Pearson BTEC Nationals in Engineering

Delivery Guide

Pearson BTEC Level 3 National Certificate in Engineering

First teaching September 2018

Pearson BTEC Level 3 National Extended Certificate in Engineering

Pearson BTEC Level 3 National Foundation Diploma in Engineering

Pearson BTEC Level 3 National Diploma in Engineering

Pearson BTEC Level 3 National Diploma in Electrical and Electronic Engineering

Pearson BTEC Level 3 National Diploma in Mechanical Engineering

Pearson BTEC Level 3 National Diploma in Computer Engineering

Pearson BTEC Level 3 National Diploma in Manufacturing Engineering

Pearson BTEC Level 3 National Diploma in Aeronautical Engineering

Pearson BTEC Level 3 National Extended Diploma in Engineering

Pearson BTEC Level 3 National Extended Diploma in Electrical and Electronic Engineering

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Pearson BTEC Level 3 National Extended Diploma in Manufacturing Engineering

Pearson BTEC Level 3 National Extended Diploma in Aeronautical Engineering

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Welcome to your BTEC National delivery guide

This delivery guide is a companion to your BTEC Level 3 National specifications, Authorised Assignment Briefs (AABs) and Sample Assessment Materials (SAMs). It contains ideas for teaching and learning, including practical activities, realistic scenarios, ways of involving employers in delivery, ways of managing independent learning and how to approach assessments. The aim of this guide is to show how the specification content might work in practice and to inspire you to start thinking about different ways to deliver your course.

The guidance has been put together by tutors who have been close to the development of the qualifications and so understand the challenges of finding new and engaging ways to deliver a BTEC programme in the context of the qualifications from 2016 to 2018.

Guidance around what you will need to consider as you plan the delivery of the qualification(s) has been provided. You will find information around the structure of your course, how you may wish to build the course for your learners, suggestions for how you could make contact with employers and information around the other support and resources available to you.

Unit-by-unit guidance has been provided and includes suggestions on how to approach the learning aims and unit content, as well as ideas for interesting and varied activities. You will also find coverage of assessments, including useful advice about external assessment, as well as tips and ideas around how to plan for and deliver your assignments.

You will also find a list of carefully selected resources for each unit. The lists include suggestions for books, websites and videos that you can either direct your learners to use or that you can use as a way to complement your delivery.

We hope you will find this guidance relevant and useful.

Enjoy your course!

What's new

The BTEC Level 3 Nationals 2016 to 2018 are the result of more than three years' consultation with employers, higher education institutions (HEIs), and many thousands of tutors and managers in colleges and schools. Our aim has been to ensure that the BTEC Level 3 Nationals continue to allow a recognised and well-respected route into employment or higher education by meeting the needs of these key stakeholders, and that learners continue to enjoy a stimulating course of study and develop the skills and attributes that will enable them to progress.

As a result of this consultation, and on the advice of employers, higher education institutions and most importantly of those of you who teach BTEC, some key changes have been made to the BTEC Level 3 Nationals. These are described through this delivery guide and include the following.

- **Updated content and a larger proportion of mandatory content** – both employers and universities said they wanted a greater consistency in coverage of the subject for BTEC learners. Employers wanted to see systematic coverage of core knowledge and skills for their sector, and for the Nationals to reflect up-to-date industry practice.
- **The reintroduction of external assessment** – employers were keen to see an element of rigour and consistency across the country in terms of assessment, while higher education institutions wanted learners to be better prepared for meeting deadlines and preparing for formal exams, where appropriate. Both were keen to

see learners applying their knowledge and skills to new contexts through synoptic projects and assessments.

- **A focus on employability skills** – the BTEC approach to learning, through projects, self-directed assignments, group work and work placements has always supported the development of employability skills, e.g. self-management. In the new Nationals, the balance of cognitive and skills work has been carefully calibrated to ensure that learners get a range of different opportunities across their course.
- **Broader assessment in internal units** – the assessment criteria for each unit are carefully structured to set a clear level of demand. Distinction criteria encourage and require depth of study, including demonstration of the application of knowledge and understanding as well as a synoptic element for the learning aim or unit.
- **Alignment with DfE criteria for performance measures for 16–19 year olds in England** – all new BTECs are designed as either Applied General qualifications or Tech Levels to fulfil criteria for inclusion in 2018 performance tables and funding for 16–19 year olds and 19+ learners.

Please check the qualifications website to know the status of funding and performance measure recognition for each year.

We are providing an enhanced support programme with exemplar and practice materials and training. Please see the *Support and resources* section for details of this support, and the link to sign up for tutor training, which continues throughout the lifetime of the qualification.

Notes:

The specification tells you what **must** be taught and what **must** be assessed. This delivery guide gives suggestions about how the content could be delivered.

The suggestions given in this delivery guide link with the Authorised Assignment Briefs provided by Pearson, but they are not compulsory. They are designed to get you started and to spark your imagination.

Contents

Overview

Delivery Guides as support

In the specification, the 'Unit content' tells you what must be taught and the 'Assessment criteria' what must be assessed. The 'Essential information for assessment decisions' explains what the assessment criteria mean.

This delivery guide provides suggestions and ideas on how to plan and deliver the qualification, and includes a summary of recent changes.

Unit-by-unit guidance has been provided, which includes suggestions on how to approach the learning aims and unit content. Teaching, learning and formative assessment activities are also suggested. You will also find delivery plans to help you timetable your course and ensure that your learners are well prepared for internal and external assessments.

Links to carefully selected resources are provided for each unit. The lists include suggestions for books, websites and videos, which will help you plan and deliver your course. Alternatively, you may wish to direct your learners to these resources.

Use the delivery guides as model templates or an interpretation on which you can base your own plan. Every delivery guide presents each unit as an exemplar, highlighting engineering links to motivate tutors and learners.

Significant changes for those teaching to the 2016-18 specification

The BTEC Level 3 Nationals (FT 2016-2017) contain significant changes to the previous 2010 version. These changes reflect the views and demands of engineering practitioners, those working in this sector, and government bodies with oversight of the qualifications.

For those familiar with the older 2010 specification, these changes are summarised in the table below:

Change	2016, 2018		Old 2010	
Programme Name	Engineering		Engineering	
Qualification Names/GLH	Certificate in Engineering (FT 2018)	180 GLH	Certificate in Engineering	180 GLH
	Extended Certificate in Engineering (FT 2016)	360 GLH	Subsidiary Diploma in Engineering	360 GLH
	Foundation Diploma (FT 2016)	540 GLH	90 Credit Diploma in Engineering	540 GLH
	Diploma in Engineering (FT 2016)	720 GLH	Diploma in Engineering (including pathways)	720 GLH
	Diploma in Electrical and Electronic Engineering (FT 2016)	720 GLH		720 GLH
	Diploma in Mechanical Engineering (FT 2016)	720 GLH		720 GLH
	Diploma in Manufacturing Engineering (FT 2016)	720 GLH		720 GLH
	Diploma in Computer Engineering (FT 2016)	720 GLH		720 GLH
	Diploma in Aeronautical Engineering (FT 2016)	720 GLH		720 GLH
	Extended Diploma in Engineering (FT 2016)	1080 GLH	Extended Diploma in Engineering	1080 GLH

	Extended Diploma in Electrical and Electronic Engineering (FT 2016)	1080 GLH	(including pathways)	1080 GLH
	Extended Diploma in Mechanical Engineering (FT 2016)	1080 GLH		1080 GLH
	Extended Diploma in Manufacturing Engineering (FT 2016)	1080 GLH		1080 GLH
	Extended Diploma in Computer Engineering (FT 2016)	1080 GLH		1080 GLH
	Extended Diploma in Aeronautical Engineering (FT 2016)	1080 GLH		1080 GLH
Mandatory Units	National Certificate = 2 Extended Certificates = 3 Foundation Diploma = 4 Diploma = 5 or 6 depending on pathway Extended Diploma = 7 or 8 depending on pathway		Between 1 and 5 dependent on qualification and pathway	
Optional Units	National Certificate: There are no optional units Extended Certificates: Choose 1 from 11 available Foundation Diploma: Choose 3 from 20 available Diploma: Choose 4 or 5 from up to 41 available depending on pathway Extended Diploma: Choose 7or 8 from up to 41 available depending on pathway		Choose from up to 65 dependent on qualification and pathway	
Assessment	Internal through assignment and up to 3 External depending on qualification		Internal only through assignments	

Structure

The table below shows the structure of the qualifications in the Engineering suite of qualifications. By a clear understanding of the units and careful selection, centres can tailor the qualification to suit the needs of their learners and the resources of the centre. Ensure that you use the full structure found in *Section 2* of the specification when planning your course:

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

Key

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

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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	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

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	
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

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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

In order to maximise the quality of learning, the structure of the qualifications has been developed with significant input from all sectors that require learners to have underpinning skills in engineering, including a breadth of employers, higher education institutions and delivery centres.

Learners on the smaller size qualifications who find they have a continuing interest in engineering can move on to a larger qualification in the suite. This flexibility is facilitated through a considered number of mandatory and externally assessed units, which avoids unnecessary repetition of assessment of units.

As Tech Level qualifications, the Diploma, Extended Diploma, Foundation Diploma and Extended Certificate focus on enabling learners to move into industry, ensure they can manage a client brief, realise intentions and have an awareness of professional practice through their mandatory content. Note, however, that the Certificate is not a Tech Level qualification as such, rather an Applied General (AG).

All qualifications require meaningful employer involvement that is relevant to the industry, sector or occupation, except the Certificate, which does not require this. This employer involvement can include:

- work experience and placements
- projects set by employers
- co-delivery of units with employers
- industry guests that contribute to learner practice.

The external assessment encompasses units that are critical to the purpose of each qualification, ensuring realistic and vocational learning experiences.

We firmly believe in the relevance of learning through employer engagement and the qualifications provide ideas on how this can be achieved. Most of the units highlight where employer involvement would benefit the learning and make useful suggestions for how to initiate this participation.

Overview of the Engineering qualification suite

The Engineering BTEC qualifications suite offers a combination of mandatory and optional units with internal and external assessment, which will drive the quality of learning. It will also help learners take increased responsibility for their own development.

The demands within industry mean learners need to be able to manage deadlines and communicate their ideas in different ways. This assessment methodology closely matches experiences learners will have in employment and thus increases their chances of successful progression.

The units provide valuable ways for learners to develop highly transferable skills and to be assessed in a synoptic way. All of the units can contain opportunities for stakeholder or employer engagement to stimulate learning experiences.

The combination of mandatory and optional unit content means that the qualification in Engineering is tailored to suit a mix of mechanical engineering, electrical/electronic engineering and general engineering needs.

These qualifications may also cover a limited amount of specialist engineering content, for example on manufacturing processes or computer programming.

Certificate

The Certificate provides a basic introduction to engineering for learners to include alongside their wider study programme. Learners are given the opportunity to engage with and explore engineering processes and teamwork. Suitable for learners intending further study at higher education, including progression onto one of the more specialist engineering Extended Certificates.

Extended Certificate

This qualification is designed to support progression to apprenticeship or employment when taken as part of a programme of study that includes other appropriate BTEC Nationals or A levels. The Extended Certificate has four units, of which three are mandatory. Units 1 and 3 are externally assessed. The fourth unit is an optional unit.

Foundation Diploma

This qualification supports entry to employment in the sector as well as progression to a further year of study at level 3. It would also support progression to higher education if taken as part of a programme of study that included other BTEC Nationals or A levels. The qualification consists of four mandatory units and three optional units.

Diploma

This qualification is designed to be the substantive part of a 16–19 study programme for learners who want a strong core of engineering study. This programme may include other BTEC Nationals or A levels to support progression either directly to employment in the engineering sector or to higher education courses in engineering. Learners are able to focus on specialisms in electrical/electronic engineering, mechanical engineering, manufacturing engineering, aeronautical engineering, computer engineering, or a general engineering pathway. The additional qualification(s) studied allow learners to either give breadth to their study programme by choosing a contrasting subject, or to give it more focus by choosing a complementary subject. This qualification can also be used to progress to employment in this sector.

Extended Diploma

This qualification is designed to be the main focus of learning in a typical two-year, 16–19 study programme.

This size qualification is particularly appropriate for those with an interest in progressing directly to a career in a specialist area of engineering or to enter the sector following a course in higher education. The same pathways are available as for the Diploma sized qualification. The Extended Diploma features an additional externally assessed unit which is a task that explores microcontroller systems in engineering, which has practical applications in every engineering sector.

Making the right choice for your learners

The qualifications are meant to be inclusive and support individuals in their progression. The prior achievement and aspirations of learners is key to advising the most appropriate study programme.

For learners who wish to progress directly to higher education, the qualifications ensure they will have the skills to cope with the academic and independent learning. In recognition of some of the highly specialised areas within the engineering industry, the qualifications provide opportunities for learners to gain vocational experience in parallel with other specialist qualifications. As Tech Level qualifications, these Diplomas support progression into industry at entry or apprenticeship levels with the understanding required to progress in their careers.

Below are some examples of learners' potential progression routes:

16-year-old student choice		
Progression intention	**Prior achievement**	**Potential BTEC National route**
Engineering subject in HE in Electrical Engineering	Five GCSEs at grade C or above, including Maths and English	BTEC Diploma in Electrical and Electronic Engineering alongside A levels in e.g. Maths, Physics.
Engineering subject in HE, but uncertain of specialism	Five GCSEs at grade C or above, including Maths and English	BTEC Extended Certificate in Engineering alongside A levels in e.g. Maths, Physics, Computing.
Higher Apprenticeship in Engineering but uncertain of specialism	Five GCSEs at grade C or above, including Maths and English	Year 1: BTEC Foundation Diploma in Engineering. Year 2: Start Apprenticeship or continue into BTEC Diploma in a chosen specialism.
Higher Apprenticeship in Aeronautical Engineering	Five GCSEs at grade C or above, including Maths and English	BTEC Extended Diploma in Aeronautical Engineering.
Non-Engineering subject in HE	Five GCSEs at grade C or above, including Maths and English	BTEC Extended Certificate in Engineering alongside A levels in e.g. Business, Economics, Maths, Physics.
Directly to employment in a manufacturing environment	Five GCSEs at grade C or above, including Maths and English	BTEC Diploma in Manufacturing Engineering alongside other BTEC or A level qualifications in e.g. Product Design, Business, or standalone BTEC Extended Diploma in Manufacturing Engineering.

*Routes to higher education (HE) or employment are dependent on prior experience.

19+ learner choice*		
Progression	**Prior achievement**	**Potential BTEC National route**
Employment in an engineering environment	No experience in engineering, but with five GCSEs at grade C or above, including Maths and English	BTEC Extended Diploma in an appropriate specialism.
Engineering subject in HE	Some experience in engineering with five GCSEs at grade C or above, including Maths and English	BTEC Foundation Diploma in Engineering alongside other A level qualifications in e.g. Maths, Physics.

Making contact with employers

Employer contact is one of the most cherished experiences BTEC National learners can have, as it ensures realistic and valuable learning.

Partnerships between companies, freelance practitioners and centres can often develop a relationship that is beneficial to both parties. Here are some ideas that may support centres expanding their employer engagement.

Employability skills

Employers not only look for technical skills, but also employability skills. These include:

- **Self-management**: readiness to accept responsibility, flexibility, time management, readiness to improve own performance
- **Team working**: respecting others, co-operating, negotiating/persuading, contributing to discussions
- **Business and customer awareness**: basic understanding of the key drivers for business success and the need to provide customer satisfaction
- **Problem-solving**: ability to analyse facts and circumstances and applying creative thinking to develop appropriate solutions
- **Communication and literacy**: application of literacy, ability to produce clear, structured written work, and oral literacy (including listening and questioning)
- **Application of numeracy**: manipulation of numbers, general mathematical awareness and its application in practical contexts
- **Application of information technology**: basic IT skills including familiarity with word-processing, spreadsheets, file management and use of internet search engines.

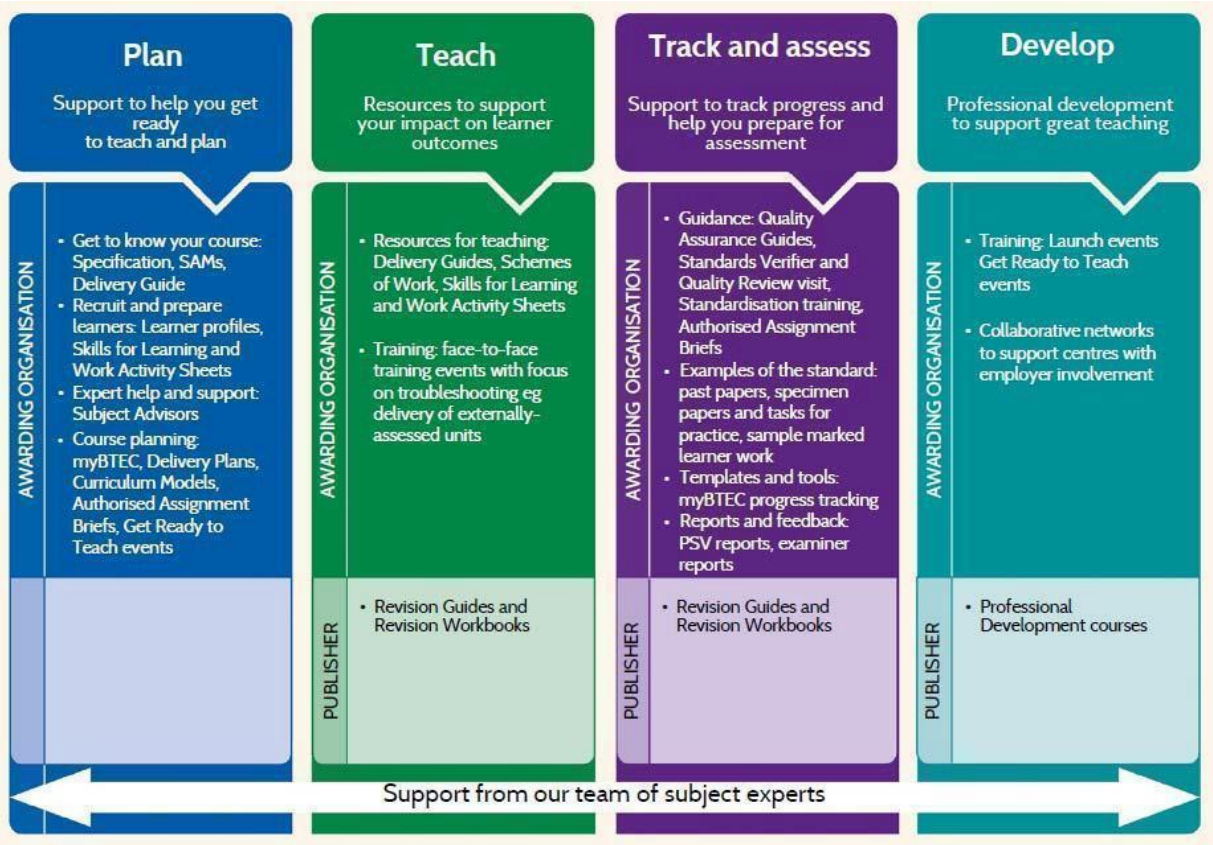
SUPPORT AND RESOURCES

There is a wealth of resources available to ensure you feel confident delivering your BTEC National qualification throughout your entire course.

All the 'Awarding Organisation' resources can be found on the Pearson Qualifications website here: https://qualifications.pearson.com/en/qualifications/btec-nationals/engineering-2016.html

As well as the free resources supporting the qualification, provided by Pearson as an Awarding Organisation, Pearson Learning Services ('Publisher' in the tables below) provides a range of engaging resources to support BTEC Level 3 Nationals. The diagram below shows the resources available (by format and category of use).

In addition to the 'publisher' resources listed above, other publishers in addition to Pearson may produce textbooks that are endorsed for BTEC. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.



There are also a number of people who are available for you to speak to:

- **Standards Verifiers** – they are subject specialists who can support you with ensuring that your assessment plan is fit for purpose and whose role is to confirm that you are assessing your learners to national standards as outlined in the specification by 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.

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Training for the new BTEC Level 3 Nationals can be found on the Pearson website here: http://qualifications.pearson.com/en/support/training-from-pearson-uk.html

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Unit 1: Engineering Principles

Delivery guidance

Approaching the unit

This mandatory unit is intended to give learners the mathematical skills and knowledge of the physical principles that underpin electronic, electrical and mechanical engineering, that they will need in order to meet design challenges and produce effective engineering solutions to solve problems. There is opportunity within the delivery of the unit for a range of problem-solving activities to be carried out, along with some hands-on practical experimentation to gain deeper understanding of principles.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

Delivery of the unit is likely to use a range of different methods, including a large proportion of tutor presentation, along with individual and group work and some paired problem-solving activities. There should be an opportunity for learners to put theory into practice when investigating mechanical principles. The focus should be on equipping learners with the skills they need to be able to apply the mathematical and engineering principles studied in order to solve engineering problems.

Learners will develop the skills needed to be able to identify and respond to engineering problems so that they can perform appropriate procedures in order to arrive at justifiable responses. They should be equipped with the theoretical knowledge that will allow them to explain how systems perform, and to be able to draw together knowledge from different strands of engineering to solve synoptic problems.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the topics

Topic A gives the mathematical foundation for the unit, introducing learners firstly to algebraic methods and then trigonometric methods. In both cases these should be related to engineering problems and scenarios.

Firstly, you could introduce learners to the laws of indices. This could be approached by demonstrating laws to learners before giving them the opportunity to solve problems where the laws need to be applied. This could then be expanded upon by introducing learners to the laws of logarithms, including natural and base 10 logarithms. Following this, you could review understanding of linear equations and the representation of these using graphs and methods to solve simultaneous equations. Building upon this, you could consider quadratic equations and methods to solve them, including use of the quadratic equation.

You could then use the knowledge and understanding of algebraic methods as a foundation for demonstrating how to carry out conversions between angular and circular measurements. Learners should be given the opportunity to apply their understanding of circular measurements to determine areas of sectors and also arc lengths. This should be done in relation to engineering products, for example the arc length for a brake pad. Continuing, you could review understanding of trigonometric functions and the related waveforms for each. This could then be developed through introducing sine and cosine rules to learners, which in turn gives learners a foundation that they can use to develop their understanding of vectors.

Having given learners a foundation of mathematical skills and techniques that they will need to apply to a range of engineering problems, you will need to introduce them to static engineering systems as an introduction to topic B. This will initially build directly on the work undertaken on vectors for topic A, with learners developing the skills needed to represent forces using free body and space diagrams. Further development of the theories relating to forces should then focus on the conditions for static equilibrium, which could be demonstrated visually to learners, along with the principles of moments. This should give learners the skills that they will need in order to investigate simply supported beams and solve related problems.

Once learners have an understanding of forces within static systems, you should introduce more complex concepts that relate to loaded components. Initially, this could be done through an investigation into direct stress and strain, using demonstrations as appropriate. Learners should also be given the skills needed to carry out calculations for both stress and strain. This should then lead into considering shear stress and strain, followed by shear strength and tensile strength. Again, these concepts could be demonstrated visually to learners. Finally, you should give learners the skills to be able to determine the modulus of elasticity and modulus of rigidity. Learners should also be able to interpret the results in order to understand the characteristics of the materials that they have analysed.

You could introduce topic C by reviewing prior understanding of linear motion, before giving learners a research task to investigate the various parameters associated with linear motion, prior to solving problems that relate to the theory. Leading on from this, you could introduce a range of dynamic parameters for each of which you could give learners a research task to help gain an understanding of parameters. This could then be developed by considering conservation of momentum prior to moving onto angular motion. Finally, you could introduce learners to a range of lifting machines, and how both linear and circular motion theories can be applied depending on the nature of the machine. Again, there is scope for individual investigation into a range of lifting machines. Learners should be able to analyse lifting machines in order to determine values such as torque, power and efficiency.

Topic D introduces learners to fluid and thermodynamic systems. There is opportunity within the teaching for both practical demonstrations and activities especially when considering flow rates or methods to determine density. Initially, you could introduce learners to the procedures that need to be followed to calculate the hydrostatic pressure and thrust on submerged planes. Develop this understanding by considering methods to determine density. You could then use a virtual demonstration to explain how flow changes in a gradually tapering pipe, making reference to incompressible flow. Learners could be given a range of activities that test their understanding of these concepts.

With a secure understanding of fluid systems in place, you could then consider thermodynamic systems with learners. You could give learners an opportunity to carry out some independent learning whilst investigating heat transfer parameters. Following discussion of this, learners could be introduced to heat engines and carry out further investigatory work into these. To conclude with thermodynamics, you could give learners a further piece of investigatory work concerning thermodynamic process parameters and introduce them to the Gas Laws. Finally, it would be appropriate to give learners an opportunity to analyse engineering problems that relate to fluid and thermodynamic systems and to perform the necessary procedures to derive solutions to problems.

You could then progress onto topic E with a session to gauge prior understanding. To complement this there could be an opportunity for learners to work collaboratively to produce definitions of terms that relate to direct current and static electricity. This could be followed by an introduction to Coulomb's law prior to learners embarking on a number of exercises to analyse given circuits. Further group work could then follow to consider factors that influence resistance, with learners also investigating a range of different resistors. Once understanding of current and resistance is embedded, you could introduce learners to the concepts of electrical field strength and subsequently capacitance. Again, there is scope for individual or collaborative learning to allow learners to gain a deeper understanding of concepts.

