Plan (when used in learning aim)	Learners map outcomes related to a given or limited task. Learners create a way of doing a task or a series of tasks to achieve specific requirements or objectives showing progress from start to finish.
Reflect on	Learners draw conclusions from their own learning, skills and development.
Review (when used in learning aim)	Process for learning (knowledge or skills) through research, peer review or reflection.
Select (when used in learning aim)	Learners make the best or most suitable choice of something for a specific purpose.
Set up (when used in learning aim)	Learners set the way in which something, for example equipment, is organised, planned or arranged.
Undertake (when used in learning aim)	Learners demonstrate skills. Often referring to given processes or techniques.
Accurate	Free from error, defect or within a tolerance that is appropriate for the context.
Adapt	To change something to suit different conditions or uses.
Analyse	Learners present the outcome of methodical and detailed examination either: <ul style="list-style-type: none"> • breaking down a theme, topic or situation in order to interpret and study the interrelationships between the parts and/or • of information or data to interpret and study key trends and interrelationships.
Application	The action of putting something into operation.
Apply	Bring or put into operation or use.

Term	Definition
Assemble	Fit together the separate component parts of (a machine or other object).
Assess	Learners present careful consideration of varied factors or events that apply to a specific situation, or identify those which are the most important or relevant and arrive at a conclusion.
Build	Construct (something) by putting parts or material together.
Calculate	Produce a numerical answer, showing relevant working.
Capabilities	The ability of a machine/product to meet specified requirements.
Capture	To represent an electronic circuit accurately using software.
Carry out (when used in assessment criterion)	To do or complete something, as in a process to produce an outcome.
Characteristic	A feature or quality belonging typically to an object or thing and serving to identify them.
Check	Examine (something) in order to determine its accuracy, quality, or condition, or to detect the presence of something.
Client brief	A document produced by a client specifying the requirements for a product they are commissioning.
Compare (and contrast)	Learners can identify the main factors relating to two or more items/situations or aspects of a subject that is extended to explain the similarities, differences, advantages and disadvantages. This is used to show depth of knowledge through selection and isolation of characteristics.
Complete	Make or do something to completion.
Component	A part or element of a larger whole, especially a part of a machine or product.
Conduct	The undertaking a series of activities as part of a task.
Consistently	In every case or every occasion.
Constraints	The state of being restricted or confined within prescribed bounds.
Construct	Build or make something.
Create	Bring something into existence, e.g. drawings.
Critically analyse	In a way that involves the objective analysis and evaluation of an issue to form a judgement.
Demonstrate	Learners' work shows the ability to carry out and apply knowledge, understanding and/or skills in a practical situation.
Describe	Learners' work gives a clear, objective account in their own words showing recall and, in some cases application, of the relevant features and information about a subject.
Design (when used in assessment criterion)	The process of creating the form, function and characteristics of a product, system or process.
Determine (the characteristics of...)	To discover the facts or truth about a process or product.
Develop (when used in assessment criterion)	To design, build/manufacture and test a product, circuit or system.

Term	Definition
Diagnose	Identify the nature of a problem or fault by examination of the situation or artefact.
Diagram	A simple plan that represents a machine, system, or idea, etc., often drawn to explain how it works.
Discuss	Learners consider different aspects of: <ul style="list-style-type: none"> • a theme or topic • how they interrelate • the extent to which they are important. A conclusion is not required.
Draw	Make a graphical representation of engineering data or information.
Evaluate	Learners draw on varied information, themes or concepts to consider aspects such as: <ul style="list-style-type: none"> • strengths or weaknesses • advantages or disadvantages • alternative actions • relevance or significance. Learners' enquiries should lead to a supported judgement showing relationship to its context. This will often be in a conclusion.
Examine (when used in assessment criterion)	To test or assess the characteristics of a process or product.
Experiment	A test done in order to learn something or to discover if something works or is true.
Explain	Learners' work shows clear details and gives reasons and/or evidence to support an opinion, view or argument. It could show how conclusions are drawn.
Explore (when used in assessment criterion)	To enquire into or discuss something (for example an option or possibility) in detail.
Feature	A distinctive attribute or aspect of an object or thing.
Find	Ascertain by calculation or enquiry or to discover the facts about something.
Hazards	Something that is dangerous and likely to cause damage to an object or harm to an individual(s).
Identify	Learners indicate the main features or purpose of something by recognising it and/or being able to discern and understand facts or qualities.
Implement (when used in assessment criterion)	Learners consider the relevant factors to put a plan into practice, requiring self-direction of selection of outcome, planning, research, exploration, outcome and review.
Inspect	Look at (someone or something) closely, typically to assess their condition or to discover any shortcomings.
Interpret (when used in assessment criterion)	Learners are able to state the meaning, purpose or qualities of something through the use of images, words or other expressions.
Investigate (when used in assessment criterion)	Learners' work tests the following through practical exploration: <ul style="list-style-type: none"> • qualities of materials • techniques • processes or contexts

