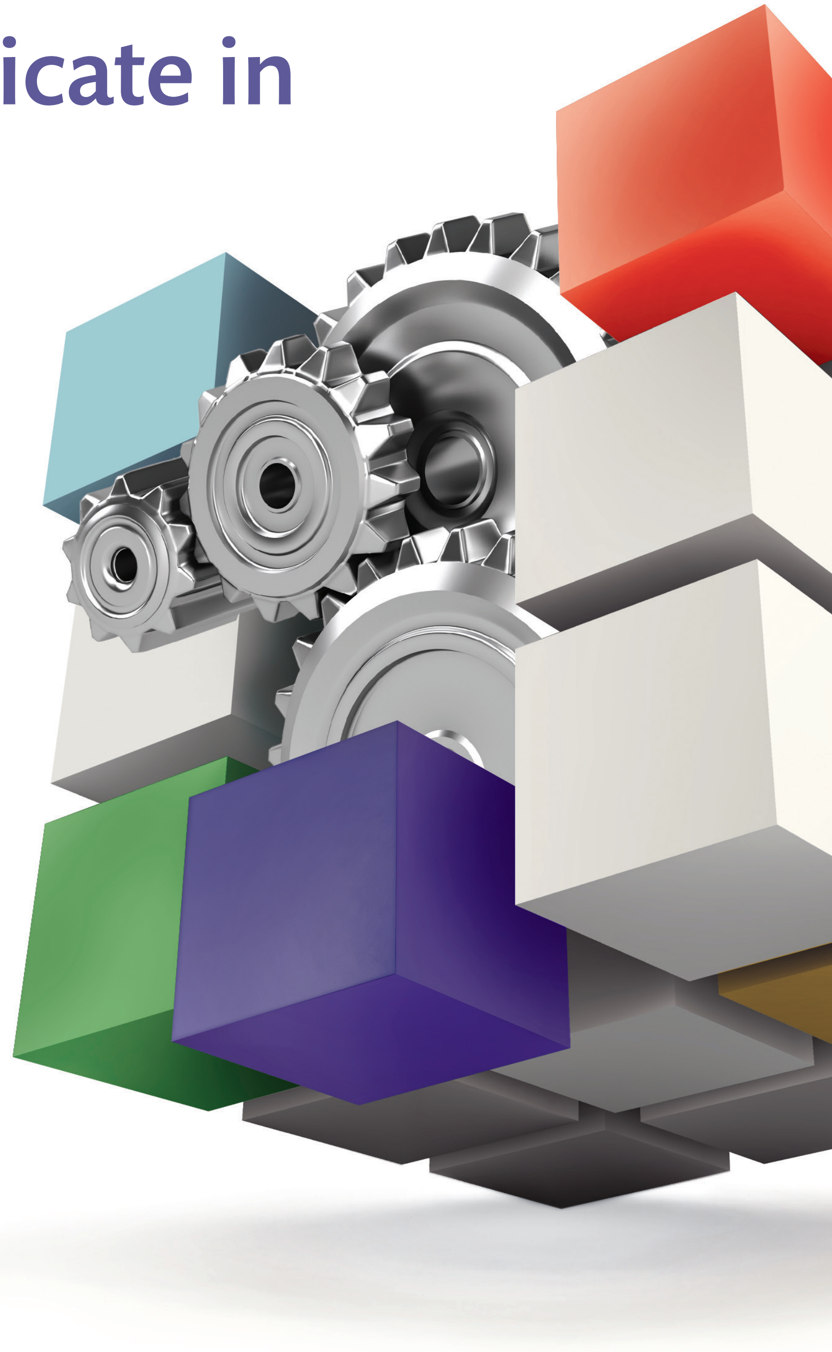
Pearson BTEC

Pearson
BTEC Level 3 National Extended Certificate in Engineering



Specification

First teaching from September 2016

First certification from 2017

Issue 9

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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 Extended Certificate in Engineering specification Issue 9 changes