To continue, you could introduce learners to Ohm's Law and related factors that they could then investigate individually and carry out appropriate investigations to find unknown values based on applying appropriate theories. This could be followed by introducing Kirchhoff's laws to learners and them performing the required procedures for capacitors. With a good understanding of both resistance and capacitance, you should introduce learners to RC transients. Learners could complete some collaborative working to research RC transients before developing the skills necessary to plot graphs of charge and discharge rates. There are further opportunities for learners to work collaboratively to investigate diodes and DC power sources before completing revision activities to reinforce theories covered in topic E.

Moving on, you could introduce learners to topic F by the use of collaborative working where learners determine if a material is ferromagnetic or not, either through research or by way of practical investigation. Following this, parameters relating to magnetism should be covered, with learners applying theory to analyse information and determine unknown values. Further teaching could then focus on factors such as permeability and reluctance before progressing onto hysteresis and magnetic screening. Learners should be given an opportunity to develop understanding of electromagnetic inductance and the variables that affect emf. Finally, you should demonstrate to learners the operation of transformers along with both Faraday's and Lenz's Laws.

Finally, for topic G, you could initially review the concepts of DC theory before progressing on to alternating current theory. You could begin by considering the waveforms that are related to alternating current, demonstrating the key features to learners and how these can be used to calculate both average and instantaneous values. This could then be developed by demonstrating how the sums of waveforms can be represented by both phasor diagrams and trigonometric techniques. Further reference to DC theory can be made when introducing reactance, impedance and capacitance to learners. You could give learners information about systems for them to analyse in order to determine values of unknowns. To conclude, you should discuss the concept of rectification with learners, along with the methodologies that are to be employed in order to represent rectified waveforms graphically.

Assessment guidance

The assessment of this unit is through one external examination that will consist of a number of short- and long-answer questions, along with longer synoptic problem-solving questions. There will be one paper worth 80 marks that will have a two-hour duration. The examination will give opportunities for learners to demonstrate knowledge and understanding of the unit content in a range of engineering contexts that will examine a range of cognitive skills. The examination will contain challenges for learners of all abilities through focused and synoptic problems that will require individual and combined application of mathematical techniques, along with electrical, electronic and mechanical principles.

Getting started

This gives you a starting place for one way of delivering the unit. Activities are suggested to assist in preparation for the external assessment.

Unit 1: Engineering Principles

Introduction

In the delivery of this unit there is the opportunity for you to help learners develop the skills that they will need in order to respond to a range of engineering challenges or scenarios that will require them to apply their understanding of a range of concepts. You could approach this unit in a number of ways, however, it is likely that once the underpinning knowledge and understanding has been addressed for each topic, you could give learners a number of tasks and challenges that test their understanding and application of theories. There is some opportunity for collaborative working when considering aspects such as thermodynamic parameters. However, due to the nature of assessment of this unit, it is beneficial for learners to be given the opportunity to attempt challenges similar to those that they will encounter in the external assessment.

Topic A – Algebraic and trigonometric mathematical methods

- Topic A1 could be introduced by discussing their prior experience of using algebraic methods to solve problems with learners, along with their understanding of linear equations and simultaneous equations. This could be either through discussion or through simple assessments. You could then introduce learners to the laws of indices, explaining the importance of accurate application with regards to engineering situations. This gives a logical lead-in to logarithms, which learners will later apply when considering rates of growth and decay. You should emphasise the importance of logarithms as a tool that engineers use to investigate problems, perhaps referencing capacitors as an application. You could give learners a range of learning activities where the laws of logarithms are applied, both for base 10 and natural (base e) logarithms.
- You could introduce learners to the method of plotting graphs from linear equations prior to giving learners a range of equations that they should plot for themselves. This leads into using graphical methods to solve pairs of simultaneous equations. You could give learners scenarios where the direction of travel of two objects is represented by linear equations, with learners needing to locate the intersect between the lines represented by each equation.
- You could then develop learners' ability to apply algebraic concepts by introducing them to factorisation of linear equations and subsequently quadratic equations for which learners should be taught how to apply the quadratic equation to find roots of an equation. You should give an appropriate engineering context for problems.
- Moving onto topic A2, you could begin by explaining the importance of circular measurements to learners, introducing radians as the unit of circular measurement, explaining the advantages of using radians especially with regards to finding arc lengths and areas of sectors. You could then expand upon the notion of angular measure by introducing angular rotation to learners. You could give them an opportunity to work collaboratively to gain experience of applying theories to solve problems that relate to angular motion. You could consider a range of trigonometric functions, demonstrating to learners how to plot the waveforms of each prior to giving learners an opportunity to plot waveforms themselves.
- Once learners have an understanding of each of the trigonometric functions, you should introduce them to the sine and cosine rules. Learners can then apply the

rules to solving problems including those related to vectors. Finally, you could review methods of determining surface areas of solids and related volumes before giving learners further opportunity to work individually on solving problems.

Topic B – Static engineering systems

- You could initially introduce learners to the basic principles of static engineering systems by relating to the theory of vectors as covered in topic A. You should demonstrate to learners that forces can be represented using space and free body diagrams, applying the theory of vectors to determine resultant forces. You could then expand upon this understanding by introducing learners to moments. There will then be an opportunity for collaborative working in order to find moments of forces and also the horizontal and vertical components of forces. You could use practical demonstrations in order to show learners the conditions for static equilibrium, prior to explaining how these conditions can be arrived at. Learners could then be given further opportunity for collaborative working to investigate systems. You should expand upon the application of moments and conditions for equilibrium by introducing learners to simply supported beams. You should initially introduce learners to the methods of resolving forces with point loadings, before introducing uniformly distributed loads.
- This leads into topic B2 where you could begin by considering direct stress and strain, giving learners the knowledge of how to calculate values from given information. This can then be expanded to consider shear stress and strain. There are further opportunities for learners to work individually to solve problems before demonstrating tensile strength and shear strength to learners. This could be through practical demonstrations or virtually. Following investigation of these concepts, learners should be introduced to both the modulus of elasticity and the modulus of rigidity. You could demonstrate how to derive values for these from values of stresses and strains. You should give learners an opportunity to work independently to apply critical thinking skills so that they can solve non-routine problems that relate to structural systems.

Topic C – Dynamic engineering systems

- You could begin to introduce topic C by demonstrating the principles of linear motion through simulations. This could be used as a lead-in before learners begin a collaborative research activity to investigate kinetic parameters and then describe the link between each of these parameters when considering linear motion. You could give learners a range of tasks to check their understanding of linear motion and uniform acceleration. Further collaborative working could then consider forces and related factors before learners present their findings to the wider group in the form of a presentation. You could give other learners the opportunity to question their peers to determine depth of understanding.
- You could then use practical demonstrations to introduce learners to potential and kinetic energy, making reference to conservation of energy. You could make some problem-solving activities where learners will be able to apply their understanding of conservation of energy to unfamiliar situations available. Once learners have a good understanding of the processes involved in the application of conservation of energy, you could expand upon Newton's Laws of Motion and introduce the theory of conservation of momentum. This could initially be demonstrated prior to setting a collaborative task to solve a range of problems that relate to Newton's Laws of Motion.
- To progress, you could introduce learners to angular motion, linking the knowledge of linear motion and angular measure. You could discuss the differences between types of motion before setting learners an information gathering activity to investigate parameters related to angular motion. You should also demonstrate the procedures for determining values of parameters such as centripetal acceleration along with more complex concepts such as rotational kinetic energy to learners.

- Once learners have a good understanding of both linear and rotational movement within dynamic systems, you should draw together the various concepts and introduce learners to lifting machines. You could give learners an investigation into the different types of lifting machines, and the types of motion involved with each. You should give learners an opportunity to consider aspects such as mechanical advantage and velocity ratio and then apply their understanding to solve problems that relate to raising loads through specified heights.
- Finally, to conclude the topic, you could give learners some challenges to solve which relate to both linear and angular motion, including some that will require both types of motion to be considered in order to arrive at solutions.

Topic D – Fluid and thermodynamic engineering systems

- Topic D1 could be introduced with a range of practical demonstrations to illustrate concepts including hydrostatic pressure and hydrostatic thrust. You could, for example, demonstrate these through the use of a flat vertical surface within a tank of water and relate the concepts of equal and opposite forces being in equilibrium to demonstrate the hydrostatic thrust of water. This could be developed by considering hydrostatic pressure and centre of pressure and you could link this to applications such as dams where the variation in pressure leads to the thickness of the wall increasing with depth. Learners should also be equipped with the skills necessary to carry out calculations to determine the aforementioned quantities.
- With a good understanding of hydrostatic thrust, you could then use further practical demonstration to explain both the flotation method for determining relative densities and the Archimedes principle. This could lead into some small group collaborative working where learners carry out their own investigations with regards to density.
- There is further opportunity for concepts to be demonstrated, either virtually or, if available, through the use of suitable pipework with regards to flow in a gradually tapering pipe. Firstly, you could introduce learners to flow rates prior to considering flow velocities. It is important that learners have an understanding of incompressible fluid flow when considering flow in a gradually tapering pipe to make sure that they are able to apply concepts correctly when carrying out collaborative learning activities.
- You could continue by introducing learners to topic D2. Initially, this could focus on the prior understanding learners have of heat transfer processes before setting an independent learning activity for learners to investigate both heat transfer processes and the phases of linear expansivity. You could then consider a range of heat engines that could be used as a basis around which discussions regarding thermal efficiency could be held. This would offer further opportunity for learners to carry out individual research activities to gain an understanding of heat engines. You could then further develop understanding of thermodynamic systems by introducing learners to the principles of entropy and enthalpy. Learners could be given the opportunity to apply these concepts to heat engines.
- Finally, you should introduce learners to the Gas Laws giving them individual research tasks to investigate thermodynamic process parameters and the Gas Laws. You could then make a range of activities available that would test learners' understanding of fluid systems and thermodynamics, including tasks that are more synoptic and draw together a range of concepts from within the topic.

Topic E – Static and direct current electricity and circuits

- Topic E again allows learners the opportunity to carry out some practical investigations into concepts. This could be through the use of electronics kits to construct direct current circuits and then take measurements of values such as voltage, current and resistance. Learners could work collaboratively to generate their own definitions for each of the factors that they have investigated. This could then be supplemented by introducing learners to Coulomb's law and the principles of charge flow. Further collaborative working could be used for learners to investigate the parameters that affect resistance and also the different types of resistor that are commonly found in electrical circuits. Learners could be given the opportunity to trial different resistors within circuits in order to further their understanding of resistance.

- Learners should then be introduced to the notion of electrical field strength and the calculations that need to be performed in order to determine values. There is an opportunity for learners to carry out some collaborative work to determine the electrical field strength from given data, and to also produce a factsheet which could be used to teach other learners the theory of electrical field strength. Building on the understanding of resistance and related factors, you should introduce learners to capacitance and the different types of capacitor that are commonly found in direct current circuits. To further understanding, you could give learners an opportunity to research both capacitors and capacitance collaboratively.
- Having considered the principles of direct current, you could introduce learners to direct current theory. Initially, this could be through considering Ohm's Law and the calculations that need to be carried out to determine unknown values. This could be through either paired investigations or individual study. You could then lead a discussion on Kirchhoff's voltage and current laws.
- Having recapped capacitance and resistance, you could set learners a task to complete collaborative research in order to investigate RC transients along with detailed consideration of the charge and discharge rates for capacitors. It is appropriate to link back to topic A and logarithms at this point and the skills developed in plotting graphs in order to represent growth and decay rates graphically.
- To conclude topic E you should consider DC current networks. This could begin with learners being set an individual investigation to consider the different power sources for DC circuits, possibly in the form of a presentation or a report. You could then revisit resistance, explaining to learners the methods of determining the total resistance in a circuit that has resistors in both series and parallel. Finally, as with other topics, you could set learners revision tasks to solve problems that relate to direct current electricity. These could focus on individual aspects of the unit content, or be broader in nature and draw together various strands from within the topic as a whole.

Topic F – Magnetism and electromagnetic induction

- You could introduce topic F through a practical investigation into ferromagnetic materials. Learners could work collaboratively to identify those materials that are ferromagnetic. You could then use this as a starting point to introduce learners to the various parameters that relate to magnetism, including flux density and magnetomotive force. You should demonstrate to learners how to determine values from given information prior to setting them an individual study task to complete.
- Much of the teaching and learning for this topic is theoretical, therefore it will be important that when you are demonstrating how to derive values for factors such as permeability, learners are clear on both the variables that they need to know, and the procedures they need to perform in order to arrive at values. This will be the case when you introduce permeability and reluctance. You should demonstrate how these values are arrived at, and the importance of each within engineering contexts, such as placing air gaps within transformers increasing the reluctance within the magnetic circuit, allowing for more energy to be stored (similar to resistance in an electrical circuit).
- You can then give learners a further individual research activity to investigate magnetic screening and hysteresis. Learners could feed their findings back to the

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group, before continuing to investigate further concepts such as induced emf. You should give learners sufficient structure to the task so that they are able to demonstrate an understanding of the various factors and how these relate within a magnetic circuit.

- You could consider applications of magnetism within engineering, such as for transformers, generators and motors. You could initially focus on the relationships between the number of turns in a conductor and the length of magnets along with aspects such as permeability and inductance that have been previously investigated. There is scope for practical demonstrations to highlight the differences in outcomes when these values are changed. You could then provide a piece of collaborative work for learners to investigate applications of magnetism, producing a factsheet to explain the links between the various factors. It would also be appropriate to demonstrate to learners how motors and generators operate in detail, perhaps using video resources. Learners could expand upon this through an individual study activity where they could use calculations to support their descriptions and explanations.
- Finally, having introduced learners to Lenz's and Faraday's Laws, you should focus on transformers, both as step-up and step-down transformers. You should equip learners with the knowledge of how each of these functions, and demonstrate how to carry out calculations to determine the number of turns required for a given application from available data. This could then be followed by some overarching problems to solve which would draw together the various pieces of theory from the topic and allow learners to apply their understanding to solve a range of problems.

Topic G – Single phase alternating current

- Topic G draws together aspects of theory that have been covered in topics A, E and to a lesser extent F. You could therefore introduce the topic by referring to the prior learning in addition to introducing learners to alternating current theory. You could reference the similarities between some of the concepts, such as impedance and resistance, the vector addition of forces and phasor diagrams, and also waveforms.
- This could give a starting point, with sinusoidal and non-sinusoidal waveforms being explained and demonstrated to learners. You should demonstrate how to interpret these waveforms in order to identify values, such as amplitude, time period and frequency. You should also demonstrate how values such as peak-to-peak can be derived from the waveforms before giving learners a range of waveform plots that they can interpret to find values of unknowns.
- You could revisit vector theory before explaining to learners how the concept can be applied to generate phasor diagrams. You should demonstrate to learners how to construct phasor diagrams, and how these can be interpreted to determine the sum of the addition of two sinusoidal voltages. Learners should then be given the opportunity to put the theory into practice in order to develop the skills needed to represent the addition of voltages.
- You could consider theories related to reactance, impedance and capacitance. This gives you an opportunity to revisit the theories covered for DC circuits, prior to introducing the calculations that would need to be performed to determine reactance and impedance for components.
- To conclude, you could investigate with learners the need to rectify an alternating current. You should consider both half-wave and full-wave rectification. This could include reasons for rectification, associated processes including smoothing, and methods of representing rectified waveforms graphically. You should give learners the skills necessary to carry out calculations to determine values, and give them the opportunity to apply these through a range of exercises.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This mandatory unit can be linked to all other units in the qualification.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Bird J – *Higher Engineering Mathematics, Seventh Edition* (Routledge, 2014) ISBN 9780412662826.
  Includes logarithms, trigonometry, angular measure.
- Bird J – *Electrical Circuit Theory and Technology, Fifth Edition* (Routledge, 2014) ISBN 9780415662864.
  Includes AC theory, DC theory, electromagnetism, transformers.
- Bird J and Ross C *Mechanical Engineering Principles* (Routledge, 2014) ISBN 9781138781573.
  Includes stresses and strains, coplanar forces, simply supported beams, linear and angular motion, Newton's Laws of Motion, angular motion, lifting machines, hydrostatics.
- Greer A et al – *BTEC National Mathematics for Technicians, 4th Edition* (Nelson Thornes, 2004) ISBN 978-0748779499.
  Includes solving linear equations, logarithms, area and volume, trigonometry.

Videos

- www.youtube.com/watch?v=LAtPHANEfQo
  Demonstration of a DC motor.
- www.youtube.com/watch?v=LrRdKmjhOgw
  Conservation of energy.
- www.youtube.com/watch?v=4IYDb6K5UF8
  Conservation of momentum.
- www.youtube.com/watch?v=NvJcrGlzGAg
  Magnetism.

Websites

- www.livescience.com/38059-magnetism.html
  Live Science – What is Magnetism?
- www.learnabout-electronics.org/index.php
  Covers both AC and DC theory

Unit 2: Delivery of Engineering Processes Safely as a Team

Delivery guidance

This unit is a mandatory unit and it is envisaged it will be delivered quite early in the programme to allow development of engineering and team working skills. This unit will be the start of practical engineering learning for many learners and will give a starting point for many other units. It also allows learners to start to consider their preferred vocational pathway. Some learners may bring their knowledge and experience of different products, processes and servicing technologies to bear, gained from employment or previous learning.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

You should encourage learners to develop their knowledge of various processes and the related practical skills. It will be necessary to focus on a limited range of processes given the time available for delivering this unit. A large amount of the content of the unit involves practical activities - manufacturing/servicing items and Computer Aided Draughting. For assessment, it is recommended that learners spend no more than fifteen hours on learning aim C, which requires them to manufacture a product or deliver a service effectively as a member of a team.

To complete this unit your learners will need access to various resources and the consumables and materials associated with them. Your learners will need to understand and apply safe working practices designed to protect them from various hazards that are inherent to engineering processes.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions
- individual or group presentations – discussing the technical documentation, performance and progress
- demonstrations of the set up of various equipment/processes and safety issues associated with the processes that may be used
- case studies illustrating components, systems and activities created by the team working processes
- internet sources – learners may benefit from using internet sources, such as videos
- specialist books that cover engineering principles, processes and service activities.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Approaching the unit

Delivering the learning aims

For learning aim A, introduce the topics by indicating what a batch of a product or service is, including reference to the support documentation, drawings and possible tooling required. At this point it would be advisable to define what a service or a product is. The unit defines a product as 'a tangible and discernible item, eg a car', and a service as 'an intangible benefit, either in its own right or as a significant element of a tangible product, eg a car service'. The engineering processes to be considered could be relevant to the final product or service to be produced (learning aim C), but do not have to be.

Discuss and use practical examples of the common processes used for manufacturing processes, for example turning, fitting and milling, or the common processes for services for example, installation or disassembly. It is essential that all safety aspects are discussed and embedded within the delivery of the content, with particular reference to legislation/regulations.

At this point introduce human factors. This can be introduced to learners by setting up role play activities. These can be used to examine and teach areas such as ethical principles that could include rigour, honesty, integrity, respect and responsibility. This can be achieved by setting up a workshop scenario relating to a missing item.

For learning aim B, first introduce the concept of 2D drawing and the principle involved. It is probably best to give learners a series of existing drawings and explain the different conventions and then allow learners to identify conventions such as line types, dimensions and develop these towards identifying different views and projections. Move on to explain how items are drawn to real world size in CAD package, and scaled to fit a sheet of drawing paper on a 2D paper drawing.

Then introduce the topic by demonstrating what can be achieved with a 2D CAD package and the benefits of 2D CAD models to businesses across different sectors. Have learners share their knowledge and experiences of working within different 2D CAD environments. You could then give initial input for your learners on the different CAD packages available and introduce them to setting up the various parameters, such as grid, snap and layers, and explain that CAD drawings are created full size and scaled for output to a printer or plotter. In small groups your learners could carry out small tasks to draw various items such as a 'drawing template'. These could be produced to show absolute, relative and polar co-ordinates. These tasks could then be extended to develop the use of geometric drawing tools and dimensioning, by creating a simple part like a drill gauge, complete with different line types, dimensioning, and all orthogonal views, including cross-hatching.

At this point, it may be beneficial to introduce layers, so that learners can practise creating the template or dimensioning on separate layers. You also need to introduce the creation of a final output as a printed or plotted drawing within a template to the relevant scale. The use of layers can then be extended further to create individual symbols for electronic items, and these can be inserted into a drawing to create circuit diagrams, and finally inserted into a drawing template.

For learning aim C, learners could complete a practice project to manufacture a product or to deliver a service as a team. The essence of team working is planning, communication and an ability to work with others. Once the teams are selected, they will need encouragement to choose a leader and plan alternate leaders in rotation. Teams will need encouragement and appropriate documentation so they can keep diaries or logs to determine the appropriate way forward and record and review team and individual activities, strengths, weaknesses and contributions. It is important that learners are familiar with the relevant safety legislation, as the team leader and team members will be responsible for the creation of the HSE 5 step risk assessments, identifying hazards and risks, and reviewing the identified risks.

The learners will need to be given direction in using the given planning, drawing and other documentation, to ensure they are fully aware of the processes that they will need to use. This will lead them into the manufacture of their product or delivery of their service as a team, where they will require support and some direction.

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 electrical 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 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.

Assessment guidance

This unit is internally assessed through a number of tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be a portfolio containing reports, drawings, 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. Learners should also produce screenshots to show process and editing on the CAD system. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence. The original learner-generated evidence must also support them.

Getting started

This gives you with a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 2: Delivery of Engineering Processes Safely as a Team
Introduction Begin by introducing the unit to learners through a group discussion exploring their knowledge of the use of common engineering processes and the possible skills that they will need or they have developed. This can be followed by outlining the overall learning aims of the unit. It is essential that you ensure throughout this unit that learners understand all the safety aspects of the processes and the typical safe working practices required.
Learning aim A: Examine common engineering processes to create products or deliver services safely and effectively as a team
• Introduce the learning aim by showing products and services the learners could produce for learning aim C. This puts relevance into the consideration and use of the different processes. • Ask learners to collaborate in small groups to come up with examples of different possible products or services that they could manufacture or deliver. • Introduce the next topic by examining the support documentation required to manufacture a product or deliver a service. Learners need to be familiar with engineering drawings, planning sheets and quality control documents. These can often be explained in context, using the creation of a small product or service. This can also be used to develop knowledge and awareness of engineering processes and standards. • Lead the group to use some of the common engineering processes. These should be practical exercises to create awareness of engineering activities such as the use of machinery, hand tools, forming operations, and disassembly and inspection tasks. • During every activity and certainly prior to every practical activity, all the necessary safety considerations should be emphasised and reinforced. The health and safety considerations of and from the H&S at Work Act 1974 that need to be covered, as a minimum, are RIDDOR, PPE, COSHH and Manual Handling. • Show learners how coercion and undue influence can affect single team members or the whole team. Role play may be a good way to emphasise these points to the learners. Create a boss who is only interested in output and profit, placing these both before the quality of the product or service and the individual or team's personal feelings, or the safety of the individual or team.
Learning aim B: Develop two-dimensional computer-aided drawings that can be used in engineering processes
• Using the examples from earlier, demonstrate how to create simple 2D engineering drawings and the basic principles that must be followed (views, dimensions, layout etc). Explain the basic structure of a 2D drawing package and guide learners through the completion of setting up a 2D computer-aided drawing system. • Using items like grid, snap, and coordinate systems, allow learners to create a simple shape using drawing commands such as line, arc, circle and text. Learners will also discover that the undo and erase commands are very useful.

- These basic commands will allow the learner to create a drawing template to be used in conjunction with the layers command to output drawings.
- Ensure that learners understand the advantage of creating drawings in the correct orientation and the order of creating centre lines, dimensions and the object to be drawn. Give learners graduated tasks to develop their use of the 2D drawing software commands.
- You could then enhance the practical skills by demonstrating the creation of different chamfers, radii, springs and threads, to an appropriate scale.
- You could demonstrate further commands and skills to allow learners to utilise the layers. Ensure that learners understand the advantage of creating drawings by layers to switch drawn items on and off and symbols to aid drawing and placement of multiple objects, particularly within the construction of electronic circuits. Give learners further graduated tasks to develop their use of the software commands in the creation of drawings and circuit diagrams.
- Ensure that learners understand features like hatching. Give learners graduated tasks to develop their use of the software commands.
- You could demonstrate how to set up and output drawings to a printer or plotter from within a drawing template, to allow learners to create orthographic views.

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

- Support learners with the main elements of team working which are planning, communication and an ability to work with others. Show them how to minute meetings and perhaps use internet-based videos to show teams that work well together, and the approaches they take.
- Once teams are selected, they will need encouragement to choose an initial leader and plan alternate leaders in rotation.
- Give learners a series of tasks so the teams can choose their product or service. Give them the required documentation, to create the given batch of products or service, and support them with their technical understanding of what is required and how to divide up the activities.
- The teams will need encouragement and appropriate documentation so they can keep diaries or logs to determine the appropriate way forward and record and review team and individual activities, strengths, weaknesses and contributions. They will also need support in planning time effectively
- It is important that the learners are very familiar with the relevant safety legislation. The team leader and team members must recognise that they will be responsible for creating the HSE 5 step risk assessments for the processes to be used, identifying hazards, risks and reviewing. Make a suitable proforma available and support them through the creating risk assessments.
- As learners become ready to start their practical tasks, it is essential that all safety considerations are explained and demonstrated and that they have an understanding as to how to set up each of the processes to be used.
- Support the learners in creating a practice product or service. Enhance their technical knowledge and practical skills where appropriate as they create their product or service, and encourage them to support each other where difficulties or issues arise.
- Support learners through their technical errors and emphasise the need for iteration, review and adaptation as the product or service develops.