Term	Definition
Justify	Learners give reasons or evidence to: <ul style="list-style-type: none"> • support an opinion; or • prove something right or reasonable.
Label	Add text to a graphical representation to identify specific parts.
List	Learners provide information as an item by item record of names or things.
Manage	Learners engage with and influence an activity or process.
Manufacture	To make something using machinery, tools and materials.
Measure	The action of measuring something, for example dimensions, surface finish and voltage.
Methods	A particular procedure for accomplishing or approaching something, especially a systematic or established one.
Models	A representation, either in a graphical, physical or numerical format of something.
Optimise	The process of improving and perfecting a process or product by incremental steps to achieve the best performance possible (given constraints).
Organisation	An organised group of people with a particular purpose, such as a business, company or government department.
Outline	Learners' work, performance or practice provides a summary or overview or a brief description of something.
Perform	Learners can carry out or execute what has to be done to complete a given activity.
Plan (when used in assessment criterion)	Learners create a way of doing a task or a series of tasks to achieve specific requirements or objectives showing progress from start to finish.
Practical	Learners apply knowledge and demonstrate skills to a given task to produce an outcome.
Prepare	Learners gather materials, tools and procedures ready to undertake a process and/or make something ready for use.
Present	To give, provide, or make something known.
Principles	A general scientific theorem or law that has numerous special applications.
Procedure	A set of actions that is the official or accepted way of doing something.
Processes	A series of actions or steps taken in order to achieve a particular end.
Produce	Learners' knowledge, understanding and/or skills are applied to develop a particular type of evidence, for example a plan or report.
Product	A product contains one or more than one component and is offered for sale or use.
Quality control	The process of looking at products or components when they are being manufactured to make certain that all the items are of the intended standard.
Recommend	To suggest that a particular action should be done.
Refine	To improve an idea, method, system, product etc. by making small changes.

Term	Definition
Repair	Restore (something damaged, faulty, or worn) to a good condition.
Research	An analysis of substantive research organised by learners from secondary and if applicable primary sources.
Review (when used in assessment criterion)	Learners make a formal assessment of their work. They appraise existing information or prior events, or reconsider information with the intention of making changes if necessary.
Risks	The possibility of something, most likely negative, happening or a future event which could adversely or positively impact project processes or outcomes.
Select	Learners choose the best or most suitable option whether this is of materials, techniques, equipment or processes. The options and choices should be based on specific criteria.
Set up (when used in assessment criterion)	To set up a machine or process ready for operation or to assemble.
Simulate	A representation, either in a graphical or numerical format, of something or a realistic work situation.
Solve	Find an answer to, explanation for, or means of effectively dealing with an engineering problem.
State	Declare definitely or specifically.
Sustainability	The ability of a product or process to be sustained, supported, upheld, or confirmed over a long period of time.
System(s)	An assemblage or combination of things or parts forming a complex or unitary whole.
Test	Take measures to check the quality, performance, or reliability of something, especially before putting it into widespread use or practice.
Tolerance	The permissible range of variation in a dimension of a product or component as determined by the constraints.
Undertake (when used in assessment criterion)	Learners select and apply knowledge to demonstrate skills.
Use	Take, hold, or deploy (something) as a means of accomplishing or achieving something; employ. Learners' practice evidences the ability to carry out and apply knowledge, understanding and skills in a practical situation.

This is a key summary of the types of evidence used for BTEC Nationals.

Type of evidence	Definition and purpose
Artefact	An object or output from a human devised process.
Case study	A specific example to which all learners must select and apply knowledge. Used to show application to a realistic context where direct experience cannot be gained.
Design documentation	A way to communicate the design itself, the rationale for decisions made, and the tools for clients to carry on once the project is complete.

Type of evidence	Definition and purpose
Logbook	A record made by learners of how a process of development was carried out, including experimental stages, testing, selection and rejection of alternatives, practice or development steps.
Observation record	An observation record is used to provide a formal record of a judgement of learners' performance (for example during presentations, practical activities) against the targeted assessment criteria. It must be completed by the assessor of the unit or qualification. An observation record alone does not confer an assessment decision.
Portfolio of evidence	A collection of documents which demonstrate knowledge-based skills and work that has been undertaken to be assessed as evidence to meet required skills outcomes.
Practical task	Learners undertake a defined or self-defined task to produce an outcome of a defined quality.
Production of plan	Learners produce plans as an outcome related to a given or limited task.
Project management	A large-scale activity requiring self-direction of selection of outcome, planning, research, exploration, outcome and review.
Reflective account/development log or logbook	A record kept by learners to show the process of development. Used to show method, self-management, skill development, experimental stages, testing, selection and rejection of alternatives, practice or development steps.
Report/research report	A self-directed, large-scale activity requiring, planning, research, exploration, outcome and review. Used to show self-management, project management and/or deep learning, including synopticity.
Research project	An analysis of substantive research organised by learners from secondary and if applicable primary sources.
Test plan	A document detailing the objectives and processes for a specific test for a product. The plan typically contains a detailed understanding of the eventual workflow.
Witness statement	Can be used to provide a written record of learners' performance against targeted assessment criteria. Anyone within the work experience placement who has witnessed the skills being demonstrated can complete a witness statement, including staff who do not have direct knowledge of the qualification, unit or evidence requirements, but who are able to make a professional judgement about learners' performance in the given situation.

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BTEC Level 3 Nationals

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Engineering

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Foundation Diploma in Engineering

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- Engineering
- Electrical and Electronic Engineering
- Mechanical Engineering
- Computer Engineering
- Manufacturing Engineering
- Aeronautical Engineering

Extended Diplomas in:

- Engineering
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