Summary of changes made between the previous issue and this current issue	Page number
The *Structures of the qualifications at a glance* table has been updated to include units that have been added to the Extended Certificate, Diploma and Extended Diploma.	Pages 10 and 13
Unit 7: Calculus to Solve Engineering Problems has been added to the optional unit list to allow learners to select an appropriate choice of units if progressing into Higher Education,	Pages 19, 57
Removal of references to MyBTEC, as that service is retiring.	Pages 186, 190, 195, 208, 209

Summary of Pearson BTEC Level 3 National Extended Certificate in Engineering specification Issue 8 changes

Summary of changes made between Issue 7 and Issue 8	Page number
The last paragraph of the *Qualification and unit content* 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
Changes made to *Unit 19: Electronic Devices and Circuits* Content for B3, Assessment criteria for Learning aim B and Essential information for assessment decisions section Learning aim B Distinction and Merit standard.	Pages 100, 102, 105

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.

Contents

Introduction to BTEC National qualifications for the engineering sector

This specification contains the information you need to deliver the Pearson BTEC Level 3 National Extended Certificate in Engineering. The specification signposts also 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
Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering	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%).	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.
Pearson BTEC Level 3 National Diploma in Mechanical Engineering	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%).	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.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Diploma in Computer Engineering	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%).	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. 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.
Pearson BTEC Level 3 National Diploma in Manufacturing Engineering	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%).	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. 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.

Title	Size and structure	Summary purpose
Pearson BTEC Level 3 National Diploma in Aeronautical Engineering	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%).	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. 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.
Pearson BTEC Level 3 National Extended Diploma in Engineering	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%).	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. 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 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

(shaded)	**Unit assessed externally**
M	**Mandatory units**
O	**Optional units**
E	**Engineering**
EE	**Electrical/Electronic**
ME	**Mechanical**
C	**Computer**
MA	**Manufacturing**
AE	**Aeronautical**

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**			O	O		O		O	O	O		O		O	O
14 Electrical Installation of Hardware and Cables	**60**				O	O		O			O	O		O	O	
15 Electrical Machines**	**60**			O	O	O	O	O		O	O	O	O	O		O
16 Three Phase Electrical Systems	**60**				O	O		O	O	O	O	O		O	O	O
17 Power and Energy Electronics	**60**				O	O					O	O				
18 Electrical Power Distribution and Transmission	**60**				O	O		O			O	O	O	O		
19 Electronic Devices and Circuits	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
20 Analogue Electronic Circuits	**60**				O	O	O	O			O	O	O	O		
21 Electronic Measurement and Testing of Circuits	**60**			O	O	O	O	O			O	O	O	O	O	O
22 Electronic Printed Circuit Board Design and Manufacture	**60**			O	O	O		O	O		O	O		O	O	
23 Digital and Analogue Electronic Systems	**60**				O	O					O	O				
24 Maintenance of Mechanical Systems	**60**			O	O	O	O	O	O		O	O	O	O	O	
25 Mechanical Behaviour of Metallic Materials	**60**		O	O	O	O	O	O	O	O	O	O	O	O	O	O
26 Mechanical Behaviour of Non-metallic Materials	**60**				O		O		O	O	O	O	O		O	O
27 Static Mechanical Principles in Practice	**60**			O	O	O	O	O	O		O	O	O	O	O	
28 Dynamic Mechanical Principles in Practice	**60**				O		O		O		O	O	O		O	O
29 Principles and Applications of Fluid Mechanics	**60**				O		O			O	O		O		O	O
30 Mechanical Measurement and Inspection Technology	**60**		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
31 Thermodynamic Principles and Practice	**60**				O		O			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						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 Extended Certificate 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 Extended Certificate in Engineering is designed for learners who are interested in a career in the engineering sector and want to progress to further study in the sector. Learners will take a practical, applied engineering course as part of their Level 3 study programme, which gives them an introduction to the sector. They will be able to combine this with other qualifications, such as a GCE A Level in Mathematics or Physics, which would allow them to progress to higher education to study engineering or other STEM-related programmes.

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.