- Support the teams and learners as they further develop their practice batch of the product or service and refer them back to the technical specification at appropriate points, so that the product or service meets the fitness for purpose criteria or their documentation shows what corrective action would be required to overcome issues and problems.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 5: A Specialist Engineering Project*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources needed for this unit are 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, eg printers and plotters, as well as 2D CAD software that is capable of professional 2D drawings and their output, eg 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 a batch of an engineered product or to deliver an engineering service, as a member of a team.

Websites

Many software houses produce CAD software, some of which offer free educational software to download:

- www.autodesk.co.uk
- www.solidworks.co.uk
- www.solidworks.com/sw/products/draftsight-getting-started-guide.htm
- www.turbocad.co.uk/windows-range/turbocad-deluxe-2d-3d.

Unit 3: Engineering Product Design and Manufacture

Delivery guidance

Approaching the unit

This mandatory unit is intended to give learners the skills that they will need to meet design challenges and produce effective engineering solutions to solve problems. There is opportunity within the delivery of this unit for a range of design activities to be carried out, along with hands-on practical investigations of existing engineering products. Delivery of this unit is likely to use a range of different methods, including tutor presentations, individual and group work along with paired investigations. The focus should be on equipping learners with the skills they need to be able to develop their design concepts coherently using an iterative approach and to be able to validate their own designs.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

Learners will develop the skills needed to identify and respond to design triggers so that they can develop their own product design specifications and subsequently their own developed design solutions. They should be equipped with the skills needed to address a range of challenges including those related to sustainability issues or modern manufacturing techniques. They should be able to draw on their wider experience of engineering from other units and the wider engineering world to present coherent design solutions.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the topics

Topic A gives the foundation for the unit, introducing learners firstly to possible reasons for developing a product, and then the theory related to consider the suitability of a range of manufacturing processes.

Firstly, you could introduce learners to the range of design triggers and challenges that are often the starting point of the design process. This could be introduced by considering an engineering product and discussing with learners the possible reasons that led to its development. You could use a product which learners are familiar with, such as a smartphone, or something less familiar such as product manufactured by a local engineering organisation. This analysis could provoke discussion that you can then build upon by directing learners to carry out their own independent study into other design triggers.

You could then carry this forward by discussing how design triggers often lead onto a design challenge. Again, the same products could be considered with learners investigating the trends that have led to a particular design challenge being placed on a product. You could consider more holistic challenges, such as those associated with integration of different power sources into vehicles that could also have sustainability issues, and consider energy recovery features.

You could then continue to investigate the factors that give opportunities or place limitations on the design of engineering products, the properties of materials that learners will need to have familiarity with, before finally considering mechanical systems and manufacturing processes. These topics are likely to be delivered using a range of methods, including paired and group research tasks.

Having considered a range of factors that will need to be considered whilst designing a product, you will then need to help learners gain the skills that they will need to be able to develop a product design specification (PDS) from a given design brief in topic B. You should make sure that learners have an understanding of how to interpret product requirements in order to produce a product design specification. This could be achieved by giving learners a range of case studies that feature a client brief from which they can then develop a PDS.

You could give learners a research task so that they gain an understanding of commercial protection of designs. This could then be complemented by further paired or group activities where learners investigate the regulatory constraints associated with given engineering products and scenarios. Finally, you could introduce learners to the various analysis skills which they will need to employ when producing their own designs, and how engineering goals can be affected by factors relating to the potential market, the performance requirements of the product and the likely manufacturing methods that would be used to produce a solution.

The delivery of topic C is likely to be approached more holistically, using a range of design challenges to build on the presentation skills which learners will need to possess in order to present their design proposals in their external assessment. You could approach the topic by refreshing the required presentation skills which learners will be expected to employ, for example 2D and 3D sketching, rendering, use of technical drawings etc. These skills could then be employed by tasking learners with a number of design challenges for which they will need to develop a range of initial ideas. These challenges could be linked to work with an industry partner who may give learners suitable contexts to address.

You should encourage learners to take an iterative and cyclical approach to their design work, refining and improving their ideas until they have a solution that best fulfils the needs of the design. You should emphasise to learners the level of detail that they will need to include in their developed design solution.

You could give learners the opportunity to investigate design documentation that accompanies existing engineering products. This will give them an insight into the level of detail and range of documentation that they should include in their work. You should also develop learners' ability to use concise and appropriate annotation to accompany design ideas, and discuss the importance of recording and justifying changes they make to their concepts.

Finally, for topic D you could again use a range of existing engineering products that learners can investigate to justify the design solution. The investigation is likely to involve some form of data analysis, using routine statistical methods that are often used for validating design decisions. For example, you could give learners a data collection activity, such as collecting data about car wheel rim sizes, types of computers used or wattage of lamps in light fittings. This could then be analysed and presented using a number of routine statistical methods with which learners need to be familiar.

You could work in partnership with a local engineering organisation to give learners the opportunity to validate designs, based on the organisation's PDS or a weighted matrix. You should allow learners the opportunity to consider the manufacturing of the product and how advances in technology may lead to design improvements.

Assessment guidance

Due to the nature of this unit, with the extended external assessment relating to a pre-release case study, it is important that learners are fully prepared with the skills they need to be able to interpret a design brief, produce a PDS and then apply an iterative approach to the development of a solution. This is most likely to be achieved with a range of practical design tasks where learners could address aspects of the content prior to carrying out a practice task, probably based on the sample assessment materials.

It is important that learners have a good understanding of the materials and processes involved with the manufacture of engineering products. You should ensure that they also are proficient in presenting design ideas and have the skills to be able to analyse both products made by others and those designed by themselves.

Getting started

This gives you a starting place for one way of delivering the unit.
Activities are suggested in preparation for the external assessment.

Unit 3: Engineering Product Design and Manufacture
Introduction In the delivery of this unit, there is the opportunity for you to develop links with local engineering organisations who may be able to give learners suitable design challenges or scenarios that could be used by learners to develop their design skills. You could approach this unit in a number of ways. However, it is likely that once the underpinning knowledge and understanding which is covered through topics A and B has been addressed, a more holistic approach encompassing topics C and D could be employed which would give learners a similar experience to that which they will encounter in their external assessment.
Topic A – Design triggers, challenges, constraints and opportunities, and materials and processes
• Introduce Topic A with a discussion on possible design triggers that can lead to the development of both new and improved engineering products or services. Consider an existing common product, such as a smartphone or a tablet computer. As a group, discuss the possible triggers leading to the development of the product, whether technological or consumer led. Ask learners, in pairs, to research a range of design triggers that are considered by engineering designers when developing products. Extend the investigation by considering the design challenges which engineering designers face when developing products. This again could be approached through a paired investigation that would allow learners to develop their interpersonal skills. • Ask learners to work collaboratively in groups to consider the constraints and opportunities that exist at either an equipment or system level concerning the design and development of engineering products. They can then present their findings to the wider group thereby developing the transferable skills they may need in future employment. • Once learners have an understanding of design triggers and challenges, review the understanding of material properties which learners may have developed through their studies in other units, and expand upon this knowledge with reference to the need to select materials for engineering applications that have the properties required to fulfil the design requirements. You could set either individual research activities or group tasks where individual research skills could be developed. Existing products could be used to consider the materials used, and therefore the properties of these materials identified, with surface treatments and finishes also considered. • Look at the linkages that are used within engineering systems along with the potential power sources that could be used to power these systems, and the related control systems used within systems to manage power transmission. Try to set up a visit to an organisation where such power transmission systems are manufactured, or use video resources to demonstrate to learners how mechanical power is transmitted. • To complete topic A learners will need an understanding of the manufacturing processes that are used for a range of materials. If possible, arrange for learners to visit an industrial partner where manufacturing processes are carried out, as learners will observe first-hand how products are manufactured. Similarly, there is

scope for the use of video resources to illustrate to learners a range of manufacturing processes.

Topic B – Interpreting a brief into operational requirements and analysing existing products

- The focus of topic B is for learners to be able to develop a product design specification (PDS) which addresses the requirements of the design brief, whilst also taking into consideration external factors such as regulatory requirements or intellectual property rights. This topic offers you the opportunity to develop links with an industry partner who could give design briefs which your learners will need to interpret in order to develop a PDS that addresses the client needs. There is scope for collaborative working between learners in the first instances, with learners developing their skills to be able to work independently prior to beginning their external assessments.
- Introduce the topic by giving learners a relatively simple design brief. They could then work through this, in either groups or pairs, to come up with specific criteria needed for the PDS. Following on from this, learners should consider the regulatory opportunities and constraints that relate to a design brief. Discuss as a group, and then allow learners to work in pairs to investigate the relevant legislation, codes of practices and other regulatory factors that relate to a given design brief. Learners could then modify their own PDS in light of the regulatory constraints that they have identified.
- Learners can then look at a further range of external factors, which although not regulatory, can have an impact on the design of an engineering product. Look at engineering products that are considered to have a marketing advantage over competitors' products. This will allow learners to consider the unique selling point of a product, or the benefits of the design for the potential consumer. Concerning consumer electronic products, there could also be some consideration of obsolescence as a method to stimulate the market. Finally, learners could again work collaboratively to consider a number of products that they would analyse with respect to the performance requirements of the product and the manufacturing considerations of the product. This should include a consideration of both the processes used during manufacturing and the need to consider how a product would be manufactured or assembled whilst being designed.
- To draw together learning for this topic, you could offer learners the opportunity to complete a number of revision activities where they could develop a product design specification which considers the customer and external influences, and would allow designs to be produced that would fulfil the requirements of the design brief.

Topic C – Using an iterative process to design ideas and develop a modified product proposal

- As with topic B, there is the opportunity to take advantage of industry links in order to deliver topic C. To address this topic begin by revisiting a range of presentation techniques that learners will potentially need to employ when presenting their design proposals. This could be addressed by initially presenting the techniques to learners, with the use of practical exercises by learners to refine their skills. This could then be followed by a review of graphical presentation techniques used when presenting design propositions to potential clients.
- Once you have covered the presentation skills required of learners you could then introduce a simple design challenge. This could be in the form of a product design specification that learners can use to produce a range of initial design proposals. These could then be refined with respect to the criteria. You should emphasise to learners the importance of creativity in their design work, and that any designs that are produced should be in the correct context.

- You should give learners suitable design opportunities that will require them to refine and develop their concepts, generally with the need to carry out further secondary research. The use of an iterative approach to design should be encouraged, with a cyclical refinement process being employed.
- A number of similar design tasks could be used to develop the design skills of learners prior to them producing a developed design idea. You could prepare learners for the production of a developed design by considering each of the criteria that could be included in the design, explaining to learners that much of this information can be shared using detailed and concise annotation of design work.
- As a final preparation for their external assessment, you could give learners a further design brief from which they will need to devise a PDS, and then subsequently produce ideas, and develop a design proposal that will be presented using a range of appropriate design documentation. The product to be designed need not be complex, however it must offer learners the opportunity to be able to refine an idea prior to presenting it as a design solution.

Topic D – Technical justification and validation of the design solution

- Topic D draws together the design process with developed designs and solutions being justified and validated against a set of criteria. Introduce this topic by considering the statistical measurements that are routinely used by engineers. This could involve a combination of classroom teaching along with individual study to develop the skills needed to both interpret data and then to present data to an audience. There is scope for you to offer learners the opportunity to collect their own data from sources in your centre, although should this not be possible you could give learners the data that they could present graphically.
- Once you have considered data handling with learners, you could progress onto the process of validating designs. Initially you could approach this by giving learners examples of products along with their related product design specification. They could then analyse the products with respect to the PDS to validate the success of the design. As previously, this could be done in partnership with an industry partner who could give learners examples of products and related documents.
- You could use the same products to consider the validation of the designs with respect to a weighted matrix, comparing the results to determine if there are any differences.
- Finally, you could discuss with learners the concept that improving a product for one reason will often have other benefits, and the overall benefit of redesigning or developing a new product should be considered with respect to the costs. This could be considered by learners using case studies, for example hybrid technologies used in vehicles could be considered with the principle goal being the environmental benefits caused by a reduction in emissions. Learners could then consider the costs of developing these technologies and any indirect benefits that have been achieved as a result.
- You could then give learners a final design challenge that could be based around the sample assessment materials. They should follow the design process through from the beginning by interpreting a given brief into a PDS that takes into account external factors. An iterative approach should then be taken to produce a developed design proposal that is finally validated with regards to both the PDS and a weighted matrix. You could also give learners the opportunity to suggest further refinements to their solution, which could be based on modern materials, or other technology led developments, along with a consideration of how the product would be manufactured.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This mandatory unit can be linked to all other units in the qualification.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Gibson I, Rosen D, Stucker B – *Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping, and Direct Digital Manufacturing* (Springer, 2014) ISBN 9781493921133.
  Wide range of additive manufacturing methods are covered in detail.
- Johnson A & Gibson A – *Sustainability in Engineering Design* (Academic Press, 2014) ISBN 9780124045910.
  Features a range of techniques to use in engineering design including an iterative approach.
- Mitchell B – *An Introduction to Materials Engineering and Science for Chemical and Materials Engineers* (Wiley, 2004) ISBN 9780471436232.
  Comprehensive range of engineering materials are covered, along with an iterative design approach.

Videos

- www.youtube.com/watch?v=l0SXlkrmzyw
  GE Engine manufacturing, additive manufacture.
- www.youtube.com/watch?v=Dw6cs7opvzA
  Koenigsegg, composite manufacturing.

Websites

- www.gov.uk/government/organisations/intellectual-property-office
  Intellectual property office, for official guidance on copyright, designs, trademarks and patents.
- www.jamesdysonfoundation.co.uk
  James Dyson Foundation. Contains many resources that relate to an iterative approach to design.

Unit 4: Applied Commercial and Quality Principles in Engineering

Delivery guidance

Approaching the unit

In this unit, learners will explore how an engineering organisation can develop a competitive advantage over other companies. To allow learners to gain an insight into the systems employed, there is scope to use case studies or visits to organisations. Learners could consider leading organisations in either the automotive or the aerospace sectors to investigate how a competitive advantage has been gained, and how the organisations protect their innovations. This could also form a starting point for the investigation of quality systems and values management principles that are employed by organisations to further develop their competitiveness.

In order for an engineering organisation to be viable, it must be able to control costs. In this unit, learners will also develop the skills necessary to carry out activity based costing and consider the cost of quality.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could introduce learners to the functions that are found within an engineering organisation. There is the opportunity for you to develop links with a local engineering organisation, or for you to use case studies about larger national or multinational enterprise. You should encourage learners to become familiar with the activities that are carried out by the different functions within an organisation, for example, you may use the example that increasing brand awareness would be within the remit of marketing and sales. Learners will need to understand that each function within the organisation contributes to its competitiveness and has an impact on profitability.

Once learners have a good understanding of the roles of the functions within an organisation, you should move the focus of the investigations to the trade considerations that are relevant to the organisation. It is important that you make sure that learners have an understanding of the tendering and contracting processes and why these are important to an organisation and its competitiveness. Finally, you should encourage learners to develop the analysis and evaluator skills so that they are able to evaluate the methods that an organisation has used to develop a competitive advantage. You may wish to deliver this using a case study based on an innovative product from a multinational organisation or alternatively this could be completed in conjunction with an industry partner.

In learning aim B, you will introduce learners to costing methodologies, and in particular, activity based costing. Initially, you should ensure that the focus of studies should be on introducing learners to the reasons for cost control for an engineering organisation. You may wish to consider this holistically and focus on the whole organisation, or by considering one or more of the functions which have been covered in learning aim A. Leaners will also need to understand the main categories into which costs can be classified, specifically direct and indirect costs. They will also need to understand that within each of these classifications there are further categories into which the costs can be subdivided and that different organisations may classify one particular cost base in one way, whilst another will classify it differently.

Once learners have an understanding of the different types of costs, you should introduce them to the activity-based costing method. You should explain to learners that there are other costing methods that could be used, however activity-based costing allows costs to be allocated to activities more accurately than some other methods and is applied in many organisations.

Learners will need to gain the analytical skills needed to understand and apply activity based costing, therefore a you should select a relatively simple engineering activity to consider in the first instance when introducing the methodology, for example a servicing activity to replace a component in a machine, or a machining operation on a simple part.

For learning aim C, you will encourage learners to explore quality systems and standards which are associated with engineering operations, including the ISO 9000 and 14000 series. This could be achieved by setting individual research activities where learners should select and synthesise appropriate information that relates to one of the standards and then prepare a presentation to share their findings with other learners.

The difference between quality assurance and quality control should be considered in depth; this offers you a further opportunity to develop links with an industry partner so that learners can see quality control activities in action. Alternatively, you may wish to use case studies or video resources to demonstrate typical examples of quality assurance and quality control. This will provide learners with the background knowledge in order to understand the purposes of quality systems.

Using the knowledge of costings and quality systems as a foundation, learners should then be introduced to the principles of values management. This should draw on their understanding of costings, and revisit the functions considered in Topic A1. You may wish to introduce this topic with the use of case studies, considering processes or products that offer poor value, and those that offer high value. You should then guide learners through the phases of carrying out a value analysis exercise for a simple product or service activity; you should provide enough structure for them to be then able to carry out a similar activity independently, for a different product or service, for their assessment.

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

Assessment guidance

The assessment of this unit is most likely to be in the form of three assignments, one per learning aim. For learning aim A, the evidence would normally be presented in the form of a written report; however, presentations along with presenter notes could be used to present the same information. Recordings of such presentations could then also be acceptable. For learning aims B and C, learners will present research into a number of engineering activities. This could either be in the form of a report or a presentation. learning aim B requires a costing activity to be carried out; therefore, data in the form of spreadsheets should be included in the learner work. Similarly, there should be calculations to support decisions made for the value analysis exercise for learning aim C.

Getting started

This provides you with a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 4: Applied Commercial and Quality Principles in Engineering

Introduction

This unit offers the opportunity for learners to gain first-hand experience of how engineering organisations can develop a competitive edge by either controlling costs or applying quality systems. There are opportunities for you to develop links with engineering organisations so that visits could take place; these could then provide the underpinning for case studies. Alternatively, you could provide case studies or invite guest speakers who could allow learners to get a wider experience of the systems used by a range of organisations.

You will encourage learners to develop the skills required to carry out an activity based costing exercise, and then apply these to determine the impact of cost centres on profitability. Learners will also develop the skills needed to research effectively and then analyse quality systems so that they can carry out a values analysis, in turn this will be used to evaluate methods of increasing the value of an engineering solution.

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

- Learning aim A provides the foundation of knowledge that is required for learners to be able to carry out both the activity based costing exercise and the values analysis activity. As an introduction, learners need to have a solid understanding of the various functions that are found within engineering organisations, how these interact with each other, and how key decisions are made. This offers an ideal opportunity for you to work with industry partners through either visits or guest speakers who could be used to relate the theory to real life scenarios.
- Each of the functions that are generally found within engineering organisations should be investigated; this offers an ideal opportunity for learners to work in pairs to research methodically the activities associated with each of the functions. If it is possible for you to link this activity to an industry visit, then learners will gain more of an insight into how the functions interact with each other and gain a deeper understanding of an engineering workplace that will help in their preparation for employment.
- Following the investigation into the internal operation of engineering organisations, the focus then should move to the external influences associated with trade considerations. There is again scope for you to encourage learners to work in pairs or small groups to investigate and research contracting. This could be achieved using contracts for large-scale engineering activities such as Crossrail, or the model contracts which are produced by the Institute of Mechanical Engineers.
- Following the study of contracts and the terms that are contained within, learners should understand that there are consequences for non-performance concerning contracts. Examples could include the Millennium Stadium in Cardiff, Wembley Stadium or faulty airbag sensors installed in cars.
- There is further opportunity for you to arrange for learners to visit an engineering organisation in order to experience how a company could gain a competitive advantage over other organisations; alternatively virtual tours or guest speakers could be used. It is important to emphasise that there are a range of techniques which could be used to gain a competitive advantage, and that these are likely to be different depending on the product or service provided by the organisation.

- You should give learners the opportunity to consider a range of different organisations that operate in a range of fields, for example Boeing or Airbus could be considered in the aerospace sector for their use of advanced composites in airframes, whilst Tesla or Nissan could be appropriate examples for the automotive sector with their developments in electric vehicles.
- Having considered methods of gaining a competitive advantage, learners are at the point where they are able to complete the first assignment, which targets learning aim A. This will involve them investigating the key business activities and trade considerations that influence a local engineering organisation; this should be a different organisation to the one that they have studied, but it would be appropriate to either have a guest speaker from the organisation or perform a visit so that learners have some familiarity with the organisation.
- You should provide learners with the information that they will need in the form of a case study, which will allow learners to critically analyse and evaluate how business activities and trade considerations influence the organisation and to evaluate how business activities and trade considerations can be used to create a competitive advantage.

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

- Learning aim B is designed to give learners an insight into how engineering organisations firstly classify costs and then how the identify hidden costs. As with learning aim A, there is opportunity for you to work alongside industry partners who may be able to supply costing data for activities that they carry out.
- Initially, you should encourage learners to work individually or in pairs to investigate the different types of costs that are associated with engineering activities such as machining components or carrying out servicing activities. With appropriate guidance, they will determine how these costs can be classified, and then in groups they could identify all of the costs associated with a less complex engineering activity and justify their reasons for their classification of these costs.
- Once learners have a good understanding of the types and categories of costs that can be associated with engineering activities, you should move on to considering how hidden costs can be identified within activities and the reasons why an organisation would wish to control costs. As previously, there is further opportunity for you to provide learners with a first-hand insight in to an actual engineering organisation as it could be appropriate for an industry partner to provide case studies which relate to processes which they carry out; this could be further enhanced by a guest speaker from the organisation who could respond to questions from learners with regards to costings.
- With a good understanding of the need to carry out costing activities and the knowledge of how different types of cost can be classified, learners then should have the opportunity to carry out an activity based costing activity. This could be approached by leading learners through the stages as a group, and then progressing through each stage of the costing activity in pairs. This would allow learners to support each other and develop their intrapersonal skills whilst also providing them with the opportunity to critically evaluate information which they have been provided with. By taking an approach where each stage of the process is considered fully in turn learners will gain the skills and knowledge required to complete the activity based costing exercise that forms part of assignment two. The engineering activity which you select for delivering the process of activity based costing should offer some challenge to learners, therefore may consist of a small number of operations; examples could be the manufacturing of an engineered bracket which involves several machining processes or a servicing activity where some components and lubricants may need to be replaced. Learners should develop

the skills needed to evaluate the results of the activity based costing exercise in order to firstly identify those cost areas which impact on profitability and the relative impact of these cost areas.

- Once learners have completed the process in pairs, you should provide them with a further opportunity to carry out a similar activity based costing activity for a different engineering product or service. As previously, there should be an opportunity to identify a number of different potential cost savings that can be evaluated for their impact on profitability.
- Following revision of each of the topics, learners should complete their second assignment for the unit; assignment two which is targeted at learning aim B. In the assignment learners will investigate how costs are allocated and controlled within an engineering organisation using activity based costing. As during the delivery of the topic, it could be appropriate for an industry partner to provide suitable data to complete the costing exercise. Learner will also consider how controlling costs can be used to identify inefficiencies associated with engineering activities. In their evidence, learners would be expected to consider a number of aspects, including an explanation that considers why engineering organisations control costs. They should also include their research about a product or service, based on a case study for an engineering organisation that outlines the costs associated to engineering activities. Finally, there should be evidence of the completion of an activity based costing exercise for an engineering product or service, along with an evaluation of the major cost areas that could impact on the profitability of a product or service.

Learning aim C – Explore how engineering organisations use quality systems and value management to create value

- You could introduce learning aim C by considering some high profile engineering organisations that are synonymous with high quality products, such as Dyson, Jaguar Land Rover or GKN. As with learning aims A and B, there is opportunity for employer engagement and the potential to organise visits to engineering organisations. You may find the use of video resources to be effective in order to demonstrate to learners some of the quality control and assurance procedures that are carried out within innovative engineering operations.
- There is opportunity for you to encourage collaborative working between learners in order to research and investigate the role of the ISO and the ISO9000 and ISO14000 families of standards that are applied for quality and environmental systems. Learners could also present their findings to the group in order to develop their presentation skills.
- With the foundation of an understanding of a range of quality issues, you should provide learners with the opportunity to develop an understanding of the systems associated with total quality management, and in particular the PDCA cycle. As with the activity based costing activity, this could be approached by leading learners through the stages as a group, with them being subdivided into smaller groups to analyse appropriate products or systems. Each of the stages should be considered in detail, with the process progressing through each stage in turn. Again, this would allow learners to support each other and develop their interpersonal skills. By taking an approach where each stage of the process is considered fully in turn learners will gain the skills and knowledge required to complete a values analysis activity independently.
- There is further opportunity for you to encourage collaborative learning as the results of the values analysis are evaluated within the groups; discussions could be held where the results are considered and the various opportunities to improve the value of an activity are considered and prioritised based on which would offer the greatest improvement for the organisation.
- Once learners have the knowledge and understanding of how to carry out a

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thorough values analysis they should research how an engineering organisation can apply quality systems and value management tools to overcome any inefficiencies which occur during engineering a given engineering processes. As with the activity based costing activities, there is an opportunity for you to develop industry links with an appropriate engineering organisation who could provide suitable data that could be used by learners for their analysis. Learners will need to investigate a range of quality systems, such as quality assurance and control, which are employed by the organisation, and evaluate the use of value management systems to create a competitive advantage. This will be supported by a value analysis exercise for a given engineering product, for example a circuit board or electronic device; or a service, such as servicing a car brake system, to allow methods of increasing the value of the solution to be identified and subsequently evaluated to prioritise improvements to engineering processes.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This mandatory unit is linked to many of the other units in the qualification, in particular:

- *Unit 1: Engineering Principles*
- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 5: A Specialist Engineering Project*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Hicks D – *Activity-Based Costing: Making It Work for Small and Mid-Sized Companies* (Wiley, 2002) ISBN 9780471237549.
  A practical guide to implementing ABC for businesses which can be used as a basis for a step-by-step approach to delivery.
- Hoyle D – *ISO 9000 Quality System Handbook* (Routledge, 2009) ISBN 9781856176842.
  Covers in detail the ISO9000 family of standards.
- Miles L – *Techniques of Value Analysis and Engineering* (Miles Value Foundation, 2015) ISBN 9780070419261.
  A guide to carrying out a values analysis exercise in an engineering context.