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 aas 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:

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

2 Structure

Qualification structure

Pearson BTEC Level 3 National Extended Certificate in Engineering

Mandatory units

There are three mandatory units, one 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 one optional unit.

Pearson BTEC Level 3 National Extended Certificate 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
	Optional units – learners complete 1 unit			
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
19	Electronic Devices and Circuits	**60**	**Optional**	Internal
25	Mechanical Behaviour of Metallic Materials	**60**	**Optional**	Internal
30	Mechanical Measurement and Inspection Technology	**60**	**Optional**	Internal
35	Computer Programming	**60**	**Optional**	Internal
41	Manufacturing Secondary Machining Processes	**60**	**Optional**	Internal
44	Fabrication Manufacturing Processes	**60**	**Optional**	Internal
45	Additive Manufacturing Processes	**60**	**Optional**	Internal

External assessment

This is a summary of the type and availability of external assessment, which is of units making up 66% 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	• 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	• 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 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 *Section 2* 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 *Appendix 2*.
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	Each learning aim has Pass and Merit criteria. Each assignment has at least one Distinction criterion. A full glossary of terms used is given in *Appendix 2*. All assessors need to understand our expectations of the terms used. Distinction criteria represent outstanding performance in the unit. Some criteria require learners to draw together learning from across the learning aims.
Essential information for assignments	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.
Further information for teachers and assessors	The section gives you information to support the implementation of assessment. It is important that this is used carefully alongside the assessment criteria.
Resource requirements	Any specific resources that you need to be able to teach and assess are listed in this section. For information on support resources see *Section 10*.
Essential information for assessment decisions	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.
Links to other units	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.
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.

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 *Section 2* 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 *Section 10*.
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.

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 $TSA = 2\pi rh + 2\pi r^2$
    - volume of sphere $V = \frac{4}{3}\pi r^3$
    - surface area of a sphere $SA = 4\pi r^2$
    - volume of a cone $V = \frac{1}{3}\pi r^2 h$
    - curved surface area of cone $CSA = \pi rl$

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)

  $E = \frac{\sigma}{\varepsilon}$; 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 $F = \rho gAx$
  - 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 $F = \frac{q_1q_2}{4\pi\varepsilon_o r^2}$
- 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 $C = \frac{\varepsilon A}{d}$
- 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 $(\eta) = \frac{P_{out}}{P_{in}}$
- 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

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

  - 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):

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

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

      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	**A1** Common engineering processes **A2** Health and safety requirements **A3** Human factors affecting the performance of engineering processes	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	**B1** Principles of engineering drawing **B2** 2D computer-aided drawing	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	**C1** Principles of effective teams **C2** Team set-up and organisation **C3** Health and safety risk assessment **C4** Preparation activities for batch manufacture or batch service delivery **C5** Delivery of manufacturing or service engineering processes	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 scriber, 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 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 summating 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. $\int\left(x^2 - 3x + 4\right)dx$
  - 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. $\int\left(e^{3t}\right)dt$
- 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. $\int x^2\left(x^3 + 5\right)^2 dx$
  - 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 summating 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

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the benefits of work experience in engineering for own learning and development</td><td rowspan="4">AB.D1 Justify the benefits of preparation in supporting own understanding of the expectations of work experience.</td></tr>
<tr><td>A.P1 Explain how work experience can support the development of own professional skills and personal attributes for work in engineering.
A.P2 Discuss ways in which work experience can inform own career choices and help prepare for employment in engineering.</td><td>A.M1 Analyse how work experience can provide support in gaining a realistic understanding of the engineering sector.</td></tr>
<tr><td colspan="2">Learning aim B: Develop a work experience plan to support own learning and development</td></tr>
<tr><td>B.P3 Explain own responsibilities and limitations on work experience in engineering.
B.P4 Explain how to meet own specific personal and professional development goals while on work placement.</td><td>B.M2 Assess the importance of own work experience plan to support own learning and development.</td></tr>
<tr><td colspan="2">Learning aim C: Carry out work experience tasks to meet set objectives</td><td rowspan="4">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.</td></tr>
<tr><td>C.P5 Demonstrate work-related skills to meet set objectives for work experience tasks.
C.P6 Discuss ways in which work shadowing and observation can support development of own skills while on work placement.</td><td>C.M3 Demonstrate work-related skills with confidence and proficiency to meet objectives in different situations.</td></tr>
<tr><td colspan="2">Learning aim D: Reflect on how work experience influences own personal and professional development</td></tr>
<tr><td>D.P7 Review own strengths and areas for development in response to feedback on work experience placement.
D.P8 Produce a personal development plan which identifies improvements to personal and professional skills for the future.</td><td>D.M4 Assess how self-reflection can contribute to personal and professional development in a work experience placement.</td></tr>
</table>

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 draftsperson 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	A practical drawing activity to produce a 3D model of a product and determine the material properties of components. A portfolio of drawings should include: orthogonal, 3D shaded or solid model, parts list/bill of material and a detail view.
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	A practical drawing activity to produce 2D drawings for an assembled product. A portfolio of drawings should include: orthogonal, an assembly drawing, parts list/bill of material and a sectional view.
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	A practical drawing activity to produce a rendered 3D model of a thin walled and fabricated product. 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.

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

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely</td><td rowspan="2">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.</td></tr>
<tr><td>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.</td><td>A.M1 Compare, using examples, the characteristics and suitability of three different types of maintenance used for the continued operation of plant and equipment.</td></tr>
<tr><td colspan="2">Learning aim B: Examine the use of condition monitoring techniques to detect faults and potential failures before they occur</td><td rowspan="2">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.</td></tr>
<tr><td>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.</td><td>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.</td></tr>
<tr><td colspan="2">Learning aim C: Undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation</td><td rowspan="2">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.</td></tr>
<tr><td>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.</td><td>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.</td></tr>
</table>

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	**A1** Hydraulic and pneumatic power supply components **A2** Hydraulic and pneumatic actuator components **A3** Hydraulic and pneumatic system control components **A4** General system safety and maintenance **A5** Common applications of industrial hydraulic and pneumatic power systems	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	**B1** Creating hydraulic and pneumatic power circuit diagrams **B2** Simulating the operation of hydraulic and pneumatic power circuits	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	**C1** Health and safety requirements for the safe operation of hydraulic and pneumatic power systems **C2** System assembly **C3** Testing and fault finding pneumatic and hydraulic powered systems	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 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
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 **A2** Diode devices and diode-based circuits **A3** Transistor devices and transistor-based circuits **A4** Operational amplifier circuits **A5** Schematic capture and simulation of analogue circuits **A6** Testing physical analogue circuits	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.
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 **B2** Combinational logic circuits **B3** Sequential logic circuits **B4** Schematic capture and simulation of digital circuits **B5** Testing physical digital circuits	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.
C Review the development of analogue and digital electronic circuits and reflect on own performance	**C1** Lessons learned from exploring electronic devices and circuits **C2** Personal performance while exploring electronic devices and circuits	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. The portfolio of evidence generated while exploring electronic devices and circuits, reflecting on own performance.

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 $h_{\text{fe}} = \beta = \dfrac{I_b}{I_c}$
  - circuit voltage gain (transistor amplifier, non-inverting and inverting op-amp circuits) $A_V = \dfrac{V_{\text{out}}}{V_{\text{in}}}$
- Cut-off frequency for op-amp filters $f_C = \dfrac{1}{2\pi RC}$