Videos

- Rolls Royce - How To Build A Jumbo Jet Engine, BBC
  Covers a wide range of aspects including competitive advantage and quality.
- www.youtube.com/watch?v=844UiRBVxlY
  Gear inspection using a co-ordinate measuring machine.

Websites

- www.gov.uk/government/organisations/intellectual-property-office
  Official guidance for each type of intellectual property.
- www.ipo.gov.uk/blogs/iptutor
  IPO web-based training tool for intellectual property training.
- www.iso.org
  International Standards Organisation – information concerning ISO standards.
- www.mindtools.com/pages/article/newPPM_89.htm
  Mind Tools – how to apply a PDCA approach.

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Unit 5: A Specialist Engineering Project

Delivery guidance

Approaching the unit

This unit is the culmination of learning for many learners and brings together knowledge and understanding from numerous units. It allows learners to follow their intended vocational pathway to define and then solve a problem, using project-management processes. This unit could follow on from all the other units and is often delivered towards the end of a programme of study. Learners may also use their knowledge and experience of different technologies, via employment or previous learning, to their advantage in this unit.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

You should encourage learners to develop their theoretical knowledge of various processes and the related practical skills, as this unit contains a considerable number of hands-on activities. It is recommended that learners spend at least thirty hours developing their project and solution; encourage them to develop their rationale for completing a project, which may be either manufacturing, maintenance or system based.

To complete this unit, your learners will need access to various resources and the consumables and materials that support them. They will need to understand and apply strict safe working practices designed to protect them from the various hazards that are inherent to engineering processes.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions
- individual or group presentations – discussing the project rationale, performance and progress
- demonstrations of the set-up of various equipment and safety issues associated with the processes that may be used
- case studies illustrating components, systems and activities created via project-management processes.

Learners may benefit from internet sources, such as the videos available (stated in the Resources at the end of this Delivery Guide). There are also specialist books available for project-management processes.

You can involve local employers in the delivery of this unit if there are local opportunities to do so. For instance, an industrial visit to a manufacturing company or a technological exhibition could enhance each learner's skills base.

Delivering the learning aims

For learning aim A, introduce the topics by showing what can be achieved via a project. Perhaps pose the question: 'What do you want to make, maintain, or devise a system for?' Learners need to consider how they will meet the project criteria, and the first and hardest task is focusing them on a specific idea or problem. This may include manufacturing artefacts, maintenance tasks in an aerospace scenario, analysing and improving automotive components, devising new flexible manufacturing systems etc. You could then provide initial input for your learners on the identification and clarification of their problem. Support the learners to develop a specification by developing graphic solutions, outline costings and an initial technical specification. This should be followed by looking at feasibility studies of the project and selecting a proposed solution.

For learning aim B, introduce the topics by discussing project-management skills and the development of a solution. You could then move into project planning and look at items such as time planning, the use of Gantt charts and recording progress via a log book.

This could be followed by an explanation of the planning and design of a project. You could introduce the development of the project process and the need to control any risks and issues. Highlight the factors that could go wrong during the development or the practical operations and explain how these can be categorised into low, medium and high risk and the actions that should be taken as a result. The next phase of delivery should be to support the learners to produce a technical specification for a project. This should enhance and provide much greater detail then the outline specification created during the delivery of learning aim A. Learners could then use some of their experience from other units as they start to develop their design solution to their problem, with the creation of sketches, drawings, flow charts, models etc.

Learning aim C explores the creation of the project solution and its presentation. Learners will need support here to enhance their technical knowledge and practical skills as they create their project solutions. It is essential that they refer back to the initial proposal and technical specification to ensure that the product, or system, meets the fitness for purpose criteria or shows what corrective action would be required to overcome issues. It may be an advantage to explain testing techniques and suitable recording of testing. You could follow this by directing learners to consider what went well and what did not go as well. The learners will need to examine their technical understanding of general engineering skills, processes and safety issues. Encourage the learners to evaluate lessons learned and consider any improvements that could have been included. Similarly, direct learners to examine their behaviour during the unit by, for example, considering whether they showed initiative and took responsibility for their own actions. The final consideration is the creation of the project portfolio. Much of the content will have been produced during the project process, but learners may need help in ordering and cross-referencing the various sections. The portfolio should be a document that the learner would be proud to present to a future employer.

It is essential that, throughout this unit, you ensure that learners understand all the safety aspects of the processes involved.

An industrial visit to a design exhibition could enhance the learners' skills, particularly during learning aim B. A visit and delivery from a guest speaker who works within project development may be useful during learning aim A as they may provide some useful ideas for actual projects. Clearly, the active involvement of engineering employers with actual problems to solve and ideas for projects would be highly advantageous in this unit, especially when learners require expert feedback.

Learning aim	Key content areas	Recommended assessment approach
A Investigate an engineering project in a relevant specialist area	**A1** Project life cycle **A2** Project idea generation and solution development **A3** Feasibility study of solutions	Research evidence, investigating an initial idea and possible solutions, scoping out alternative technical solutions and completing a feasibility study report of the possible solutions.
B Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry	**B1** Planning and monitoring project-management processes **B2** Risk and issue project-management processes **B3** Technical specification **B4** Design documentation	Evidence of applying project-management processes such as planning during the design of a solution. Also, the development of a technical specification that may include design documentation, such as orthographic projections of the chosen solution.
C Undertake the solution for a specialist engineering project and present the solution as undertaken in industry	**C1** Undertake and test the solution to the problem **C2** Demonstrate relevant behaviours **C3** Present a solution to the problem	Evidence of applying project-management processes, such as project monitoring, and applying relevant behaviours during the development and testing of a solution. A portfolio of evidence generated while completing the specialist project, reviewing the processes and reflecting on own performance.

Assessment guidance

This unit will be assessed internally through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be portfolios containing reports, learner logbooks, planning documentation and testing documentation, printed or plotted portfolios of drawings and the annotated photographs of the process of solving a problem through a project-management approach. Learners should also produce screenshots to show processes and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 5: A Specialist Engineering Project

Introduction

Begin by introducing the unit to learners through a group discussion exploring their knowledge of the use of project-management processes and the possible skills that they will need or they have developed. This can be followed by outlining the learning aims of the unit.

It is essential that, throughout this unit, you ensure that learners understand all the safety aspects of the project processes.

Learning aim A: Investigate an engineering project in a relevant specialist area

- Ask learners to collaborate in small groups to come up with examples of different projects that they would like to investigate, manufacture or design.
- Ask learners to consider the how major manufacturers develop projects at component, assembly and product level. Consider the project development of systems and maintenance activities. A series of case studies could be used here to highlight either failures or successes in the development of different projects. Encourage learners to explore the rationale for success or failure.
- Lead the group on project development and consider the different stages: identifying a problem, planning and design, implementation and evaluation.
- Ask learners to focus individually or in small groups on possible projects. It may be advantageous to divide the learners into small groups that relate to their project outline ideas, manufacturing, systems, maintenance or hardware/software. The input of employers at this point with possible ideas for projects would be highly advantageous.
- Show learners how to use different thinking skills to analyse a problem, such as brainstorming, challenging previous assumptions and thinking in reverse.
- Allow learners to research the basic features of their project. In small groups, learners could then explore the physical resources, associated materials and the different types of input and outputs required.
- You could then provide input for your learners on developing an outline project specification. Help them to develop their working knowledge of sketching, storyboarding and how to create flow charts.
- You could then provide input on how an Excel spreadsheet is beneficial to record and maintain project costings, for materials, resources and time.
- The next input should allow learners to develop their initial technical information that relates to, for example, approximations of voltages required and batteries that may be used, and that outlines performance parameters of the project, such as an analogue input from a transducer to output to a digital LED display.
- The consideration then is the feasibility of the project. This will require a lot of tutor support to ensure that resources are available. Cost and time availability will be major considerations.
- It may be useful to provide further input on the benefits and use of objective testing to determine how well three or more possible solutions may fulfil the learners' criteria.

Learning aim B – Develop project-management processes and a design solution for the specialist engineering project as undertaken in industry.
• This learning aim can begin by exploring the development of project-management processes. • Ask learners to consider how they intend to develop their project. Lead the group on project development, as they will need to begin the planning stage. Demonstrate some of the tools they need and ask the learners to explore the resources that they will use to investigate the project. • Look at time considerations and discuss with learners how they can use their time effectively. Consider recording and planning activities, using Gantt charts and critical path analysis. • Explore the budget and resource considerations, and how both the learner and their project supervisor will monitor these. Explain to the learners that they cannot all use, for example, the additive machining equipment simultaneously and that planning is needed to utilise resources effectively. • Lead a discussion on issues and problems that are likely to arise during the development of the project. Explain what the potential risks are and how managing the risks can determine the success of a project. • Demonstrate to learners how to develop a technical specification. This should enhance and provide a much greater technical detail than the outline specification created for learning aim A. For example, actual voltages should be stated and the correct battery size and type should be specified. • Develop or enhance the learners' skills base, as necessary, so that they can create a design from the technical documentation to support their project. • Support the learners as they develop their design for the product, system or maintenance activity that they are pursuing. • Explain to the learners how to develop the relevant testing procedure for their project, to ensure that it is fit for purpose or meets the audience's requirements.
Learning aim C – Undertake the solution for a specialist engineering project and present the solution as undertaken in industry.
• This learning aim builds on learning aim B as learners are now ready to generate their solution and to test and present the results. • Support the learners to enhance some of their technical knowledge and practical skills, where appropriate, as they create their project solutions. • Support the learners as they further develop their solutions and refer back to the initial proposal and technical specification, to ensure that the product or system meets the fitness for purpose criteria or shows what corrective action would be required to overcome issues and problems. • As learners become ready to start their practical tasks, it is essential that all safety considerations are explained and demonstrated. • Support learners through their technical errors and emphasise the need for iteration as the project develops. • As the learners start to consider their portfolio presentation, it is well worth reminding them that the portfolio should be a document that they would be proud to present to a future employer. • You could direct learners to consider what went well and what did not go as well, particularly with relation to time planning and management.

- Explain to the learners that they will need to examine their technical understanding of their general engineering skills and safety issues.
- You could then direct the learners to evaluate lessons learned and consider any improvements that could have been included, particularly with reference to the success or the fitness for purpose of the final artefact or system. Again, it would be highly advantageous if engineering employers could be asked for their feedback at this stage.
- You could then direct learners to examine their behaviour during the unit, for example, whether they showed initiative and took responsibility for their own actions.
- You could then direct learners to examine the support they received from various sources during the project, such as technicians, tutors, guests, local employers etc.
- The final part will be to support the learners in compiling their final project portfolios, ensuring that they evaluate the success of the project against the project theme and initial idea.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

This mandatory unit can be linked to all other units in the qualification.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are determined by the project the learner is undertaking, be it system development, manufacturing, or maintenance.

Textbooks

Various textbooks are available for project development. These often cover project development at graduate level and above and may not always be suitable for a Level 3 project. There are textbooks that reference various technical stages, including graphics packages software command structure. Learning materials are available for the different companies that supply CAD/CAM software and the different versions of the software packages that they produce. Books and magazines are available on electronics, maintenance, CNC, 3D printing and many more subject areas to support technical detail.

- Bond WT – *Design Project Planning: A Practical Guide for Beginners, 1st Edition* (Prentice Hall, 1995) ISBN 9780133492750
  This book explores basic project management, linking it to the design process. It enhances basic design concepts and introduces the design process and its relationship to modelling.
- Plummer F – *Project Engineering: The Essential Toolbox for Young Engineers, 1st Edition* (Butterworth-Heinemann, 2007) ISBN 9780750682794
  This is a book aimed at the young engineer who wants to enter project management or who has just started in project management. It is written with a work-based approach.
- Smith NJ – *Engineering Project Management, 3rd Edition* (Wiley-Blackwell, 2007) ISBN 9781405168021
  This book describes engineering project management and aims to have a multi-disciplinary approach to projects. It is useful because it explores the management of small and large projects.

Videos

There are very many YouTube videos for projects and support for CNC manufacturing. Some examples are shown below.

- www.youtube.com/watch?v=WuGKnL0q1ps
- www.youtube.com/watch?v=Gu0EWKYzXpM
- www.youtube.com/watch?v=ibE626hR0sk
- www.youtube.com/watch?v=jMwrkB4JQ4M

Websites

Project ideas and development:

- www.realworldengineering.org/library_search.html
- www.sciencebuddies.org/science-fair-projects/Intro-Mechanical-Engineering.shtml
- www.electronicshub.org/electronics-projects-ideas/
- http://nevonprojects.com/project-ideas/

Maintenance projects:

- www.machinerylubrication.com/read/1330/planning-maintenance.

There are links below to some of the support systems available, including software houses producing CAD software. Many of these provide free educational software.

- www.autodesk.co.uk/
- www.solidworks.co.uk/
- www.solidworks.com/sw/products/draftsight-getting-started-guide.htm
- www.turbocad.co.uk/windows-range/turbocad-deluxe-2d-3d.

There are many links available on the web to some of the many software houses producing CAD/CAM and CNC programming software and machine tools, which may be useful, dependent upon the choice of project.

- www.haas.co.uk/
- http://website.denford.ltd.uk/
- www.techsoft.co.uk/
- www.fanuc.eu/uk/en
- www.heidenhain.co.uk/

Unit 6: Microcontroller Systems for Engineers

Delivery guidance

Approaching the unit

This unit will inspire and challenge learners to use the knowledge and skills they develop during the unit to create an inventive microcontroller system solution to a given problem. Learners have the opportunity to find out about the important part that microcontroller systems play in the world around them in the 'Internet of Things' (IoT). This unit cultivates learners' understanding of the types of microcontroller hardware and the diverse range of peripherals available that can be connected. It also teaches learners how to control them through programming. There is an opportunity to develop a varied range of practical activities – selecting a microcontroller for various common problems, identifying pertinent peripherals and physically programming the systems to achieve their own desired solutions.

Learners will develop incremental programming skills to enable microcontrollers to respond to several different types of inputs and produce relevant and expected, sometimes imaginative, output/s through an assortment of interconnected devices. They will systematically plan and devise their own coding solutions, methodically testing them under simulation and upon individually constructed microcontroller systems. These skills, an essential part of the growing research and development field of the IoT, will inspire learners to design and create tailored solutions.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the topics

Before beginning this unit, it is important that learners are issued with a suitable toolbox that contains the relevant tools, integrated circuits (ICs) and components that they will use throughout.

For topic A, topic A1 covers the underpinning theory and knowledge of the internal make up of a microcontroller IC.

Firstly, you could deliver this aspect by selecting a specific microcontroller that you will issue to each learner, together with a breadboard. Following learner research for the datasheet, learners could identify each pin and its primary/secondary function. You could give practical examples for each type of possible input and output, eg analogue input (temperature) and output via a single port to an LED array. This could be followed by the internal hardware specification and functions available within the chosen microcontroller, memory types, method of programming and how this can affect the cost and type of microcontroller required. This is an opportunity to begin a discussion on selecting the correct microcontroller for a given problem. Practical tasks could be introduced – using the selected microcontroller, building a simple power supply for the required operating voltage and powering up the microcontroller.

- This is also the ideal topic to introduce the IDE that you intend to use and how to obtain the software, whether it is open source or shareware.
- This gives an opportunity at this stage to map across with skills and knowledge from *Unit 19: Electronic Devices and Circuits*.

Topic A2 identifies many of the input peripherals, their operation and the characteristics that you can use with microcontrollers.

At this stage, it is important to have samples of the different possible input devices that can be used with your chosen microcontroller, including datasheets, so learners can get a feel for the size, shape and pin outs for the device. As you progress through this topic, it would be good to have working examples of each input device, a simple program and an output through a simple array of eight LEDs. This will enable you to hold several Q&A sessions about existing real-life applications for the related input device, which learners can also investigate. This can be a physical or simulated example but a physical example is preferred as it gives learners an input device they can physically adjust and see instant results.

Using each device leads into discussions about types of interface and practical examples of each type of interface and real-life applications.

- This gives an opportunity at this stage to map across with skills and knowledge from *Unit 19: Electronic Devices and Circuits* by wiring eight LEDs directly to a port.
- This is the ideal topic to reflect on the simplicity of some of the programs that control the input devices and give the output to the LED array. By downloading and running a simple program to light, the LEDs give learners examples of the structure and layout of any program that they will develop later in the unit.

Topic A3 identifies many of the output peripherals, their operation and the characteristics that you can use with microcontrollers.

Again, at this stage, it is important to have samples of the different possible output devices that can be used with your chosen microcontroller, including datasheets, so learners can get a feel for the size, shape and pin outs for each of the devices. As you progress through this topic it would be good to have a working example of each output device, a simple program and an input through an analogue device – a potentiometer is typically the most common. This is also an opportunity to have input devices connected through different interfaces, which links directly back to topic A2. This will enable you to hold several Q&A sessions about existing real-life applications for the related output device, which learners can also investigate. They can also develop imaginative ideas for potential uses. The example you use can be physical or simulated, but a physical example is preferred as it gives learners an output from an adjustable input that they can observe physically.

- This gives an opportunity at this stage to map across with skills and knowledge from *Unit 19: Electronic Devices and Circuits*. Connect a potentiometer to analogue input.

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- Again, this is the ideal topic to reflect on the simplicity of some of the programs that control the input devices and give the output to the LED array. This gives learners examples of the structure and layout of any program that they will develop later in the unit.

Topic A4 enables learners to investigate different problems that require a microcontroller system to enable application.

It is important that learners understand the importance of working systematically through any problem that may have a microcontroller system solution:

- investigating and identifying potential suitable options for inputs
- investigating and identifying potential suitable options for outputs
- researching aesthetics, cost and usability and
- reviewing the environment parameters of use.

It is important that you have a minimum of three complete examples to work through at this stage. Some groups of learners can grasp the concepts quickly and therefore, examples of varied complexity are required. Detailed discussions can develop about the advantages and disadvantages of each type of potential input and output for the desired solution. The example problems also allow learners to review and research different families of microcontroller that can be used as a potential solution and the reduction of costs.

It is better to incorporate the teaching of topic A5 throughout A1 to A4. The programming environment should be included as you introduce each topic. This is achieved by building the microcontroller system from the ground up – creating the power supply, building an output of eight LEDs, having input from a potentiometer (this could be already completed in another unit), connecting the IDE to the system, downloading a simple program to light the row of LEDs, or manipulating the LEDs through the potentiometer.

For topic B, topic B1 should initially be a reflection of the programs downloaded to visually identify types of inputs and outputs and how they can be easily manipulated. Revisit how the learners connected to the IDE and compiled, downloaded and ran programs on the microcontroller. At this stage identify the rules, folder structure, libraries, declarations, chip setup and syntax for any of the programs issued. It can also be worthwhile, depending on the ability of the cohort, getting the learners to write the code into the IDE directly during topic A so they encounter the common pitfalls early in the unit. Many of the compilation and downloading issues will then have been encountered during the delivery of topic A and typically peer learning will develop as learners share problems encountered and solutions. This enables more time to be spent on creating the program itself. These developed and given programs will also enable you to instruct the learners on how to step through a program and to simulate the full microcontroller system, if software is available.

Topic B2 covers the use of embedded C as the most common programming language used for microcontroller systems. It is important at this stage to identify any books and/or have several examples that will help and give example coding for the majority of the aspects required for the unit. At this stage as you introduce each new coding construct, it can be related directly back to topic A and the peripherals examined.

This an opportunity to revise topic A and create discussions on how each peripheral can be controlled in order to get learners to research and investigate types of communication, control mechanisms and modes of operation for peripherals, such as LCDs and coding necessary to operate. To structure the learning more clearly from this point, it is best to select one input and a single defined output to deliver content on program flow, logic and arithmetic variables. This will enable the refinement of the initial program, developing libraries, calling subroutines, using delays and other subroutines to develop logic and arithmetic structures to aid learner understanding. The continual development of the program enables learners' understanding and the reinforcement of tools available within the IDE being used.

In order to cover topic B3, you should supply the pseudo code, flowchart and/or decision chart for some of the initial basic programs and create a class discussion on the comparisons and links between the finished code and the program design. It is useful at this stage to get learners to write the design for some of the other basic programs already developed to understand the structure.

At this point set a standard programming task such as incrementing a count that is output on an LED array. Get the learners to develop the solution using the structure taught, creating the code, including libraries and calling suitable subroutines. The learners should again consistently use peer learning to ensure that they each get a complete running program.

In topic B3, it can be difficult for some learners to understand unfamiliar mathematical concepts. One of the best methods for this topic is to incorporate it with B1 or teach in advance. The best way to begin is by breaking down decimal numbers into Base 10 and then identifying how Binary (Base 2) is structured and how a decimal can be written in binary. Even though Octal (Base 8) is not required, it is useful to introduce in order to explain to learners that a decimal number can be represented in any Base number.

Delivery of the methods of conversion can be enhanced by a number of apps and games available online for learners to develop a quick understanding of the conversion between binary and decimal. As the learners develop their understanding of binary, it can be useful to incorporate hexadecimal for ease of programming if using embedded C.

In order to cover topic C, topic C1, you need to have a minimum of three complete projects for the learners to work through and have a reserve for those learners who enjoy the additional challenge. The first should be a straightforward project that you guide the learners through. The aim of this is to give them confidence that following the process is the best way to ensure that the solution meets the client's needs.

If possible, it is important to link this learning outcome with *Unit 19: Electronic Devices and Circuits* so that learners develop the self-assurance required for the detailed construction of circuits for microcontroller systems being created from individual components and ICs. It is still important if developing the finished system using an off-the-shelf development board, as the learners still need to be able to identify the necessary components and peripherals to visualise the final solution.

Testing the system can be one of the most critical features of the process. It gives justification and analysis for parts of the project that the learner cannot complete or ensure full functionality for, and is therefore a critical part of the delivery of this topic.

To deliver topic C2 it is best to have a template for the learners to follow when creating the supporting documentation for any chosen solution and a completed example of the depth required for the external assessment. Make sure at this point that learners have a method to record their finished solution to include in the finished documentation.

Assessment guidance

This unit is externally assessed. The assessment will require the learners to follow the processes as developed during delivery. This highlights the need for several practical examples for the learners to refer to and work through. The assessment will place the learner in the role of a microcontroller design engineer with a client requiring the design and construction of a real-life product to meet a need. The learners will need to give evidence of understanding each topic and associated topic in order to realise the finished product.

Preparation of the learners is essential and it is important that they have access to all tools, ICs and components that they will need to construct the final product. Familiarity with the IDE is crucial, as is understanding downloading and coding errors, to ensure that the learners can develop a prototype which may not meet the full client brief but gives evidence of each topic.

During the delivery of this unit, one of the key aspects is the ability of the learners to construct a prototype microcontroller system. As assessors, you are encouraged to develop the assessment of this unit in conjunction with *Unit 19: Electronic Devices and Circuits* to reinforce learners' skills in this area. Another key aspect is the use of the chosen IDE, coding, downloading and error checking programs. Learners develop a good grounding in this area by developing and expanding simple programs to deliver gradually more complex outcomes.

Getting started

This gives you a starting place for one way of delivering the unit. Activities are suggested to assist in preparation for the external assessment.

Unit 6: Microcontroller Systems for Engineers
Introduction The delivery of this unit allows for input from local electronic and research & development engineering employers. As a result, there is an opportunity for the employers to set real world problems for the learners to work through. Following the development process enables learners to cultivate transferable skills in problem-solving, creative development, independent learning and teamwork. The external assessment will require learners to be able to plan a project and more importantly schedule that project to ensure completion by the due date. The logical format of the essential content allows for a systematic understanding of the necessary skills to ensure learners can undertake the external assessment.
Topic A – Investigate typical microcontroller system hardware
• Topic A is broken up into several topics that should be delivered individually, building upon each aspect as you progress. Before beginning, it is important that learners have a suitable toolbox that includes a breadboard and basic tools. The contents can be expanded upon as the unit develops. • Choose a microcontroller that suits the IDE used within your department and school. This can be either an externally purchased development board or an in-house developed solution. • First, issue the learners with the selected microcontroller, eg PIC 16FXXX, relevant basic datasheet and connect to a breadboard. If possible, use a component constructed 5V power supply developed through an associated unit to power the microcontroller and construct the IDE programming input. • You can now direct the learners in a research task on the internal architecture of the chosen microcontroller that will create an opportunity for class discussions and a Q & A session. This allows learners to develop an understanding of the requirements for a microcontroller system, eg the number of ports needed, RAM, hardware features and input/output capabilities for use in different applications. • This topic requires extensive theory and discussions, therefore follow with an introduction to the features of the IDE and the method of connecting to the microcontroller. Develop learner understanding by repeatedly opening the software and connecting to the microcontroller, identifying and correcting the common connection issues that exist. This is an opportunity to introduce some peer learning and guidance that will become essential as the unit develops. • Topics A2, A3 and A4 allow group tasks and the teaching to overlap. Each group could be given details of a device that may have one or multiple microcontroller systems within it. Learners can then take one microcontroller system and try to identify the potential inputs that there could be within the system, what the input is measuring and how it is being displayed (output). This allows learners to review real-life microcontroller systems, their component parts and how they have been constructed. • It is important to define the inputs into either digital or analogue and create a discussion on the differences and what potentially can be measured by each type and how any output/s could be monitored. For example, why a fridge door light

illuminates (type of input and output), how a washing machine knows when to stop heating water, why the lights in corridors turn off if no one is there, burglar alarms, reversing sensors etc.

- This allows the learners to delve into topic A4 considering when and why you would use certain input or output devices, taking into account factors such as cost, style, accuracy and power requirements. For example, why have an LCD output if the door of a washing machine is locked when a red LED would suffice?
- This comfortably leads into interface requirements, how to convert an analogue input that can be understood by a microcontroller, signal conditioning and serial and parallel communications.
- It is essential that there are several examples of different types of input and output devices. Make sure that you can relate each device to a real world application, both seen and unseen. Learners should be encouraged to conduct research for the relevant datasheet for each device with time taken in class to review the operational characteristics of the main input and output peripherals that can be used.
- Once learners have identified the main input and output peripherals, this will be the opportunity to further develop the IDE, with circuit construction and by downloading simple programs to manipulate outputs based on digital or analogue input. For example, push button input to increment a count displayed (output) on LEDs, 7-segment display or LCD. The LCD requires more structured programming if connected by learners and not part of a development board.
- Other examples are:
    - Temperature sensor input that sounds a buzzer (output) at a certain temperature.
    - LDR input switches on a relay (output) that switches on a bulb, imitating a street light sensor.
    - Tilt switch input that switches off a relay (output) to cut power, imitating a fork lift emergency power shut off.
    - Micro switch input that changes the speed of a motor using pulse width modulation (output).
- The output interfaces can be connected in various ways using serial or parallel communications or interfacing using I^2C.
- It is advisable to have a basic task sheet for each example that includes how to interface the input and output with the microcontroller, a schematic and basic code that can be developed. Small tasks to make minor iterations to the code will build learners' confidence as they develop through the next topics.
- The more examples that the learners work through, the more confident they will become with the IDE, resolving errors connected to the microcontroller, testing the code and preparing them for the external assessment.
- Some assessors give the code as .txt file to incorporate into the IDE, others as a sheet of text for the learners to type directly into the IDE. The latter is recommended, as the learners will encounter common typing mistakes and declaration and syntax errors as a result.
- Separate sessions should be set aside for 'output interface requirements' as this is typically a difficult aspect of the theory for the learners to grasp.

Topic B – Programming techniques and coding

- This is the most vital part of the unit as most mistakes and failures to realise a microcontroller system are a result of poor coding and an inability to resolve issues by adhering to a structured plan for the code and a detailed testing schedule. For this delivery guide it is assumed that embedded C using the MPLAB® IDE (MPLAB® C) is used. A good way to start is with topic B3 (Number systems), so that learners can identify directly with the coding that they have previously written.
- Topic B3 will be straightforward for any learner who is undertaking an electronic or computing-themed final qualification, as they should have an understanding of binary at this stage in their studies.
- There are many apps and online tools to convert binary to decimal and vice versa but learners do not grasp the concept without taking it back to basics and completing the process on paper. It is important that the learners see the connection between the decimal number output through an LED array, LCD or 7-segment display and the binary or hexadecimal number in the code they develop. Hexadecimal is not part of the unit but it is used widely within embedded programs, therefore it is advisable to cover binary to hexadecimal conversions.
- By this stage, the learners will have already been using the IDE, connecting and reconnecting the microcontroller and will be familiar with compiling code, common syntax errors, debugging and safe practices. The learners will have identified the main aspects from the basic code example, such as declaring libraries, declarations, commenting and the coding structure. This allows you to reflect back over the code/construction tasks that they have completed. Discussion of each of the aspects can then follow in more detail and give the justification for each segment of code supplied.
- This is now the time to develop the basic code from the previous topic with the learners. The code will allow you to identify the input and output constructs, what they are doing and why for the learners.
- Learners can manipulate the original code to include comments that will help them develop an understanding and mean they have revision notes when they return. You can get the learners to: output to different ports and use other analogue inputs, create and include different libraries, call subroutines, create their own delays and develop different control structures that have the same ultimate function (if, if else, switch, case etc).
- Again, good planning and having several coding examples from topic A will allow the individual aspects of logic and arithmetic operators to be discussed and explained to the learners, with examples that they have already seen functioning on a microcontroller system. This will not cover each aspect, but if there are small, iteration tasks built into the examples, the learners can see the final output by including new lines of code that use different constructs to give either the same output or an extension of the initial output.
- For example:
  - A button that increments an output on a 7-segment display by one, a second input by two, a third that if held for two seconds will reset. Expand the code further so that it counts from 0 to 9 with one input, if left will stop and decrement when it reaches 8 after flashing for three seconds. Expand even further to display 0 to 9 depending on the value of an analogue input.
- This method of delivery encourages peer learning and practice-sharing to overcome coding errors, supporting any weaker learners that do not initially grasp understanding the construct and how it is written into code. The learners need to continually practise and develop code to achieve a more mature solution than that initially issued.

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• Now, the learners will have typed various example programs and developed these examples to create solutions that are more complex. Take one of the already completed programming tasks and issue the associated program design documentation. All the learners review the documentation and discuss the similarities of the plan to the finished product in groups. Discuss the structure of the pseudo code, flowchart and any related decision tables and the importance of a plan in creating any piece of code to ensure that it functions the way it needs to. To develop this topic, a new fresh task is required that you can work through with the learners, using all the skills and knowledge that they have developed to date regarding coding. This needs to be a programming task that will incorporate several of the coding constructs and should be a program that has the option to be further developed for those learners who want to stretch themselves. • Initially, you should walk through the coding problem with learners brainstorming the solution, the decisions and actions the code needs to carry out and then reflecting how this can be notarised into a document that can be interpreted by any embedded programmer.
Topic C – System development cycle
• Select one of the minimum three complete projects suggested in the initial part of this specification, which you prepare in advance. This will follow the format of the external assessment. Working through each stage of those in small class groups will allow you to identify any weak areas in learner knowledge, giving you the opportunity to recover areas of weakness if identified. This sample will allow the learners to see and understand the requirements of the external assessment, allowing them to visualise a potential solution. It is important to review each learner's design solution, as they can overthink the solution and create problems in coding and construction that is not immediately evident to them. • The completion of an in-class project will improve the learners' confidence in taking a design challenge and realising the solution in a structured methodical way that will ensure a variance of success depending on the abilities of the learner. • If the topics above have been covered in sufficient detail, the learners will only need to be instructed on how to collate their portfolio of evidence for any given process, including the amount of detail and annotation required at each stage. • Finally, a second project should be introduced with the learners spending several weeks under supervision and instruction completing a second sample project as though they were under examination conditions. There is one exception, you can give advice and guidance on direction, structure and errors identified that may prove crucial in realising the final product and/or solution.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 17: Power and Energy Electronics*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 20: Analogue Electronic Circuits*
- *Unit 21: Electronic Measurement and Testing of Circuits*
- *Unit 23: Digital and Analogue Electronic Systems*
- *Unit 32: Computer System Principles and Practice*

- *Unit 33: Computer Systems Security*
- *Unit 34: Computer Systems Support and Performance*
- *Unit 35: Computer Programming*
- *Unit 36: Programmable Logic Controllers*
- *Unit 37: Computer Networks*
- *Unit 38: Website Production to Control Devices*

As a mandatory unit on all Extended Diploma in Engineering qualifications, this unit will give a suitable foundation for learners to progress onto higher level courses or an apprenticeship.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Blum R – *Arduino Programming in 24 Hours – Sams Teach Yourself, 1st Edition* (Sams, 2014) ISBN 9780672337123.
  A good detailed guide to programming using the Arduino IDE.
- Ibrahim D – *PIC Microcontroller Projects in C: Basic to Advanced, 2nd Edition* (Newnes Elsevier, 2014) ISBN 9780080999241.
  This book demonstrates how to develop a range of microcontroller applications using a project-based approach.
- Van Dam B – *PIC Microcontrollers: 50 Projects for Beginners & Experts* (Elektor Electronics, 2008) ISBN 9780905705705.
  This book has a hands-on approach to projects and gives several useful examples for assessor and learner.
- Siegesmund M – *Embedded C Programming: Techniques and Applications of C and PIC MCUS* (Newnes Elsevier, 2014) ISBN 9780128013144.
  A hands-on introductory course on concepts of C programming using a PIC® microcontroller and CCS Compiler.

Videos

- www.youtube.com/watch?v=S1QCZW92fU4
  Tutorial to support using the MPLAB®IDE.
- www.youtube.com/watch?v=PhJKhV5l-i4
  Tutorial to support creating a project in MPLAB® IDE.
- https://youtu.be/Qps9woUGkvI
  Tutorial on soldering basics.
- www.youtube.com/watch?v=bERZ2RU_tGs&feature=youtu.be
  Pulse Width Modulation (PWM) video.

- www.youtube.com/watch?v=inBmGRQPt6U&feature=youtu.be
  I^2C video.
- www.youtube.com/watch?v=2UwxdCLFW70&feature=youtu.be
  Binary/Hex/Octal video.

Websites

- www.microchip.com
  Site for learners to download the free MPLAB®IDE and conduct research.
- www.picaxe.com
  Site for learners to download the free PIXAXE® and conduct research.

Unit 7: Calculus to Solve Engineering Problems

Delivery guidance

This unit builds on mathematical techniques covered in the mandatory unit Engineering Principles, and hence it is suggested that it is delivered after or at the same time as *Unit 1: Engineering Principles*. Learners will investigate the rules and manipulation techniques of calculus and apply them to the solution of engineering problems, making them aware of the importance of understanding advanced mathematical techniques. You should encourage learners to develop their pure mathematical skills by using them in an applied environment.

You should enable learners to appreciate why correctly modelling of an engineering system using differential and/or integral calculus techniques is important: working with numbers is much more cost effective than building hardware that does not perform to specification. Your learners' manipulation, numerical accuracy and presentational skills will develop so that assignments can be presented to an agreed standard.

A large part of this unit involves the teaching and learning of mathematical techniques that are portable and not just specific to engineering. For the first two learning aims, the unit content is structured so that your learners will initially investigate generic calculus techniques and then develop them to the solution of engineering problems. The third learning aim focuses on the solution of a complex, defined, specialist engineering problem by applying thinking skills (eg reductionism) and modelling techniques (analytical and numerical).

To complete this unit, your learners will need access to a spreadsheet package.

You can use a range of delivery methods in this unit, such as:

- formal teaching
- individual and small-group investigation
- structured worksheets
- case studies.

Learners will benefit from access to web-based mathematics support.

This unit, like the other mandatory units, could be delivered in a specialist context such as aeronautical, manufacturing or electrical and electronic engineering. For example, a centre wanting to deliver the mandatory units in an electrical/electronic context could explore a range of basic electrical products such as an iron, or a food blender to explore design and manufacturing processes applied. However, care must be taken to ensure learners are prepared for the task based external assessment that is set by Pearson.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Approaching the unit

You should make your learners aware that there are two strands to the teaching and assessment of this unit. The first strand is to teach learners how to apply the principle of calculus to a range of polynomial, trigonometric, logarithmic and exponential functions. To do this will require formal classroom delivery supported by significant amounts of learner practice in the form of graded worksheets. You should work with the universally accepted variables '*x*' and '*y*' but, as the unit develops, replace them with those used by engineers, for example '*s*' (displacement) and '*t*' (time). This first strand is, in effect, pure mathematics with an engineering 'flavour'.

The second strand is the use of calculus to solve real engineering problems and much of your teaching will be in form of supporting learners as they carry out self-directed study done on an individual or small-group basis. You should guide learners to use calculus techniques when studying other units within their programme, for example, to determine the maximum bending moment in a beam or the energy discharge from an electronic capacitor. Throughout your teaching of this unit, do reinforce the notion that mathematics is a modelling process that is much more interesting and valuable than simply a set of routines to be learnt by rote. Guide your learners to correctly present what they set out on paper, be it hand written or computer generated; mathematics is a communicative language.

Delivering the learning aims

For learning aim A, introduce the topic by showing your learners a displacement–time graph for an object that is accelerating in a straight line with constant acceleration. Discuss how you might determine the object's instantaneous velocity and acceleration at a given time point on the graph. Remind them of the concept of gradient, which they will have already investigated when they studied *Unit 1: Engineering Principles*. Through discussion, develop the concept of rate of change and think about other engineering situations where there are time dependent processes happening, for example heat transfer, flow of electrical charge, mechanical energy and power.

Explain to your learners that, in the initial stages of delivering this learning aim, they will learn about differential calculus manipulation techniques, the starting point being different types of mathematical function (building on what they learnt in *Unit 1: Engineering Principles*). Follow this up with a graphical explanation of gradient, small change and limiting value (derivative) of a simple power function such as $y = x^2$. Once your learners understand the concepts of variables and rates of change, you can go on to work through the various rules of differential calculus as set out in the unit content. This will have to be done in a formal way – up-front classroom delivery followed by worksheets. Until they are they confident in applying the various rules of differentiation, for example the product and quotient rules, your learners will not be able to move on.

To make the learning aim more accessible, it is important to incorporate spreadsheet mathematics, particularly when investigating the turning points and second derivative. You will need to explain to learners how to find the maximum and minimum points of a function (eg finding the maximum and minimum bending moments for a beam) by using differential calculus (analytical method) and plotting (graphical, spreadsheet method) and then use the second derivative to confirm that the point is a maximum or minimum.

Learners can find the concept of variables tending to zero (limiting value/Leibniz notation) very difficult to accept; for a lot of the content in learning aim A (and also B) they can just mechanically apply the rules of differentiation and work with the table of standard differential coefficients. They need to be convinced of what (d*y*/d*x* or d*s*/d*t*) means – this is easily done by setting out functions in spreadsheets, plotting, and following up with 'what if' repetitive calculation. You should use animations sourced from on-line mathematics support packages to reinforce your teaching of learning aim A.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment; your learners should be given a formulae sheet and the table of derivatives. Assignment tasks are based on the application of differential calculus techniques and not just simple recall of techniques (i.e. they are not memory tests).

For learning aim B, introduce the topic by telling your learners that, in simplistic terms, integration is the 'reverse' of differentiation. Get them to have a look at the table of standard integrals and compare with the table of derivatives. Before moving on to teach the rules of integral calculus, do introduce the concept of area measurement and summation. Start by discussing how to measure the areas of regular shapes such as rectangles and triangles. Then pose the question: 'How do we measure the area of an irregular shape?'. Lead the discussion to consider splitting the shape up into a number of smaller, regular pieces or, if the outline of the shape can be defined by a mathematical function, using a summating technique based on integral calculus and/or a numerical method such as the trapezium rule. Then step back and explain to your learners that, as with the first learning aim, before they can apply calculus techniques, they must first learn the rules. This will have to be done in a formal way, that is, by up-front classroom delivery followed by worksheets.

The types of function to be investigated will be the same as those in learning aim A; do ensure that your learners are fully competent in applying the rule of integration eg integration by parts. Having mastered the rules of integration, your learners can move on to investigate how integration is used as a summating tool; the concept of strip theory can be difficult to grasp and you may find it useful to support your delivery with animations sourced from on-line mathematics support packages. Understanding the significance of 'tending to zero' can be difficult for some learners.

As with learning aim A, in learning aim B learners can just mechanically apply the rules of integration. What you should be doing is encouraging them to investigate engineering uses for integral calculus, in particular, as a summation tool for finding the defined areas of plotted functions. To 'convince' your learners that summation using analytical calculus is valid, you will need to show them how to carry out numerical integration using spreadsheet mathematics. Summation techniques link very well to content within other units in their programme, for example mechanical/electrical energy transfer.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment for which your learners should be given a formulae sheet and the table of integrals. Assignment tasks are based on the application of integral calculus techniques and not just simple recall of techniques (i.e. they are not memory tests).

For learning aim C, you will be developing the application of thinking methods to the solution of a complex problems, that is, breaking a problem down into a set of linked manageable steps, each of which is solvable through the use of calculus (differential and integral). Your learners will have been doing this already when they were working with non-routine functions (learning aims A and B) and in other programme units. For this learning aim, you will probably only have to provide a small amount of formal input. Most of your support for learners will take the form of providing guidance as they investigate a complex engineering problem and mathematically model it.

Start by reviewing the use of reductionism, synetics (idea connection) and logical thinking; this does not have to be directly related to mathematics as the principles are generic. A group discussion led by you is a good way to cover this topic. In preparation for assessment of this learning aim, you should provide your learners with one or two well defined case studies and ask them to come up with solutions to be presented to the group and evaluated.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment for which your learners should be given a formulae sheet, the table of integrals and a pre-release case study to set the scene.

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** Second derivative and turning points **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 definition and proposed solution **C4** Solution implementation	A report containing the results of learners' analysis, planning and calculation, carried out under controlled conditions.

Assessment guidance

This unit is internally assessed and you should use three time-constrained assignments. There are authorised assignments for this unit, each covering one learning aim. If you choose to use your own assignment briefs, it is essential that each one covers a complete learning aim and is not split into sub-tasks per criterion.

Each learner must independently generate hard-copy evidence presented as a portfolio. There is no requirement for them to word process their mathematical manipulations; for most learners, hand written will be most time efficient method of presentation. Repetitive numerical evidence (eg spreadsheets and graphs) is better when presented in printed form. It is important that learner evidence is fully authenticated. For learning aims A and B, evidence should be based on fixed tasks; for learning aim C, learners may wish to discuss with you their solution strategy for an identified engineering problem and this could involve the use of an observation record to support their evidence.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 7: Calculus to Solve Engineering problems
Introduction Begin by introducing the unit to your learners through a group discussion exploring the reasons why mathematics is such an important tool in supporting all aspects of engineering. Move your learners away from the simplistic reasons for learning mathematical skills and talk to them about the wider and much more exciting aspects of mathematical modelling. Tell them that mathematical modelling is something we all do every day, for example money budgeting, and then open out the discussion to think about why it is crucial to design engineering products so that they perform to specification. Explain to your learners that calculus is a subset of mathematics that is of particular use to engineers because it allows them to investigate time-based systems, for example aircraft performance. As an example, you could talk in general terms about the design and development of a typical new commercial aircraft – everything is worked out using mathematical modelling so that, when the first one rolls off the production line, the pilot knows it will handle exactly as predicated in the simulator. Mathematics, as an engineering tool, has the same significance as the most complex CNC machining centre. Some learners may not have had the most exciting experience at school when learning mathematics. During the early stages of unit delivery they will be given learning routines that may seem tedious, much like learning a musical instrument. The challenge for you is to stimulate them sufficiently to get them through this first stage.
Learning aim A – Examine how differential calculus can be used to solve engineering problems

● Using a formal presentation you could review types of function, making reference to *Unit 1: Engineering Principles*.
● You could run a short quiz about types of function to identify learners who may require additional support.
● You could demonstrate access to the 'mathcentre' website (see Resources) and ask learners to pick a level 2/3 topic. For some topics there are four options to choose from: 'teach yourself', 'video', 'practice and revision' and 'test yourself'. As a fun group exercise, do a couple of the algebra tests.
● You should now carry out formal teaching of unit content A1 and A2, supporting your teaching with self-directed learner activities, such as worksheets.
● When your learners have mastered the basic concepts of differential calculus, you can move on the more interesting applications of differentiation in engineering (content A3 and A4). This will require formal instruction from yourself but there should also be an emphasis on learner-centred activities.
● In preparation for the assessment activity, you could guide your learners through:
  ○ plotting the graphs of given functions either by hand or by using a spreadsheet and measuring their gradients at different points
  ○ using the first derivative for each of the functions to calculate the gradient at different points and comparing with the graphically found values

- finding the first and second derivatives for given functions
- finding the turning points of polynomial and trigonometric functions
- investigating the use of maximum and minimum theory to solve engineering problems, for example optimising the dimensions of a container so that its internal volume is at a maximum but its surface area is a minimum.

- Once your learners have established the most effective dimensions for the container, it is worth repeating the exercise using numerical analysis. Using a spreadsheet, set up formulae for the volume and surface area, step through a range of dimensions, plot out the figures and find where the maximum occurs – does it agree with the value found by maximum/minimum theory?

Learning aim B – Examine how integral calculus can be used to solve engineering problems

- Using a formal presentation, you could review types of function, making reference to *Unit 1: Engineering Principles* and learning aim A.
- You could talk through the table of standard integrals and compare its layout with the table of differentials.
- You could give your learners a brief worksheet of polynomial functions, ask them to differentiate and then do the reverse action of integration; then talk about the constant of integration.
- Your learners could be reminded about the Mathcentre website and the link to integral calculus support.
- When your learners have mastered the basic concepts of integral calculus, you can move on the more interesting applications of it to engineering (content B2 and B3). This will require formal instruction from yourself but there should also be an emphasis on learner-centred activities.
- In preparation for the assessment activity you could guide your learners through:
  - finding indefinite and definite integrals for a range of given functions
  - investigating the use of numerical and analytical integration methods to solve engineering problems
  - finding the properties of periodic functions using integral calculus
  - finding the areas of shapes with outlines defined by mathematical functions and applying this to engineering situations (eg determination of work done/energy transfer).

Learning aim C – Investigate the application of calculus to solve a defined specialist engineering problem

- This learning aim builds on the knowledge and understanding from learning aims A and B. You could provide a small formal input about thinking methods but most of the topic content is best covered as self-directed investigation.
- In preparation for the assessment activity, you could guide your learners through:
  - using thinking methods to analyse an identified engineering problem (eg breaking the problem down into a series of manageable elements, and producing a specification)
  - preparing a valid proposal for solving the problem and presenting the proposal to an audience
  - producing mathematical models for the identified elements of the problem
  - solving the problem using both differential and integral calculus methods to

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produce answers for each of the elements of the problem and critically analyse the results

- presenting the solution as a formal presentation.

- The problem to be solved could be taken from another unit within the BTEC programme to suit the learner's specialist area of study, for example:
  - the stress analysis of a load carrying structure where differentiation is applied to determine maximum and minimum bending moments and integration is used to determine the 'I' value for a beam (i.e. the moment of inertia) with a non-regular cross section.
  - analysis of the signal frequency from op-amp differentiator and integrator circuits.
- Learners should be encouraged to incorporate spreadsheet maths into the presentation.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 15: Electrical Machines*
- *Unit 17: Power and Energy Electronics*
- *Unit 20: 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*

Resources

There are no special resources required for this unit but your learners will benefit from access to maths support websites.

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Boyce A, Cooke E, Jones R, Mantovani B, Roberts D and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241.
  This contains learner support activities.
- Bird J – *Engineering Mathematics* (Elsevier Science & Technology, 2007) ISBN 9780750685559.
  Useful exercises to complement teaching.
- Fuller A, Greer A and Taylor G W – *BTEC National Mathematics for Technicians, 3rd Edition* (Nelson Thornes, 2004) ISBN 9780748779499.
  Useful additional resource.
- Tooley M and Dingle L– *BTEC National Engineering, 2nd Edition* (Elsevier Science & Technology, 2007) ISBN 9780750685214.
  A good course textbook.
- Greer A and Taylor G W – *BTEC National NIII Mathematics for Technicians* (Nelson Thornes, 1991) ISBN 9780859509329.
  Maths activities.
- Greer A and Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102.
  Higher-level maths activities.

Websites

- www.mathcentre.ac.uk/students/topics
  The mathcentre is a free and robust resource. It provides easy access to topic reviews, revision worksheets, tests and animations.
- www.ncetm.org.uk
  The National Centre for Excellence in the Teaching of Mathematics website – this site provides ideas and support for teachers to enhance mathematics teaching.

Unit 8: Further Engineering Mathematics

Delivery guidance

This unit builds on mathematical techniques covered in the mandatory *Unit 1: Engineering Principles*. Learners will now investigate the rules and manipulation techniques applicable to a range of pure mathematics topics and apply them to solving engineering problems. The aim is to make your learners aware of the importance of understanding how to apply the advanced mathematical techniques used by engineers when solving complex problems such as modelling a complex electrical circuit or processing quality assurance data.

You should encourage learners to appreciate why correctly modelling an engineering system using numbers is a much more cost effective process than building hardware that does not perform to specification or machining components that are out of tolerance. Your learners' manipulation, numerical accuracy and presentational skills will develop so that assignments can be presented to an agreed standard.