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 $\left(A \bullet B\right) + \left(C \bullet \overline{D}\right)$
- 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		
A.P1 Simulate, using captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.P2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one. **A.P3** Explain, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**A.M1** Simulate, using accurately captured schematics, the correct operation of at least one diode, transistor and operational amplifier circuit. **A.M2** Build at least one diode, transistor and operational amplifier circuit safely and test the characteristics of each one accurately. **A.M3** Analyse, using the simulation and test results, the operation of at least one diode, transistor and operational amplifier circuit.	**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.
Learning aim B: Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits		
B.P4 Simulate, using captured schematics, the correct operation of at least one combinational logic circuit and two sequential logic circuits. **B.P5** Build at least one combinational logic circuit and two sequential logic circuits safely and test the characteristics of each one. **B.P6** Explain, using the simulation and test results, the operation of at least three logic circuits.	**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. **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. **B.M6** Analyse, using the simulation and test results, the operation of at least three logic circuits.	**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.
Learning aim C: Review the development of analogue and digital electronic circuits and reflect on own performance		
C.P7 Explain how health and safety, electronic and general engineering skills were effectively applied during the development of the circuits. **C.P8** Explain how relevant behaviours were effectively applied during the development of the circuits.	**C.M7** Recommend improvements to the development of the electronic circuits and to the relevant behaviours applied.	**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.

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 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
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 **A2** Types of non-ferrous metals and alloys **A3** Mechanical properties of metallic materials **A4** Grain structure of metallic materials **A5** Effects of processing on the mechanical properties of metallic materials **A6** Microstructure investigation of metallic materials	A report containing investigative research and library images of the microstructures of metallic materials, some of which will have been processed.
B Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements	**B1** In-service requirements of metallic materials **B2** Destructive test procedures **B3** Non-destructive test procedures	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.
C Explore the in-service failure of metallic components and consider improvements to their design	**C1** Ductile and brittle fracture **C2** Creep failure **C3** Fatigue failure **C4** Corrosion mechanisms **C5** Design considerations to help prevent component failure	A report containing investigative research into the failure mode of given engineered products or components and possible design solutions. Observation records are essential.

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 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

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Explore the principles applied to mechanical measurement and inspection methods as used in industry</td><td>A1 Limits and fits
A2 Tolerances
A3 Gauge types</td><td>A report focusing on gauge design and the principles of tolerancing, including notes about limits and fits.
The report to be based on research and to include the design of gauges to inspect four different product features.</td></tr>
<tr><td>B Carry out mechanical measurement and inspection methods to determine if components are fit for purpose</td><td>B1 Measuring practice
B2 Types of mechanical measurement
B3 Comparators
B4 Gauging system
B5 Component features, types and manufacturing processes</td><td>A range of practical measurement and inspection activities recorded in a developmental logbook.
Evidence will be a measurement and inspection report, annotated drawings/photographs of the components and observation records/witness statements.</td></tr>
<tr><td>C Explore statistical process control to inspect components and increase productivity</td><td>C1 Principles of statistics
C2 SPC procedure</td><td rowspan="2">A report covering the use of basic statistics and how these can be applied to control procedures during inspection.
A capability report focusing on the outputs from a particular process, reporting on its suitability.
Both reports should include notes and sketches and will be supported by a developmental logbook.</td></tr>
<tr><td>D Carry out a process capability study to establish machine suitability for a given application</td><td>D1 Pre-process capability study procedure
D2 Process capability study</td></tr>
</table>

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, 900 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

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">Learning aim A: Explore the principles applied to mechanical measurement and inspection methods as used in industry</td><td rowspan="2">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.</td></tr>
<tr><td>A.P1 Apply the principles of limits and fits and tolerances to design a range of limit gauges.</td><td>A.M1 Analyse, including the use of slip gauges, how different limit gauges rely on the principles of limits and fits and tolerances.</td></tr>
<tr><td colspan="2">Learning aim B: Carry out mechanical measurement and inspection methods to determine if components are fit for purpose</td><td rowspan="2">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.</td></tr>
<tr><td>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.</td><td>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.</td></tr>
<tr><td colspan="2">Learning aim C: Explore statistical process control to inspect components and increase productivity</td><td rowspan="4">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.</td></tr>
<tr><td>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.</td><td>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.</td></tr>
<tr><td colspan="2">Learning aim D: Carry out a process capability study to establish machine suitability for a given application</td></tr>
<tr><td>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.</td><td>D.M5 Analyse as part of a process-capability study the accuracy of a process and produce a modified control chart, explaining its use.</td></tr>
</table>