A large part of this unit involves the teaching and learning of mathematical techniques that are portable and not just specific to engineering. The first learning aim includes topics on progressions and power series. These are used by manufacturing engineers when calculating rates of deprecation on capital equipment such as machining centres. The second learning aim focuses on matrices and determinants, an engineering application being the solution of three dimensional vector arrays. The third learning aim covers complex numbers, particularly useful to electrical design engineers. The fourth learning aim investigates how statistical and probability techniques are used by quality assurance engineers to monitor manufacturing processes and product reliability.

To complete this unit your learners will need access to a spreadsheet package.

You can use a range of delivery methods in this unit, such as:

- formal teaching
- individual and small group investigation
- structured worksheets
- case studies.

Learners will benefit from access to web-based mathematics support.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Approaching the unit

You should make your learners aware that there are two strands to the teaching and assessment of this unit. The first is to teach learners the rules of pure mathematics as applied to the four discrete topic areas set out in the learning aims. To do this will require formal classroom delivery supported by significant amounts of learner practice in the form of graded worksheets. You should work with the universally accepted variables 'x', 'y', 'A', 'B' etc but as the unit develops replace them with those used by engineers, for example 'I' (electrical current) and 't' (time). The portability of techniques learnt give scope for learners to move onto level 4 and 5 qualifications that have a heavy maths content.

The second strand is applying pure mathematics techniques to solving real engineering problems and much of your teaching will be in the form of supporting learners as they carry out self-directed study done on an individual or small group basis. You should guide learners to apply what they are learning to other units within their programme, for example phasor diagram analysis of electrical circuits (*Unit 16: Three Phase Electrical Systems*).

Throughout your teaching of this unit, do reinforce the notion that mathematics is a modelling process that is much more interesting and valuable than simply a set of routines to be learnt by rote. Guide your learners to correctly present what they set out on paper, whether it is hand-written or computer generated. Mathematics is a communicative language.

Delivering the learning aims

For learning aim A, introduce the topic by looking at a very simple sequence of numbers, for example 1, 4, 9, 16 and discuss how the terms are generated. You could ask your learners to plot out the numbers and to predict what would be the sixth term in the sequence. Then have a look at a sequence that has terms which decrease in size, for example 1, 1/2, 1/4, 1/8 and plot out. Compare the shapes of the two graphs and then discuss what happens if you add together the numbers in each sequence. For the first sequence the total gets bigger and bigger ultimately going to infinity, for the second sequence it will have a finite total. Show that if the numbers in the second sequence are put into a spreadsheet and totalled then the more terms you have, the closer the total will get to a numerical value of 2. This can then lead into a discussion about divergence, convergence and accuracy.

Once your learners understand the concept of a sequence of numbers they can move on to investigate the detailed topics within the learning aim. Wherever possible you should support delivery with graphical presentations. This is very easy to do if you set up numbers and formulae in spreadsheets. The aim is to make learners appreciate the shape and form of number sequences. A particular power series that they should investigate is the one that defines 'e' (the exponential function), its numerical value and differential coefficient should be investigated.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment. Your learners should be given a formulae sheet. Assignment tasks are based on the application of mathematical techniques and not just simple recall, ie a memory test.

For learning aim B, the starting point would be solving a pair of simple simultaneous linear equations (with just two variables as this is level 2, but forms a good lead into matrices). Having solved them by subtraction or substitution methods, rewrite them in matrix form and pose the question, 'What do you do next?' Not a lot at this stage because your learners have not learnt the rules of matrix manipulation. It's worth opening out the discussion to pose a second question, 'Why bother to use a different type of mathematics to solve a pair of simple equations?' The discussion could now focus on what happens if you have simultaneous equations involving more than two variables, for example those needed to solve electrical circuits and vector arrays. Having sowed the seeds of interest now move on to demonstrate how to manipulate matrices and determinants. Your learners should then spend time practising the standard manipulations. When they are confident, pull things back to answer your questions posed earlier by showing them how to efficiently deal with linear simultaneous equations that have more than two variables.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment.

For learning aim C you could start by reviewing the number line and the graphical representation of co-planar vectors. In the early stages of delivery it is useful to have a discussion about the terminology 'complex number' because is important that your learners do not confuse the terms 'complex' and 'complicated'. This discussion is best done around some graphical presentation using vectors. Show that when combining vectors we split them into components that are at right angles (very often horizontal and vertical components). Then open out the discussion to talk about 'real' and 'imaginary' parts and convince your learners that there is much more to 'imaginary' than just its basic dictionary definition. This then leads onto another difficult concept for your learners, being able to find the square root of a negative number. A simple calculator check produces 'error' if you try, for example the square root of -4. It is now worth going back to the number line and discussing zero. In simplistic terms there is nothing less than zero, but as your learners will no doubt appreciate, it is just a reference point on a scale. The negative applied to a number is simply a coding reference, the number still has magnitude.

Having set the scene you can now go on to teach the routine and non-routine operations relating to complex numbers. When your learners are confident working with these routines, they can investigate the application of them to engineering situations. Assessment of this learning aim will be through the use of a time-constrained, controlled assignment.

For learning aim D, the starting point is for you to present a review of data collection and graphical presentation, for example bar charts and histograms. This is very much a level 2 activity and could be delivered as a quick overview presentation from a spreadsheet that is manipulated. At this point it is worth discussing that care should be taken when presenting statistical data to people who are not trained statisticians. The media presentation of 'shock horror' statistics is a good example to home in on. Explain to your learners that they will be investigating statistical techniques that are used as analytical tools by engineers across a whole range of functions in engineering businesses.

Your learners will probably all have experience of working with spreadsheets. If not then it is worth arranging additional work to get up to speed. Much of the work that you do with your learners will involve working with large data sets and it becomes tedious if they have to present and manipulate data using pencil/pen and paper.

The focus in this learning aim is on the manipulation and interpretation of statistical data set in an engineering context, for example dimensional data gathered during inspection of a machining process. Your learners can let the spreadsheet 'take the strain' when they are 'number crunching'.

Assessment of this learning aim will be through the use of a time-constrained, controlled assignment. Any processing using a spreadsheet must include displaying of formulae. To prevent plagiarism it is suggested that learners be given different data sets to work with.

Learning aim	Key content areas	Recommended assessment approach
A Examine how sequences and series can be used to solve engineering problems	**A1** Arithmetic and geometric progressions **A2** Binomial expansion **A3** Power series	An informal report containing the results of learners' analysis and calculation, carried out under controlled conditions.
B Examine how matrices and determinants can be used to solve engineering problems	**B1** Matrices **B2** Determinants	An informal report containing the results of learners' analysis and calculation, carried out under controlled conditions.
C Examine how complex numbers can be used to solve engineering problems	**C1** Complex numbers	
D Investigate how statistical and probability techniques can be used to solve engineering problems	**D1** Statistical techniques **D2** Probability distributions **D3** Statistical investigation	An informal report containing the results of learners' analysis and calculation of measured and supplied data, carried out under controlled conditions. Where appropriate, processing of statistical data can be done using a spreadsheet.

Assessment guidance

This unit is internally assessed and you should use three time-constrained assignments. There are authorised assignments for this unit, each covering one learning aim. If you choose to use your own assignment briefs, it is essential that each one covers a complete learning aim and is not split into sub-tasks per criterion**.**

Your learners must independently generate hard copy evidence presented as a portfolio. There is no requirement for them to word process their mathematical manipulations, for most learners hand written will be the most time efficient method of presentation. Repetitive numerical evidence, eg spreadsheets and graphs is best presented in printed form. The recommended assessment approach (see above) is for evidence to be presented as informal reports that focus solely on correct presentation of mathematical manipulations. It is important that learner evidence is fully authenticated. For all learning aims learner evidence should be based on fixed tasks and to prevent plagiarism they can be given different data sets.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 8: Further Engineering Mathematics

Introduction

Begin by introducing the unit to your learners through a group discussion exploring the reasons why mathematics is such an important tool in supporting all aspects of engineering. Move your learners away from the simplistic reasons for learning mathematical skills and talk to them about the wider and much more exciting aspects of mathematical modelling. Tell them that mathematical modelling is something we all do every day, for example money budgeting, and then open out the discussion to think about why it is crucial to design and manufacture products that perform to specification over their lifetime.

Explain to your learners that unlike *Unit 7: Calculus to Solve Engineering Problems* there are no links between the four learning aims and that there will be a big emphasis on learning generic mathematical processes that can be applied more widely than just engineering.

Some learners may not have had the most exciting experience at school when learning mathematics. During the early stages of unit delivery they will be tasked with learning routines that may seem tedious, much like learning a musical instrument or sports skill. The challenge for you is to stimulate them sufficiently to get them through this first stage.

Learning aim A – Examine how sequences and series can be used to solve engineering problems

- Using a formal presentation you could review progressions, the binomial expansion and power series.
- You could demonstrate access to the 'mathcentre' website (see resources) by going to the section headed 'sequences and series'. If you then select 'arithmetic and geometric sequences and series' you will be offered a number of options including 'teach yourself', 'test yourself' and 'video'.
- You could then carry out formal presentation of topics A1 and A2.
- Learners carry out individual or small group investigation using graded worksheets.
- You could then carry out formal presentation of topic A3.
- Learners work individually or in small groups investigating power series by working through graded worksheets.
- When your learners have mastered the basic concepts of sequences and series they can individually investigate their use in engineering contexts.
- In preparation for the assessment activity you could guide your learners through:
  - evaluating the use of progression and series methods in an engineering context
  - producing expression for arithmetic and geometric progressions (AP and GP)
  - determining the sum of these progressions to a given (n^{th}) term and also to infinity for the GP
  - investigating, using the binomial series, the expansion of algebraic expressions that have two terms and are raised to a power, eg $(1- 2x)^{0.5}$
  - investigating the application of the binomial series to the calculation of small errors
  - investigating, using a series method, the exponential function.

Learning aim B – Examine how matrices and determinants can be used to solve engineering problems
• Using a formal presentation you could demonstrate the purpose of matrices and how to manipulate them (topic B1). The presentation could take two forms – hand written on a white board and an animation sourced from a download. • Learners carry out individual or small group investigation using graded worksheets. • Make a formal presentation about determinants. • Learners carry out individual or small group investigation using graded worksheets. • Bring together the principles of matrix and determinant manipulation and apply to engineering problems – tutor led small group investigation. • Whole class pooling and discussion of investigative activities. • In preparation for the assessment activity you could guide your learners through: ○ carrying out manipulation of (2x2) and (3x) matrices ○ solving the determinants of (2x2) and (3x) matrices ○ solving linear simultaneous equations using matrix and determinant methods ○ investigating the application of Cramer's rule to the part solution of simultaneous equations.
Learning aim C – Examine how complex numbers can be used to solve engineering problems
• Make a formal presentation about complex numbers. • Learners carry out individual or small group investigation using graded worksheets. • From another unit that they are following, your learners pick a problem that requires the use of complex numbers to solve it, for example from *Unit 18: Electrical Power Distribution and Transmission*. • In preparation for the assessment activity you could guide your learners through: ○ carrying out addition, subtraction, multiplication and division of complex numbers that are presented in algebraic form ○ investigating the presentation and manipulation of complex numbers by using Argand diagrams ○ solving problems about the addition and subtraction of phasors ○ demonstrating the conversion of complex numbers from rectangular to polar and polar to rectangular forms. It should be noted that the distinction criterion BC.D2 gathers evidence from learning aims B and C. The assessment of learning aims B and C should therefore be carried out in parallel.
Learning aim D – Investigate how statistical and probability techniques can be used to solve engineering problems
• Make a formal presentation about topic D1 (statistical techniques). • Learners carry out individual or small group investigation using graded worksheets. • Make a formal presentation about topic D2 (probability distributions). • Learners carry out individual or small group investigation using graded worksheets.

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- Make a formal presentation about topic D3 (statistical investigation), linking it to *Unit 30: Mechanical Measurement and Inspection Technology*, learning aim C Explore statistical process control (SPC) to inspect components and increase productivity.
- Working in pairs, and guided by you, learners carry out a case study investigation. For each pair you should select an appropriate topic from the list presented in the unit content or sourced from *Unit 30: Mechanical Measurement and Inspection Technology*. For day-release learners who are working in industry it may appropriate for them to select a topic from their place of work. This would require careful consideration by you to ensure that the data they are working with is sufficiently rigorous.
- In preparation for the assessment activity you could guide your learners through:
  - collating and presenting statistical data in tabular and graphical formats
  - evaluating measures of central tendency and dispersion for given data
  - investigating the correlation of a data set comprising an independent and a dependent variable – carry out linear regression on the data set.
  - plotting given data sets and investigating their distribution
  - investigating the use of the normal distribution function to calculate the expected percentages of, for example a mass-produced machined product being in tolerance/out of tolerance.

To ensure equal rigour, it is not advisable for learners to collect their own data. Each learner should be given a different data set to work with. They can use spreadsheet maths to manipulate and present data but the assessor must reduce opportunities for plagiarism by requiring learners to display formulae.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 15: Electrical Machines*
- *Unit 16: Three Phase Electrical Systems*
- *Unit 17: Power and Energy Electronics*
- *Unit 20: 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 30 : Mechanical Measurement and Inspection Technology*
- *Unit 31: Thermodynamic Principles and Practice*
- *Unit 48: Aircraft Flight Principles and Practice*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

The textbooks listed are a very useful tutor resource but please note that they do not map to the unit content as presented in the learning aims.

- Pledger K, Clegg A and Gardner S – *Edexcel AS and A Level Modular Mathematics – Statistics 1* (Pearson, 2008) ISBN 9780435519124.
  A good core mathematics guide for the course.
- Boyce A, Cooke E, Jones R, Mantovani B, Roberts D and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241.
  Contains learner support activities.
- Bird J – *Engineering Mathematics* (Elsevier Science & Technology, 2007) ISBN 9780750685559.
  Useful exercises to complement teaching.
- Fuller A, Greer A and Taylor GW – *BTEC National Mathematics for Technicians, 4th Edition* (Nelson Thornes, 2004) ISBN 9780748779499.
  Useful additional resource.
- Tooley M and Dingle L – *BTEC National Engineering, 2nd Edition* (Elsevier Science & Technology, 2007) ISBN 9780750685214.
  A good course textbook.

- Greer A and Taylor GW – *BTEC National NIII Mathematics for Technicians* (Nelson Thornes, 1989) ISBN 9780859509329.
  Maths activities.
- Greer A and Taylor GW – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005), ISBN 9780748794102.
  Higher-level maths activities.

Websites

- www.mathcentre.ac.uk/students/topics/
  The mathcentre is a free and very robust resource. Gives easy access to topic review, revision worksheets, tests and animations.
- www.ncetm.org.uk/
  National Centre for Excellence in the Teaching of Mathematics – gives ideas and support to tutors to enhance mathematics teaching.

Unit 9: Work Experience in the Engineering Sector

Delivery guidance

Approaching the unit

In this unit learners will investigate the benefits of carrying out a work experience placement with an engineering organisation. They will gain an understanding of the skills which they could develop during their placement, such as team working and intrapersonal skills. Learners will explore the expectations which an employer would have, and will also consider the different career opportunities in different engineering sectors; considering in detail the sector in which they are carrying out their work experience.

Learners will develop their own plans for their work experience placement, considering their own goals and objectives which they wish to achieve; these will include both personal and professional targets. This should then be followed by a work experience placement with an appropriate engineering organisation, which will allow for a range of tasks to be carried out, and will also offer scope to shadow experienced members of staff.

In order for the experience to be valuable, learners will finally reflect on their placement, considering their own personal and professional development. They will consider the wider impact of continual professional development in their chosen career pathway.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could introduce learners to the benefits of work experience with regards to developing their own personal skills and attributes. Initially you could consider the different types of skills which would be required within an engineering workplace, perhaps using a skills audit to determine the skills which the learners already consider that they possess. This could then be expanded upon by considering the areas where they feel that their skills are somewhat weaker and thus would need to be developed as they progress through their careers in engineering.

Once learners have a good understanding of the personal and professional skills which are needed for working in an engineering workplace, you should consider with them the expectations for employment in engineering. This should focus on both the employer and the prospective employee. You may wish to deliver this through the use of a case study based around job descriptions and person specifications. There is also opportunity to invite a visiting speaker to explain how learners should prepare themselves for employment in a particular engineering sector.

Finally, the various career options which are available to the learner should be considered. Learners could investigate the job roles which are available in a range of appropriate engineering sectors, and identify suitable sources of careers advice and guidance. They should be introduced to professional engineering bodies and have knowledge of the types of membership which would be available to learners as their careers progress. You should encourage learners to use their work experience placement as an aid to their career decision-making process.

In Learning Aim B you will begin to prepare learners for their work experience placement. You should begin by considering the expectations which their employer will have of them, especially with regards to their conduct in the work place. This again offers the opportunity to either invite a speaker in, or to use examples of job descriptions that learners can investigate. You should also explain that although the placement may be in a workplace that involves highly technical activities, the tasks carried out during work experience will be given based on the skills and ability of the learner. You could introduce the concept of work shadowing here, explaining that it is likely that learners will shadow staff who carry out highly technical roles and will gain an understanding of those job roles using that method.

You should then introduce learners to the need to set their own goals for their work experience placement. They could use the skills audit carried out for learning aim A to identify where they need to develop skills. You should introduce the concept of SMART targets to learners, which they can then apply in order to set their own targets for their work experience placement. You should introduce learners to the standards set by professional bodies such as the IMechE and IET, along with their entry requirements for membership. These standards could then be used by learners for them to set their own personal and professional development targets.

Learning aim C will be addressed during the work experience placement. You will encourage learners to participate in a wide range of tasks and activities during their placement. Learners should not only take part in tasks directly related to engineering but also some non-engineering tasks. You should emphasise to learners the importance of keeping a journal of their activities, as they can use this to link their practical experiences during their work placement with their theoretical studies in other units. You should also encourage them to use their journal to reflect on the personal development activities which they have carried out whilst on placement.

Learners should use their work experience placement to develop a wider knowledge of the activities that are carried out by employees. This is likely to be achieved through observing staff carrying out specific activities or procedures, or through shadowing staff members in different functions within the organisation. Whilst participating in these activities, learners should be encouraged to continue to develop their intrapersonal skills and develop their understanding of how these skills impact on working relationships.

Finally, learning aim D should be used to draw together the preparation for work placement with the actual activities carried out whilst on placement. You should encourage learners to consider reflection as a continuous process which they should carry out throughout their professional lives. You could introduce methodologies for reflecting on plans and activities which learners can then apply to their reflective journal based on their placement. This can then be linked to the SMART targets which they have set themselves to reflect on their personal development.

You should also encourage learners to consider their career pathways and goals; this could include highlighting those areas where they need to improve their skills and devising an action plan which can be followed for developmental purposes.

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 task **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	

Assessment guidance

The assessment of this unit is most likely to be in the form of two assignments, one for learning aims A and B, the second for learning aims C and D. For the first assignment the evidence would normally be presented in the form of a portfolio of evidence which justifies their selection of work experience placement. It is likely that the portfolio will consist of a written report which provides the background to the placement and also an action plan to be followed during the placement. For assignment 2, learners will present a reflective log which evaluates their performance on their work experience placement. This should be accompanied by observation records detailing the tasks and activities which the learner has carried out during their placement.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 9: Work Experience in the Engineering Sector

Introduction

This unit enables learners to gain first-hand experience of the skills needed to complete a range of job roles within an engineering organisation. There are opportunities for visiting speakers to explain to learners the skill set which they would need to gain employment in the different engineering sectors, whilst visits to a range of workplaces could widen the career aspirations of learners.

You should provide learners with the background knowledge which they will need to be able to audit their own skills and subsequently set themselves SMART targets to aim for whilst on placement.

On completion of their placements, learners will need to reflect on their experiences in the workplace. This should take account of the personal and professional skills which they have developed in order to plan their future career development.

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

- Learning aim A provides the background for carrying out a work experience placement.
- First, you should introduce learners to the reasons why work experience can be used by an engineer to develop a range of professional and personal skills. You should encourage learners to work in small groups to identify which skills they think could be developed during a placement, and to suggest whether these are personal or professional skills. Learners could then be asked to complete a skills audit on themselves, to identify the skills that they feel are strong and those that they need to develop.
- It is important to emphasise to learners that work experience will allow them to put into practice some of the theory which they have learned across other units, and that this is an opportunity to develop the technical skills which will increase their chances of employability within their chosen engineering sector. This could be reinforced through the use of visiting speakers from one or more engineering organisations, who would explain to learners the skills and qualities they look for in prospective employees.
- Associated with this, you could provide learners with examples of person specifications and job descriptions for a range of apprentice or technician level roles within engineering organisations which they can investigate, in pairs or individually, to identify the qualities and skills that an employer would be looking for in new members of staff.
- In order to consider the various career options available to learners, you could encourage them to work in small groups to investigate the different career pathways available to them in a number of different engineering sectors. They could consider the information available from the IET and IMechE and engineering organisations themselves. You should encourage learners to consider a wide range of sources in order to find appropriate information and reinforce the importance of work experience as a method of informing their decisions with regards to career progression.

Learning aim B – Develop a work experience plan to support own learning and development
• Learning aim B is designed to provide learners with the background knowledge and understanding needed to be able to complete their work experience placement. Again, there is an opportunity for you to invite a guest speaker from an appropriate engineering organisation, who could explain the expectations that they have of new employees in their organisation • You should provide learners with sufficient guidance to allow them to research a range of potential work experience placements within an appropriate engineering sector; this should take into account the different roles which could be available along with possible alternatives for organisations in which they could work. You should emphasise to learners that it will not always be possible for them to carry out tasks related to the job role to which they aspire because of restrictions that may be in place due to their relative lack of experience and training. However, they may be able to shadow a more experienced employee whilst they carry out specific duties. • You should also make learners aware of the role that their mentors will play in the workplace. Point out that their mentors will need to produce observation records which will form part of the learners' submission of evidence for assignment two. • Once learners have a secure understanding of the types of role which could be available to them for their work experience placement, you should introduce them to the idea of setting goals and targets which they should aim for during their placement. You could use the initial results of their skills audit as a starting point to gauge their current level of skill and then encourage learners to consider where there are gaps. You should emphasise to learners that these gaps are the areas which they should aim to develop during their work experience placement and,as a group, you could discuss methods to develop such skills. • You should reflect on the information available to learners from professional organisations, and encourage learners to investigate the entry requirements for membership of professional bodies such as the IET and IMechE. The focus should be on the skills and qualities that these bodies would expect an engineering professional to possess. This research could also form the basis for the setting of SMART targets by learners; you should discuss with them which targets are realistic for their work experience placement, and encourage them to set both personal and professional developmental goals. • Learners should collate their evidence for assignment one which will set out the role of work experience in their professional development and how they could use their work experience placement as a method of informing their future career choices. Furthermore, you should ensure that learners provide a comprehensive development plan which they can follow whilst on their placement; this should consider the expectations which the employer will have of them, a reflection of the learner's existing skills and their targeted areas for development. Learners should make sure that they consider SMART targets for the activity which reflect their personal and professional development needs.
Learning aim C – Carry out work experience tasks to meet set objectives
• Learning aim C is most likely to be addressed in a work-based environment, where there will be little in the way of formal teaching; however, you should prepare learners for the ongoing training opportunities prior to the start of the placement. You should make sure that learners have a knowledge of their roles and responsibilities within the workplace, and that these extend beyond pure engineering tasks to the wider range of activities which take place within the

organisation. You should encourage learners to have as broad an experience as possible (including involvement with non-core activities), which may be office based, or involve attending meetings as an observer. This wider understanding of the different functions within an organisation should therefore allow the learner to reflect on their experience at a deeper level.

- You should make sure that learners are aware of the importance of their reflective journal, as this can be used when considering future career pathways. Observation records and notes concerning tasks and activities carried out could be recorded in this document, and links between classroom theory and workplace practice can be made.
- You should also guide learners into making sure that they are able to develop the intrapersonal skills which are needed for working in an engineering workplace. They should be encouraged to develop their working relationships with colleagues.
- You should make sure that learners are proactive whilst on their placement in order to gain some experience of processes and activities which they are not able to carry out themselves. This experience could be in the form of work shadowing or observations, with these being recorded appropriately in their journal. You should encourage learners to reflect on their experiences on a regular basis, as these will influence their developmental needs for the remainder of the placement.

Learning Aim D - Reflect on how work experience influences own personal and professional development

- Many of the activities associated with learning aim D will be carried out at the same time as those for learning aim C due to the cyclical nature of professional development. You will need to make learners aware that it is important that they reflect on their development on an ongoing basis. To achieve this, you will need to provide learners with the appropriate frameworks for carrying out their reflection; you should encourage learners to reflect on their experiences at the earliest opportunity as this is most likely to result in them identifying further training or developmental needs. You should encourage learners to evaluate their own performance whilst on placement, and record their thoughts in their journal. It is important that learners understand that their reflective journal is also a record of the training and opportunities which they have had whilst on placement.
- You should highlight to learners the importance of continual professional development during their working life, and that they should view all feedback as formative. Learners should be made aware that feedback which is constructive will identify areas which may require further development in the future. Feedback can also highlight where skills need to be honed and enhanced and can be used to generate an action plan to achieve this. Future job roles can also be considered so that a career pathway can be mapped and future goals identified.
- The evidence submitted by learners to address learning aims C and D is likely to consist of two aspects. Firstly, it should contain detailed and personalised witness statements or observation records which describe in detail the activities that the learner has carried out, and how these enabled them to meet their targets. Alongside this, learners will need to produce a comprehensive reflective log which evaluates their performance in the workplace. This should consider three tasks in which they have participated whilst on placement, three activities that they have observed through work shadowing and also a personal development plan based on their reflective log which sets future targets and goals.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 4: Applied Commercial and Quality Principles in Engineering*
- *Unit 5: A Specialist Engineering Project*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Cottrell S – *Skills for Success: Personal Development and Employability* (Palgrave Macmillan, 2015) ISBN 9781137426536.
  This book covers a wide range of aspects, including personal development planning.
- McDavid R and Echaore-McDavid S – *Career Opportunities in Engineering* (Checkmark Books, 2006) ISBN 9780816061532.
  This book contains a range of career profiles for jobs within a variety of engineering sectors.

Videos

- www.youtube.com/watch?v=ppL_um7VmXY
  This video gives careers advice for Mechanical Engineering.
- www.youtube.com/watch?v=Rp9PfqUQ8a4
  This video identifies skills which engineers often lack.
- www.youtube.com/watch?v=FEeTLopLkEo
  This video should inspire females to become engineers.

Websites

- www.semta.org
  Engineering Sector Skills Council – this website shows careers opportunities.
- www.imeche.org
  Institute of Mechanical Engineers website.

Unit 10: Computer Aided Design in Engineering

Delivery guidance

Approaching the unit

As this can follow on from the mandatory unit, *Unit 2: Delivery of Engineering Processes Safely as a Team*, which introduces computer aided drawing (CAD), some previous knowledge of CAD is assumed. Learners will also bring their knowledge of CAD through their experiences of previous education or perhaps as employees.

You should give learners plenty of opportunities to develop their practical CAD skills as this is very much a hands-on practical unit. You should encourage them to develop their rationale for completing tasks in a specific way, dependent on the requirements of the hardware and software in which they operate and how this enhances or limits the models that they can create.

To complete this unit, your learners will need access to a computer running the required software capable of completing these tasks.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small-group discussions on the CAD environment
- individual or group presentations – covering the practical skills required
- case studies illustrating 2D and 3D models and drawing
- a visit to a design office to support the learners' skill base.

Learners may benefit from internet sources that contain appropriate videos and training sections.

There are also many specialist books available for CAD software.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with a 3D CAD package and the benefits of 3D CAD models to businesses across different sectors. Have learners share their knowledge and experiences of working within different 3D CAD environments. You could then give initial input to your learners on the different CAD packages available and introduce them to setting up the various parameters and some of the modelling skills required. In small groups, your learners could then carry out short tasks to model various items such as a 'tee piece' with drilled and countersunk holes. These tasks could then be developed to create larger models utilising 'Boolean operations'. This could be followed by developing and assembling multiple part models and the understanding of orientation and constraints.

Learners should consider processes such as storyboarding for model orientation, with the final assembly in mind. This will develop the planning aspect, particularly for removal and inclusion of surfaces and solids, prior to committing to the CAD software. They should look at the key skills to complete 3D CAD successfully – how parametric 3D models are created from sketches and then extruded, revolved, etc. Different materials can be linked to different components and adjusted to change the overall weight or for wear purposes. Various drawings can then be created and dimensioned, complete with centre lines and different views, for output to meet the requirements of different audiences.

Learners should then start planning the assessment for this unit by storyboarding their idea and ensuring that they are fully conversant with the software skills required. This should be followed by developing and assembling their models. An industrial visit to a design office could support the learners' skills base.

Introduce learning aim B by demonstrating what can be achieved with a 2D CAD package and the benefits of 2D CAD models using items such as CAM, CNC engineering drawings and architectural models to businesses across different sectors. Have learners share their knowledge and experiences of working within different 2D CAD environments. You could then provide initial input for your learners on the different CAD packages available and introduce them to setting up the various parameters, such as grid, snap and layers, and explain that CAD drawings are created full size and scaled for output to a printer or plotter. In small groups, your learners could then carry out short tasks to draw various items such as a 'drill gauge' containing drilled and countersunk holes. These tasks could then be developed to create a symbol library of standard parts. This could be followed by assembling drawings of multiple parts and developing the understanding of hatching and sectional views.

Learners will need consider skills with layers and symbols, particularly with the final assembly in mind, It is essential that learners choose to develop the final assembly within an area that they are familiar with, or are given a 3D model from which to draw a 2D representation.

Learners then should start planning the assessment for this unit by careful consideration of their assembly. Alternatively, they could use the idea from learning aim A, provided that it is re-drawn in a 2D CAD package, and ensuring they are fully conversant with the software skills required. An industrial visit to a design office could support the learners' skills base.

For learning aim C, instruct your learners on the specialist areas of the CAD package, such as the creation of thin wall objects and fabrication and pipework. Introduce them to setting up the various parameters and some of the modelling skills required. In small groups, your learners could then carry out short tasks to model various items, such as a 3D solid cube, and use the shell command, or equivalent, to produce a hollow cube. They could develop this by removing faces or creating holes and radii to create a small bracket. These tasks could then be developed to create larger models. This could be followed by assembling multiple part models and developing the understanding of orientation and constraints.

Learners should consider processes such as storyboarding for model orientation, with the final assembly in mind. This is in order to develop the planning aspect of the creation of the model, particularly for the creation of bends and folds (fabrication), prior to committing to the CAD software. They should look at the development of the key skills from learning aim A to complete 3D CAD successfully – how parametric 3D models are created from sketches and then extruded, revolved, shelled, bent and folded. Various drawings can then be created and dimensioned, complete with centre lines, and different views can be created, for output to meet the requirements of different audiences.

Learners then should start planning the assessment for this unit by storyboarding their idea and ensuring they are fully conversant with the software skills required. This should be followed by developing and assembling their models.

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 two dimensional 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 and detail view, rendered output and flat patterns.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be a printed or plotted portfolio of drawings, containing 2D orthographic projections, 3D models, parts lists and a bill of materials.

Learners could also produce screenshots to show process and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work should complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 10: Computer Aided Design in Engineering

Introduction

Begin by introducing the unit to learners through a group discussion exploring their knowledge of the use of CAD and the practical skills that they have developed. This could be followed by outlining the learning aims of the unit.

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

- Ask learners to collaborate in small groups to come up with examples of different CAD software and models that they have experienced. Each learner could then contribute to a class discussion on the types of drawings and models that are used in industry. Discuss available software and the different sectors of industry in which CAD is used.
- Ask learners to consider, individually, what they think are successful CAD drawings and models. In small groups, learners could then explore the physical resources available and the CAD software and types of output that can be created. Learners should present their findings on the choice of appropriate software for different tasks to the class.
- Using the learners' examples from earlier, demonstrate how to create a simple 3D model. Explain the basic structure of a 3D modelling package and guide learners through the completion of a 3D model. Start with a simple shape that can be easily extruded and then, perhaps, add a hole, chamfer or radii. This could then be recreated with dimensions, transferred into a 2D and/or isometric drawing and then printed/plotted.
- You could demonstrate further commands and skills to allow learners to create components that are more complex, including, for example, revolving, Boolean operators and primitives. Ensure that learners understand the advantage of creating models in the correct orientation and the order of creating drilled holes, pockets and removing surfaces. Give learners graduated tasks to develop their use of the 3D modelling software commands.
- You could demonstrate how to set up and output drawings within a drawing template, to allow learners to create drawings containing orthographic views created from a base view and projected views. These should be fully dimensioned, inclusive of 3D solid model/surface model, provide detail views, show centre lines, and show isometric views, to an appropriate scale. You could also demonstrate the creation of an assembly drawing, including a parts list or bill of materials (BOM).
- You could demonstrate further commands and skills to allow learners to use commands to create assemblies from two or more components. Ensure that the components are placed within their correct orientation and that all constraints are applied.
- Demonstrate commands to apply materials to components and to interrogate components to determine their volume and mass.

Learning aim B – Develop two-dimensional detailed computer aided drawings of an engineered product that can be used as part of other engineering processes

- Using the learners' examples from earlier, demonstrate how to create simple 2D drawings. Explain the basic structure of a 2D drawing package and guide learners through the completion of setting up a 2D drawing, using items like grid, snap and coordinate systems. Allow learners to create a simple shape using drawing commands such as line, arc and circle. Learners should also discover that commands such as undo and erase are useful.
- You could demonstrate further commands and skills to allow learners to create components that are more complex. This could include arrays, polar coordinates, trim and mirror. Ensure that learners understand the advantage of creating models in the correct orientation and the order of creating drilled holes, pockets and removing surfaces. Give learners graduated tasks to develop their use of the 2D drawing software commands.
- You could demonstrate further commands and skills to allow learners to utilise the layers and symbols. Ensure that learners understand the advantage of creating drawings by layers to switch drawn items on and off and the symbols to aid drawing and placement of multiple objects. Give learners further graduated tasks to develop their use of the software commands.
- You could demonstrate further commands and skills to allow learners to create assembly drawings. Ensure that learners understand hatching, sectioned drawings and bills of materials. Give learners graduated tasks to develop their use of the software commands.
- You could demonstrate how to set up and output drawings to a printer or plotter from within a drawing template, to allow learners to create orthographic views.
- You could then enhance the skills learnt in learning aim A to demonstrate the creation of a sectional view, to an appropriate scale. This could be followed by the creation of an assembly drawing which includes a general arrangement, parts list or 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

- This learning aim builds on the knowledge and understanding from learning aim A.
- You could demonstrate further commands and skills to allow learners to create components that are more complex for items to be manufactured from sheet metal, such as folding and bending . Ensure that learners use their understanding of the advantage of creating models in the correct orientation and the order of creating bending and folding and applying corner reliefs. Give learners graduated tasks to develop their use of the 3D modelling software commands for sheet metal.
- You could demonstrate further commands and skills to allow learners to create components that are more complex for items to be manufactured from thin walled sheet (probably a polymer), such as imprint/shell, sweep and loft. Ensure that learners use their understanding of the advantage of creating models in the correct orientation and the order of creation using commands such as imprint/shell, sweep and loft. Give learners graduated tasks to develop their use of the 3D modelling software commands for a thin walled polymer.
- You could build on the skills learnt in learning aims A and B, to show the learners how to create 3D solid models/surface model drawings, including rendered models and flat patterns.

- You could demonstrate further commands and skills to allow learners to use commands to create assemblies from two or more components. Ensure that the components are placed within their correct orientation and all constraints are applied.
- Demonstrate commands to apply materials and render the assemblies and components.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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 Machining Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are:

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

There are many varieties of software available that could be used to complete this unit. Therefore it is nearly impossible to list every textbook and video that is available, so only a small snapshot of items are shown, as examples only.

Textbooks

Various textbooks showing the software command structure and learning material are available for the different companies that supply CAD software and the different versions of the software packages that they produce.

Videos

There are many YouTube training videos for Solidworks and Autodesk products available, such as:

- www.youtube.com/watch?v=JyE-6loC_Aw
- www.youtube.com/watch?v=cy3ExIAcI2Y

Websites

There are links below to some of the many software houses producing CAD software. Many of these provide free educational software.

- www.autodesk.co.uk
- www.solidworks.co.uk
- http:///www.solidworks.com/sw/products/draftsight-getting-started-guide.htm
- www.turbocad.co.uk/windows-range/turbocad-deluxe-2d-3d

The links below are for CAD blogs and online magazines. Some are subscription, some are free and some allow limited use prior to a subscription.

- http://caddprimer.com/magazine
- www.caduser.com

The sites below offer CAD training packages. Some are subscription, some are free, and some allow limited use prior to a subscription.

- www.lynda.com
- www.mycadsite.com/tutorials
- http://my.solidworks.com

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Unit 11: Engineering Maintenance and Condition Monitoring Techniques

Delivery guidance

Approaching the unit

This unit focuses on the essential tasks of maintenance and condition monitoring of engineered plant and equipment. The knowledge, skills and understanding that your learners gain should be transferable across a wide range of engineering sectors. These are key activities that help to ensure continued productivity, profitability, safety and efficiency wherever they are applied. This unit could be the gateway to new, previously unconsidered career pathways for your learners. It gives multiple opportunities for them to be engaged and motivated through a variety of approaches to teaching and learning. Contact with industry is an essential element. You can involve local employers in the delivery of this unit if there are local opportunities to do so.

In addition, you will be helping your learners develop the softer, key functional skills such as research and investigation, working collaboratively with others, problem solving and report writing as they participate in and reflect upon real-**world** engineering maintenance and condition **monitoring** activities. You will enjoy teaching this unit.

Delivering the learning aims

For learning aim A, learners will need to examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely. The different types of engineering maintenance and their characteristics are constantly evolving as engineering plant and equipment become ever more sophisticated. You can enable your learners to discover how different types of maintenance and their techniques are applied and adapted in different sectors. This can be done through research and investigation, practical activities, examination and discussion. However, you should also ensure that they receive a foundation of knowledge on the different types of maintenance, the cost considerations and the reasons it is so essential to maintain engineered plant and equipment in a wide variety of contexts. Whole class teaching, particularly if this is new to some, is one way of achieving this. Use presentations, video clips, handouts and, if possible, a personal presentation by a maintenance engineer from a local company. If any of your learners have already carried out maintenance tasks, ask them to share their experiences so that everyone can benefit from them.

You will find different types of engineering maintenance being carried out in a wide variety of local industries and organisations, eg in supermarkets, hospitals, breweries and bakeries, in garages, at airports, in the military and on farms. In fact, anywhere that has engineered plant and/or equipment – from a simple pump to a critical heart monitor – will employ some form of maintenance. Try to arrange for visits to such places, as this will allow your learners to experience maintenance activities first-hand. Make as much use of these opportunities as possible; it will help your learners appreciate how rich and varied the world of engineering maintenance is and perhaps inspire them to consider a career in this key sector of engineering. Try to obtain a local Chamber of Commerce directory, as you will find it an invaluable resource when looking for employer partners.

Collectively, your group could produce and share a comprehensive collection of 'real-world' case studies of different types of maintenance from a variety of sectors.

For learning aim B, learners will need to examine the use of condition monitoring techniques to detect faults and potential failures before they occur. Condition monitoring has become an essential component of successful engineering maintenance in the 21st century. Specialists in condition monitoring are developing ever more efficient and cost-effective solutions to monitor the condition and performance of engineered plant and equipment. These key parameters have become the triggers for smart maintenance interventions. Some basic introduction to the subject will be needed. Use simple examples, such as vibration analysis on motors, temperature monitoring of bearings or the flow rate in a pump. Your learners will be able to simulate condition monitoring activities using a range of readily available electronic and mechanical sensors in the workshop and perhaps you might invest in some data logging or diagnostic equipment. You might liaise with motor vehicle engineers, as using their diagnostic equipment would be ideal. You could also find out if there are any companies near you that specialise in condition monitoring for their clients that you could visit.

Learners will need put their mathematical knowledge and skills into practice. You should enable them to collect and interpret condition monitoring or quality assurance data, calculate predicted frequencies of failure and examine potential causes. Give your learners opportunities to observe CM taking place in situ, so as to experience circumstances that cannot be simulated. They should record and analyse all the factors that might lead to failure including design, operation and the environment.

For learning aim C, learners will need to undertake a maintenance activity safely on a piece of plant or equipment to ensure its continued safe operation. For this learning aim, you should give learners the opportunity to plan and carry out real engineering maintenance and condition monitoring activities. They will be putting theory into practice.

You could give them access to appropriate plant or equipment, either in your own workshops, in another part of your establishment or in another organisation. Complexity is not a requirement at this stage but adherence to the planning, processes, protocols and the Health and Safety requirements of engineering maintenance and condition monitoring is paramount.

You will need to recap general health and safety procedures and top these up with specific requirements relating to the engineering plant and equipment that is being maintained. You should be aware that such activities can bring learners into contact with substances, materials and conditions that they will not experience elsewhere, eg working at heights. You should ensure that learners are fully prepared for these eventualities and that all appropriate safety procedures are followed.

Learners should be made aware that different companies approach tasks in different ways and it is this breadth of experience that adds richness and variety to the learner's knowledge and understanding.

You could consider subscribing to a relevant periodical for both engineering maintenance and condition monitoring, eg *Maintenance and Engineering Magazine*. Companies usually have them in their reception areas, so ask if you can have the back copies and make them available to your learners. Build up a library of these, as they will give learners, and you, up-to-date information on new products and systems and innovative practice. It will help learners become far more familiar with the terminology and enrich their assignment work.

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment	**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 and 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.

Assessment guidance

For learning aim A, learners will need to have obtained a good knowledge of at least three different types of maintenance for their summative assessment activity. You should present the assessment in the form of an assignment brief with appropriate start and finish dates in line with your assessment plan. The assignment brief should be clearly laid out and enable the learners to develop their knowledge, skills and understanding. It should enable you to measure their learning against the learning aims and assessment criteria. In your brief to learners, ensure that they focus on the reasons for choosing one type of engineering maintenance over another; explaining, comparing and evaluating the respective characteristics, costs and reasons for using each type of maintenance and the circumstances in which they are being applied. Emphasise a correct response to the verbs used in the assessment criteria. If you are going to set the assignment tasks in local industry, brief employers beforehand so that they know what to give your learners.

For learning aim B, be aware that, whilst examining different types of engineering maintenance techniques, your learners will encounter condition monitoring in its various forms and applications. The latter informs the former.

Give learners an assignment with a number of tasks that ensure coverage of all the assessment criteria. This should enable learners to focus on the application of a range of different condition monitoring techniques on given pieces of plant or equipment. You should ensure that learners are able to generate for themselves sufficient, appropriate CM data for interpretation and analysis. This may be done at an employer's premises, in your own workshops or with the aid of a specialist in condition monitoring.

Be aware that the assessment activities for learning aim C, given below, may well arise as a result of the assessment activities in learning aim B. It does not need to be that way but there is merit in recognising the essential connection between condition monitoring and maintenance interventions.

Learning aim C presents a different challenge to you and your learners as it requires them to undertake a practical activity for assessment, therefore applying the knowledge, skills and understanding gained from the previous two learning aims. Nothing complex is required in terms of plant or equipment, or the faults to be rectified, but these must be identifiable and achievable. There may be occasions when something previously undetected is discovered and your learners are able to use their problem solving skills to resolve the issue. Be alert to this and decide if it is safe for them to proceed or whether they should simply report what they have found. The assessment can be done in your workshop or on an employer's premises. Evidence of achievement will include a maintenance plan that is followed safely and properly and which enables the selected piece of plant or equipment to be returned to service, unless other issues are discovered. Other essential documentation, a report and perhaps a log should also be generated and presented. This is a good opportunity to observe the learners 'at work', and photographic evidence can give added substance. Opportunities exist for distinction level learners to demonstrate their ingenuity in this field.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 11: Engineering maintenance and condition monitoring techniques
Introduction The maintenance and monitoring of engineered plant and equipment is key to productivity, profitability, safety and efficiency wherever such items are used. The methods used for teaching and learning for this unit should be varied, employing appropriate means to convey knowledge, skills and understanding and, above all, anchor everything in the real world of engineering maintenance. ● Begin this unit with a tutor-led overview of the three learning aims and a summary of the assessment activities for each aim. You will repeat these again in more detail later. Be sure to establish if any of your learners has previous experience of engineering maintenance and be prepared to draw on their knowledge.
Learning aim A – Examine the characteristics of different types of engineering maintenance required for engineered plant and equipment to operate safely
● Introduction to engineering maintenance. Begin this learning aim with a tutor-led overview of the content and a clear statement of the assessment requirements. Consider beginning this learning aim by establishing the need for maintenance. ● You could develop some reasons for maintenance by showing a video that demonstrates the effects of poor maintenance, eg WIPP – Poor equipment maintenance to blame for WIPP fire, available on video-sharing websites. ● Through group discussion, you can identify and record the obvious need for maintenance, highlighted in the video, then move on to consider other reasons. ● Use a second video: GBMP Lean Training 'Total Productive Maintenance', also available on video-sharing websites. This illustrates very different reasons for maintenance and in a different context. These will include: plant reliability, improved productivity, reduced wastage, improved quality and reduced costs. Your learners should make notes throughout. Show it again if required. ● Draw out, through group discussion, the essential role maintenance plays in modern, lean engineering manufacturing. ● Ask your learners to work in small groups to compile a list of other reasons why maintenance is required for engineered plant and equipment, eg adherence to legal and statutory requirements. Emphasise a range of contexts, eg medical equipment in a hospital, refrigeration in a supermarket or conveyors in an airport. ● Collate feedback from the small groups, summarise responses and fill in the gaps in learners' understanding. ● Set an individual research task: each learner should acquire an example of a manufacturer's guidance and instructions for the maintenance of an item of plant or equipment. ● Learners could give a class presentation summarising the manufacturer's guidance and instructions, the equipment it relates to etc. ● At this point, allow time for reflection and recap all the reasons for maintenance. You could employ a question and answer format to make sure that the learners have understood.

- You could prepare a spreadsheet for this aim with the following headings: Type of maintenance – Characteristics – Application/Context – Reason – Other relevant information.
- Set learners the task of completing the spreadsheet by identifying six different engineering maintenance techniques. Allow them to research the information and populate the spreadsheet. This information is readily available. Entering information in a spreadsheet requires learners to identify essential information and be concise in what they write.
- Learners could print and display spreadsheets around the room in gallery style so that they are able to see what each other has produced.
- Allow time for reflection and a class discussion to allow the group to come a consensus on the six or seven main techniques and their characteristics.
- You could begin by inviting a maintenance engineer to talk through a case study from their own company. Ask them to focus on the costs of maintenance used in their company and how they are justified.
- It would be useful to be able to look at case studies that focus on costs from other companies and organisations. Think about different sectors, eg maintaining medical equipment, maintaining air conditioning or chilled cabinets in retail. You could produce a worksheet for each case study to ensure that learners extract the key information.

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

- Begin this aim with a tutor-led overview of the content and a clear statement of the assessment requirements. Your learners should already be aware of condition monitoring to some extent due to the work done for learning aim A.
- You could ask your learners to write down what they think is a definition of condition monitoring and give ten examples from any area of life, not just engineering, to which the definition could be applied. For example, a diabetic checking their blood sugar levels with a simple kit at home each day, or checking tyre pressures, tread depth and condition of side walls on the family car once a week.
- Show the video 'Reasons for Condition Monitoring' from RMS Training (available on video-sharing websites).
- You could return at this point to the definition of condition monitoring and come to a consensus of what it should be.
- You could set up in the engineering workshop, engineering laboratory and motor vehicle workshop a carousel of practical activities that enable learners to use various condition monitoring techniques. For example, recording and analysing emissions from a motor vehicle, checking quality data from a batch of simple components produced on a machining centre, and/or monitoring the temperature of a bearing casing.
- To ensure proper procedures are followed, you could produce a crib card and record sheet on which learners could capture the data and information.
- If you have a company nearby that specialises in this type of activity, you could arrange for them to send one of their peripatetic engineers to talk to your learners. You may also be able to arrange a short-term placement for your learners that would give them the opportunity to shadow a condition monitoring engineer at work.
- To ensure that your learners get sufficient coverage of techniques, equipment and data, make use of the training free videos available on video-sharing websites (See RMS Training videos in the resources section).

- Enable your learners to write up a case study for each of the condition monitoring activities in which they have been involved. They should include appropriate data analysis and calculations.
- You could begin this topic by recapping the practical condition monitoring activities that learners have carried out, and then brainstorm them on the factors that may have contributed to potential faults and failures.
- Hold a tutor-led discussion to ensure that all the relevant factors have been included and understood.
- To ensure that learners understand the terminology and calculations relating to faults and failure, you could give a 'formal' lecture. Define the terms and work through the calculations, referring regularly to learners' own experiences of using conditioning monitoring techniques.
- To reinforce your teaching, give further examples of data to ensure mastery of calculations.
- For the final topic, there are case studies available for a wide variety of engineering faults and failures attributable to design and capability, mode of operation, etc. (See Sciencedirect.com case studies in *Engineering Failure Analysis and Engineering Technology Magazine*, 'Hard Lessons' 20/04/2009.)
- You could use a question and answer format to reinforce understanding of these factors.

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

- Begin this aim with a tutor-led overview of the content and a clear statement of the assessment requirements.
- You could choose to begin with a tutor-led introduction to health and safety requirements for maintenance activities.
- You will probably work through the key features and regulations when undertaking maintenance work, eg isolation and permit to work systems.
- As some general health and safety issues will have been covered in other units, learners could be asked to identify the key features of relevant legislation and regulations in relation to maintenance activities. You could give them worksheets to cover such items as PPE, lifting equipment and mechanical handling operations regulations.
- Again, your learners may be familiar with five step standard risk assessments, so you could ask them to produce RAs for several maintenance activities in preparation for practice, routine maintenance activities in the engineering workshop.
- To reinforce learning, you could use a health and safety video presentation, eg 'Safety Essentials' with a video questionnaire followed by a group discussion of the issues. See the Safetycare UK website for details.
- Give learners a tutor-led recap on all H&S requirements for maintenance activities. You should be able to give HSE free publications to your learners.
- Hold a tutor-led presentation to identify the essential detail required for a plan. You might source examples of plans from local companies or specialist maintenance providers. You should have manufacturers' guidance and maintenance manuals for a specific item of equipment in your workshops. Make these available for learners to read.
- You could use group discussion to agree the list of essential details required for the plan.