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.P3** Design a new software program with a user interface to meet a client brief, including an outline project plan and test scripts.	**B.M2** Analyse the user requirements, identifying areas where potential pitfalls could occur. **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.P5** Perform tests on the software program against the user requirements, repairing functional faults.	**C.M4** Build a software program with an effective user interface, using the designs and multiple programming paradigms to solve a problem. **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.P7** Explain how relevant behaviours were effectively applied during the development of a software program.	**D.M6** Recommend improvements to the development of a software program and to the relevant behaviours applied.	

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 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	A practical activity involving a risk assessment and the setting up of at least two traditional machining processes and the machining of a component. 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.
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	
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	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. The portfolio of evidence will be generated while machining a component, reviewing the processes and reflecting on own performance.

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, taping, 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 = ±0.1mm to ±0.05mm 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 = ±0.05mm to ±0.01mm and typical surface texture = 6.3 μm to 0.4 μm.
- 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 = ±0.01 mm to ±0.005 mm and typical surface texture = 0.2 μm to 0.03 μm.

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.P3** Set up safely at least two traditional secondary processing machines.	**B.M2** Use the correct tooling, work-holding devices and speeds and feeds to 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.P6** Explain how relevant behaviours 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.	

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 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	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. The portfolio of evidence will be generated while fabricating a product, and reviewing the processes and reflecting on personal performance.

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, scriber, 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.P3** Set up safely at least two cutting, two forming and two joining processes.	**B.M2** Analyse component blanks through modelling and safely and accurately mark components out.	
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.P5** Manufacture a fabricated product safely containing at least four formed components joined using at least two processes.	**C.M3** Manufacture a fabricated product accurately 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.P7** Explain how relevant behaviours were applied effectively during the manufacturing process.	**D.M4** Recommend improvements to the set up and use of fabrication processes and the relevant behaviours applied.	

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 +/− 1 °.

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 dispertion
- 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 rated, 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.P3** Explain what finishing processes could be applied to two components if they were manufactured using additive processes instead of traditional manufacturing 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.	
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.P5** Manufacture a component encompassing a hollow section and/or a support, safely using an additive and suitable finishing process. **C.P6** Check the finished component for dimensional accuracy against the original design.	**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.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.	

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.

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 though 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 of 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 an Extended Certificate 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	Merit	20
Unit 9	60	Int	Unclassified	0
Totals	**360**		**P**	**38**

The learner has achieved N or higher in Units 1 and 3 and P or higher in Unit 2.

The learner has sufficient points for a P grade

Example 2: Achievement of an Extended Certificate with a M grade

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Near Pass	8
Unit 2	60	Int	Merit	10
Unit 3	120	Ext	Distinction	32
Unit 9	60	Int	Distinction	16
Totals	**360**		**M**	**66**

The learner has sufficient points for a M grade

Example 3: An Unclassified Result for an Extended Certificate

	GLH	Type (Int/Ext)	Grade	Unit points
Unit 1	120	Ext	Merit	20
Unit 2	60	Int	Unclassified	0
Unit 3	120	Ext	Distinction	32
Unit 9	60	Int	Merit	10
Totals	**360**		**U**	**62**

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 an N or higher in Units 1 and 3 and P or higher in Unit 2.

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: • 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: • 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: • 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: • qualities of materials • techniques • processes or contexts

Term	Definition
Justify	Learners give reasons or evidence to: • 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.

Pearson BTEC Level 3 Nationals in Engineering

Certificate in Engineering

Extended Certificate in Engineering

Foundation Diploma in Engineering

Diplomas in:
- Engineering
- Electrical and Electronic Engineering
- Mechanical Engineering
- Computer Engineering
- Manufacturing Engineering
- Aeronautical Engineering

Extended Diplomas in:
- Engineering
- Electrical and Electronic Engineering
- Mechanical Engineering
- Computer Engineering
- Manufacturing Engineering
- Aeronautical Engineering

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