- Consider producing a plan template with the required headings and make it available electronically. Ask your learners to populate a plan for each of the maintenance activities referred to above in the topic Risk Assessment.
- Formative activities – you can arrange for your learners to plan and carry out routine maintenance activities on items of workshop plant and equipment. They would use their plans to ensure that they choose the correct tools and equipment, have the correct documentation, etc. Using a combination of observation records, photographs, learner activity logs, completed documentation and equipment testing, you can make formative assessments of their knowledge, understanding and skills and give appropriate feedback. Try using coaching skills to help them develop a 'self-assessment' and' continuous improvement' approach to their practical activities.
- Have individual interviews with learners after each routine maintenance activity to enable you to ensure that they know how to overcome unforeseen problems, how they could improve the process next time and that they are able to transfer skills from one scenario to another.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

For this unit, learners must have access to:

- engineering workshops including automotive workshops
- data logging and diagnostic equipment, hand held, fixed and remote
- electronic circuit materials, components and equipment
- items of engineered plant and equipment etc.

RMS Training Products – Wall Charts and Pocket Book.
These wall charts have illustrated case studies including data that has been collected and analysed for Condition Monitoring. Email info@rms-reliability.com for more information.

Textbooks

- Mobley R Keith – *Maintenance Engineering Handbook*, *8th edition* (McGraw-Hill Professional, 2014) ISBN 9780071826617.
  This is useful as a reference book.
- Richardson D – *Plant Equipment and Maintenance Engineering Handbook* (McGraw-Hill Professional, 2013) ISBN 9780071809894.
  This is useful as a reference book.
- Levitt J – *The Handbook of Maintenance Management*, *2nd edition* (Industrial Press, Inc., 2010) ISBN 9780831133894.
  This is useful as a reference book.
- Palmer D – *Maintenance Planning and Scheduling Handbook*, *3rd edition* (McGraw-Hill Professional, 2012) ISBN 9780071784115.
  Another useful reference book.

Journals

- *Engineering and Technology Magazine*
  Look through the archives for useful articles, eg 'Hard Lessons', 20/4/2009.

Videos

- Safetycare UK Ltd.
  This has safety training packs, videos and other H&S resources. A useful college resource that could be used across a wide range of programmes.
- RMS Training videos on video-sharing websites, eg YouTube.
  Reference is made to video clips in the suggestions for introducing each learning aim above. The RMS ones in particular are British and very useful:
  - www.youtube.com/watch?v=QRfNjN5IieU
    Poor equipment maintenance to blame for WIPP fire.
  - www.youtube.com/watch?v=KyefRmsa0Rg
    GBMP Lean Training 'Total Productive Maintenance'.
  - www.youtube.com/watch?v=maTUBxgSyno
    'Reasons for Condition Monitoring' from RMS Training.

Websites

- www.hse.gov.uk
  First stop for health and safety information, legislation risk assessments and other resources, has resources, guides and free downloads with example risk assessments in a variety of industrial contexts.
- www.sciencedirect.com
  Case studies analysing engineering failure.
- www.lifetime-reliability.com
  Plant and Equipment Wellness. This is an American site but has free downloads of useful information.
- www.maintenanceonline.co.uk
  Online magazine. UK organisations can register to receive regular copies.
- www.plantengineering.com
  Online access to archived issues of this monthly publication. Articles on Maintenance can be filtered and selected.

Unit 12: Pneumatic and Hydraulic Systems

Delivery guidance

Approaching the unit

This unit covers a range of pneumatic and hydraulic systems and components that learners may encounter during their early career as an engineering technician or apprentice. You should introduce learners to the safe operation of such systems, their maintenance and the function of a range of common components. Learners should be able to use industry standard symbols to develop circuit diagrams using suitable specialist CAD software before simulating and refining circuit operation. Finally, you should give learners the opportunity to carry out the safe assembly and testing of a pneumatic or hydraulic circuit.

To enable you to deliver the required content you will need access to ICT facilities equipped with appropriate specialist CAD software to develop hydraulic and pneumatic circuit diagrams and simulate their operation.

You will also need a suitable hydraulic or pneumatic system for use in the practical elements of the unit. This might be a test rig where a series of standard components could be assembled into functioning circuits or examples of whole or partial real systems that can be safely assembled, tested and adjusted in the workshop.

You can involve local employers in the delivery of this unit if there are local opportunities to do so. There is scope to develop relationships with industrial partners from a wide range of sectors who are involved in the design, use and maintenance of pneumatic and hydraulic systems. Your teaching resources will be more realistic and relevant if developed with their involvement. Additionally, it would enhance learner engagement if you plan industrial visits or invite guest speakers with relevant expertise to help in the delivery of unit content.

Delivering the learning aims

For learning aim A, you could begin by introducing the general principles of fluid powered systems and show examples of their industrial applications. You will need to devise case study materials detailing specific industrial pneumatic and hydraulic systems prior to starting the delivery of this learning aim. Examples of large complex systems can be broken down in teacher-led activities involving power, control and actuator components. The function of these elements within the overall system could then be discussed.

It is important that you give learners a broad understanding of the different types of components that are available and their suitability in particular circumstances, e.g. applications of gear or piston hydraulic pumps. Learners will need a qualitative understanding of system and component parameters such as the size of storage receivers or pump delivery volume, and the effects these have on operation. A quantitative understanding and the formulae used to determine system and component parameters is outside the scope of this unit. Learners will need to explore the effects of changing system and component parameters empirically during the simulation and practical exercises carried out in learning aims B and C.

As part of teaching, you could ask learners to research the operation of a range of power supply, actuator and control components. Operation in this context describes how the components themselves work as distinct from function, which considers their role in a complete system. The ability to work independently and undertake systematic research is a skill that will be vital in subsequent higher level study. Having example components available in the classroom for learners to see, hold and operate will improve learner engagement and help consolidate understanding. These might include a selection of control valves, rotary and linear actuators and/or pumps.

Your delivery of system maintenance and safety topics would be brought to life with the involvement of an industrial partner. A site visit or visiting speaker from industry would give valuable insight into how important safety and maintenance procedures are when dealing with high pressure fluid systems in the workplace. Learner interest and engagement can be effectively enhanced when you demonstrate the direct relevance of unit content to real-life engineering practice.

In order to deliver learning aim B, you will need one or more copies of BS ISO 1219-1:2012 *Fluid power systems and components. Graphical symbols and circuit diagrams* (or an international equivalent) and suitable examples of pneumatic and hydraulic circuit diagrams for learners to study and become familiar with.

As this is predominantly a skills based learning aim, you will also need access to specialist fluid power CAD software that has the facility to simulate circuit operation. You will need to give learners adequate time to become familiar with operating the software. You can develop the required skills by asking learners to draw and simulate increasingly complex circuits until they reach the required level of expertise. The circuits used in teaching should be sufficiently complex to prepare students for the assessment activities for this learning aim. You should encourage learners to explore circuit inputs and measure output characteristics to understand how these are influenced by changing system or component parameters.

In the delivery of learning aim C, the safety of learners must be a key consideration. Whether you choose to ask them to assemble, test and refine a given circuit from off-the-shelf components on a test rig or use whole or part of a real system, they must do so safely. Learners will need to abide by appropriate safe codes of practice and be familiar with any risk assessments carried out on the apparatus they are asked to use. For assessment purposes, learners need only carry out practical activities on a pneumatic or a hydraulic circuit. It is anticipated that most centres will choose to use pneumatic systems in this learning aim. Using pneumatics is inherently safer due to the lower pressures involved and the avoidance of potentially hazardous hydraulic fluids. Pneumatic components are also generally less expensive, easily adjustable and widely available. You may, of course, choose to work with hydraulic circuits if this is more appropriate to your expertise, facilities and the pathway being studied by your learners.

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 screen shots 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.

Assessment guidance

The assessment evidence for this unit is most likely to be in the form an illustrated written report for learning aim A and portfolios of evidence for learning aims B and C. There is, however, flexibility in the forms of evidence that are acceptable as long as the learners' work fulfils the necessary requirements of the assessment criteria and is individual to each learner.

Evidence for learning aim A will most likely be in the form of an illustrated written report based around two researched case studies of one hydraulic and one pneumatic powered system. It should include appropriately referenced images and diagrams to support the text. You should encourage learners to use standard referencing methodologies such as Harvard or APA to enhance the presentation and professionalism of their written reports.

It should be noted that the Distinction assessment criteria for this learning aim makes specific reference to the use of, 'vocational and high quality written language'. This precludes the use of certain types of evidence such as a video narrated by the learner unless a transcript of the narration is also submitted.

Evidence for learning aim B will most likely be presented as a portfolio which should be well organised and structured logically. Evidence should include circuit diagrams, written notes and screen shots of circuit simulations. The output characteristics of the simulated circuits could be presented graphically. For example, the movement of a pneumatic cylinder could be presented as a graph of displacement versus time. Further written analysis of the effects of changing system or component parameters to refine circuit operation will also be required to cover the assessment criteria in full. Observation Records should be used to support evidence relating to the use of CAD software to draw the required circuit diagrams and simulate their operation. It would be acceptable for learners to include a presentation, learner-narrated video or other form of evidence as part of their portfolio.

Learning aim C involves a significant amount of practical work so this is most likely to be assessed by means of a portfolio of evidence which again should be well organised and structured logically. This might include a log book providing a detailed record of any practical work undertaken. Evidence should include written elements with diagrams and photographs to support the text. Observation records should be used to support evidence relating to the safe assembly and testing of a pneumatic or hydraulic circuit.

Alternatively, evidence for learning aim C could be in the form of a presentation. This might include embedded video of the learner assembling and testing pneumatic or hydraulic circuits. Once delivered in front of an audience, a copy of the presentation, including presenter notes, should be submitted by each learner. Where presentations are used, you should provide an observation record detailing their content and effectiveness. This will greatly assist you when formally assessing the evidence against the required criteria and during any subsequent internal verification.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 12: Pneumatic and Hydraulic Systems

Introduction

This unit provides an introduction to the pneumatic and hydraulic systems that learners may encounter as engineering technicians or apprentices. Such systems are commonplace in a range of engineering sectors from aircraft systems to agricultural machinery. You should work with learners to develop a theoretical understanding of the function and operation of common pneumatic and hydraulic components including safety considerations and maintenance requirements. Using researched case studies, learners should analyse how examples of industrial pneumatic and hydraulic systems meet their service requirements.

Learners will progress to work with hydraulic and pneumatic circuit diagrams to ISO 1219-1:2012. You should provide the support and guidance required for learners to become proficient in drawing circuit diagrams using appropriate specialist CAD software. By simulating the operation of the circuits they have created, learners will need to explore the effects of changing circuit and component parameters on circuit output variables such as actuator speed or displacement.

Once you are comfortable that learners have a good understanding of a range of pneumatic and hydraulic systems and have used CAD simulations to explore circuit operation, they should have the opportunity to work safely with real systems and components.

Your learners will need to develop practical skills and learn the importance of safe working practices when carrying out the assembly and testing of a pneumatic or hydraulic system. You should find that the opportunity to work safely with live systems will help to engage and retain learner interest and reinforce the importance of the theoretical and simulation activities carried out earlier in the unit.

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

- Learning aim A will give learners the underpinning knowledge and understanding that will be required in subsequent learning aims.
- As this learning aim is mainly theoretical, it will help to engage learners if you have a range of hydraulic and pneumatic components to introduce during teaching. In your first lesson, you might want to make a range of control valves, actuators and power supply components available and encourage learners to categorise them into different component groups. If you have examples of cutaway components where internal workings are visible, these will further aid understanding of their operation.
- Example power supply, actuator and control components could then be used as starting points for independent research into the operation of a range of components from each group. You should guide learners to develop methodical research skills using a range of resources. Web based research, looking at manufacturers' data sheets and related information could be augmented by the use of textbooks, catalogues and physical examples of components that are safe to disassemble and photograph.
- Once your learners are familiar with the operation of a sufficient range of components, you could then ask them to identify and explain the key operational parameters for examples from each group. Some will be obvious, such as linear

actuator stroke length, but others, such as pneumatic storage receiver sizing, may require teacher-led discussion, explanation and further research to appreciate fully. It should be noted that formulae for calculating component parameters are outside the scope of this unit. A qualitative understanding of the importance and effects of setting system and component parameters will be sufficient.

- It is important that learners not only appreciate how each component operates in isolation but also their function and importance within a larger system. When planning the delivery of this learning aim you should develop a range of case studies detailing complete hydraulic and pneumatic systems from a range of sectors to facilitate this. You should consider full systems from power supply and system control components to the final operation of an actuator, including maintenance and safety requirements. These resources would gain real-world relevance if an industrial partner is involved in their development. Engaging the help of a local engineering company is often not as difficult as you might think. A good place to start is to look for partners who are recruiting engineering apprentices from your area. They often appreciate the opportunity to introduce themselves to potential future trainees. As well as helping to develop resources, they might be willing to provide component samples, allow site visits and send visiting speakers to help contextualise the unit content and bring it alive.
- You should also take advantage of any relevant in-house facilities in your centre. For example, if you have workshops with a compressed air supply and pneumatic tools or equipment, you should make these the focus of one of the case studies. There may also be site maintenance or technical staff on hand to discuss the safety and maintenance requirements of the systems that they are required to manage.
- In the assessment for this learning aim, learners will need to analyse and evaluate a pneumatic and a hydraulic system. If they have undertaken recent work experience this task could be based wholly or in part on their own industrial knowledge. The assessment could be based on each learner's own researched case study examples or on a given case study that you allocate. It is considered best practice if different systems are considered by each learner to ensure the authenticity of learner work.
- When you are satisfied that learners have sufficient knowledge and skills to analyse a complete pneumatic and hydraulic system you should issue the first assignment which covers this learning aim. You should also ensure that learners have selected or been issued with systems of sufficient complexity to allow meaningful analysis.

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

- In learning aim B you will focus on the use of component symbols and the development of pneumatic and hydraulic circuit diagrams to an appropriate industry standard. To achieve this you will need to introduce the use of suitable specialist CAD software with the facility to create fluid power circuits and simulate circuit function. It must also be capable of providing analysis of one or more output variables such as actuator speed or displacement with respect to time. There are several such software packages currently available commercially and most are available at no cost for use in education. It is important that during planning and preparation for the delivery of this learning aim you become familiar with the use and operation of the CAD package you select.
- You could start the delivery of this unit by introducing the standard component symbols and relating them to the example components that you used in learning aim A. Learners will need to become familiar with a range of standard symbols for common power supply, control and actuator components. When they can see how the schematic conventions relate to examples of actual systems and components, it will help them to visualise and interpret the information shown on circuit diagrams.

- You should discuss with learners the importance of using symbols to a recognised standard such as BS ISO 1219-1:2012. Copies of the standard should be available to learners for reference, although compliant circuit symbols should be available from component libraries in the CAD software they will use.
- You must ensure that learners are aware of the conventions used to distinguish between similar pneumatic and hydraulic components so that they are used appropriately.
- Learners are not expected to design their own circuits in this learning aim but to develop the knowledge and practical skills to draw them using CAD software to industry standards. As such, learners could be given example circuits to replicate. The complexity of these could be increased gradually as learners become more confident with using the CAD software. Learners should progress until they are comfortable creating accurate circuit diagrams containing eight or more interconnected components. You will find suitable example circuits in the unit specification, textbooks and online resources. For assessment purposes, circuit diagrams must contain at least eight components and have one or more measurable output variables.
- When learners are comfortable creating accurate circuit diagrams you can introduce the simulation capability of the CAD software. They will be able to base their simulations on the circuit diagrams created previously. Learners should record output variables such as cylinder velocity against time to establish the base line performance of the circuit.
- It is important that learners are then able to edit system and component parameters in their circuit diagrams and analyse the effects these have on simulated output variables.
- You should ensure that learners make any changes systematically so that the effects of altering a single system or component parameter can be assessed by comparing output variables with established base line performance data. Learners could then progress to gauging the effects of altering multiple parameters. In this way, several iterations could be carried out to refine the system operation so that the performance of the output variable reaches a defined goal.
- Once learners have developed the skills necessary to make effective use of CAD software to create accurate circuit diagrams and use simulation to analyse and refine circuit output variables, you should issue the second assignment which covers this learning aim.

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

- Learning aim C is primarily practical in nature. It builds upon and reinforces the skills and technical knowledge acquired in previous learning aims.
- To deliver this learning aim you will need to provide learners with access to a pneumatic or hydraulic system consisting of at least eight components in a safe and controlled working environment. This may be assembled from off-the-shelf components specifically for use here, or be the whole or part of a real system. Whatever facilities you make available, you must ensure that the assembly, testing and refinement activities undertaken by learners are safe.
- An important element of this learning aim is for learners to appreciate the potential hazards of working with live fluid power systems and the importance of safe working practices.
- As an introduction you might ask learners to conduct research into industrial accidents that have occurred involving pneumatic and hydraulic systems. They should consider the consequences and how they could have been prevented.

Sharing information about these incidents with their peers in a group discussion will serve to focus the minds of learners on safety.

- Before allowing learners to carry out any practical work they will need to be familiar with general safe working practices and those specific to your centre and facilities. It is also a good idea to share the centre's risk assessments for the activities that learners will be asked to carry out and explain any control measures that are in place along with the reasons why they are considered necessary.
- Using physical examples, you will need to familiarise learners with common types of fluid conductors and fittings with an emphasis on those that they will be expected to use in practical activities. They will also need to build up their familiarity with physical components, how these are mounted and any adjustments that are possible to make (for example, bleed screws or mechanical stops). Some instruction on the appropriate and safe use of tools will also be necessary.
- You will need to provide appropriate circuit diagrams and/or physical layout drawings for learners to work with during practical learning activities and subsequent assessment.
- Before learners undertake any practical work you should demonstrate what is required by working through an example.
- Once appropriate components have been identified, mounted and connected you should demonstrate the checks necessary to ensure components and fittings are secure and connected correctly prior to pressurising the system.
- After pressurisation, you should test the operation of the system and check for fluid leaks. Next identify, but do not carry out, any adjustments that need to be made or other issues which may need to be rectified.
- You should then demonstrate safe depressurization of the system to ensure that any changes or refinements required can be made safely.
- Again, this is an iterative process that should be repeated until the circuit is performing correctly to within given requirements.
- During initial learning activities, learners could work in pairs to assemble and test circuits to help ensure that they comply with safe working practices and to build individual confidence. It should be noted, though, that, for assessment purposes, learners must carry out the tasks required independently.
- Once you are satisfied that learners are able to apply safe working practices and assemble, test and adjust a fluid power system safely, then you should issue the third assignment which covers this learning aim.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Esposito A – *Fluid Power with Applications*, *7th edition* (Pearson, 2014) ISBN 9781292023878.
  This is an excellent text book which supports many of the subject areas included in this unit. It also includes a chapter that introduces the use of Automation Studio computer software to simulate fluid power circuits.

Websites

- www.automationstudio.com
  Automation Studio is one example of specialist fluid systems CAD software that would be suitable for use in this unit.
- www.bfpa.co.uk
  Official website for the British Fluid Power Association (BFPA) which is the UK trade body for the pneumatic and hydraulic industry. Their website has links to a range of resources available to support this unit.
- www.hpmag.co.uk
  Official website of Hydraulics and Pneumatics: The Journal of Fluid Power and Systems containing articles relating to industrial fluid power systems.
- http://hydraulicspneumatics.com
  This website provides a variety of useful resources relating to hydraulic and pneumatic technology, systems and their components.

Unit 13: Welding Technology

Delivery guidance

Approaching the unit

The theory in this unit may be new learning for many students or a subject where they have seen the process but never had to plan or practically use a welding process. This unit could follow on from those that contain some of the underlying scientific theory and knowledge of engineering materials, such as Unit 1 Engineering Principles and Engineering Processes or Unit 25 Mechanical Behaviour of Metallic Materials, or it could be taught concurrently with these units Learners may also have prior knowledge of welding technology via employment or previous experience; whilst this may be limited to MiG type welders, it may be useful to promote discussion.

You should encourage learners to develop their theoretical knowledge of various processes and materials and the related practical skills. A third of the content of this unit involves practical activities; you should encourage learners to develop their rationale for completing welding tasks in a specific way, so that they are able to weld joints successfully using the relevant process.

To complete this unit, your learners will need access to different welding processes and the associated resources – consumables and materials. You will need to ensure that the learners understand and can apply strict safe working practices designed to protect yourself, the learners and colleagues from various hazards that are present during the welding processes.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions on welding processes
- individual or group presentations– covering the practical welding skills required
- demonstrations of the set up and safety issues associated with welding processes
- case studies illustrating components and joints created by welding processes
- an industrial visit to a manufacturing company to support the learners' skills base
- a visit to a manufacturing or technological exhibition to support the learners' skills base.

Learners may benefit from internet sources, including the many training videos available online. There are also specialist books available that describe welding processes. These are detailed at the end of this unit.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with welding processes and the use of different processes and joints. Learners can share any knowledge and experiences of welding or structures created by welding that they may already have. You could then provide initial input for your learners on the different types of welding processes, materials and possible failures and how these relate to the size of the machine, materials, consumables and operational requirements. In small groups, your learners could then carry out research using the internet on the different welding processes: many websites have detailed pages that contain useful information regarding these processes. It is important that learners understand the influence that materials and product design have on the different processes, and on the underlying electrical systems that power many welding processes. It is essential that you emphasise the safety aspects of the welding manufacturing process throughout this unit.

For learning aim B, introduce the topic by discussing the major differences between families of metallic materials, concentrating on their properties and also their behaviour under load. Discuss structural steels, including alloyed and unalloyed steels, and extend this into non-ferrous materials. Items such as temperature, cooling rates and heat-affected zones can be highlighted to link to the next section, which covers defects and irregularities in welded joints. It may be beneficial to open this section with the theory of crack propagation and the reasons for joints fracturing and then allow learners to explore specimens of different materials and the crack prorogation at a macro and micro level. At this point, it may be beneficial to introduce learners to crack detection, both destructive and non-destructive, and allow the learners to use nick-break testing and liquid penetrant testing within a practical environment. This can then be followed by an explanation of the reason for applying various heat-treatment practices, such as stress relieving, to welded joints.

Finally, the learners could research the relationships between welding and corrosion and the problems of joining dissimilar metals. It is essential that you emphasise the safety aspects of the welding processes throughout this unit so that learners understand the risks involved.

For learning aim C, introduce the topic by demonstrating the different welding processes such as MMA welding of thick steel plate and TIG welding of aluminium. Ask learners to share any prior knowledge and experiences of working within different welding process environments. Your initial input will be a familiarisation of the welding bay, housekeeping and safety precautions. You could then show your learners the different processes available and introduce them to setting up the various parameters (i.e. amperage, wire speed, gas pressures and electrodes). Learners then should become familiar with the relevant planning paperwork, such as drawings or weld procedure specifications. This could be done individually or in small groups. Your learners could first carry out small tasks to create a short weld run. This should be followed by developing longer runs on different joints such as butt or tee, and using different positions, such as flat or vertical. Learners will need to record the safe working practices that they have applied throughout their welding tasks. It is essential that you emphasise the safety aspects of the welding process throughout this unit.

Learners would benefit from an industrial visit to a fabrication and welding workshop. This could follow learning aim A so as to embed the theory and provide the learners with some awareness of industrial practices.

If possible, invite a guest speaker from a local supplier of welding consumables and gases, or a local welding company, to talk to learners to explain the different types of welding processes, and support the delivery of learning aim A.

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

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be reports, weld procedure specifications, records, annotated photographs and observation records. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 13: Welding Technology

Introduction

Begin by introducing the unit to learners through a group discussion exploring their knowledge of the use of welding processes and the practical skills they have developed. This could be followed by outlining the learning aims of the unit.

It is essential that learners understand all the safety aspects of the welding process and the typical safe working practices required. You should continually emphasise this throughout the unit.

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

- Ask learners to work in small groups to come up with examples of different welding processes that they have experienced.
- Ask learners to consider individually what they think are the advantages of any welding processes and the different types available. Lead a discussion on the various welding processes, and allow learners to research the basic features. In small groups, learners could then explore the physical resources, the consumables and materials and the different types of process available and link the different process to their respective materials.
- You could then explain the different types of welding processes to your learners, emphasising the potential problems and hazards that can occur within each process.
- Using learners' examples from earlier, and continuing in small groups, your learners could then carry out research into different welding processes by looking at welding machine manufacturers, and consumable manufacturers websites. This research could then be developed to investigate the applications of the different processes.
- You could then explain the electrical systems that power the different welding plants, by considering power sources, transformers and the required settings for each different welding plant.
- Explain the required safe working practices, and the key features of health and safety regulations for each welding processes and the typical safe working practices required.

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

- This learning aim can begin by exploring the properties and behaviours of metallic materials.
- Ask learners what knowledge of material properties they have gained from previous study. This could then be expanded to cover items such as plasticity and elasticity through the study of the stress–strain diagram, which links to the behaviours of metallic materials.
- Ask learners to consider the loading on a typical component, the forces to create this loading on the component and how welding has contributed to these forces.

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- Ask learners to explore the loading and forces that could be a result of temperature distribution and the cooling rates used during welding. Extend this by looking at the grain size from a single pass weld and a multi-pass weld.
- Introduce the advantages of each different welding process for the welding of alloyed steels and non-ferrous steel. This can be expanded to look at metallurgy of materials such as aluminium alloys (by exploring items like its high thermal conductivity and low melting point). Learners could identify the most suitable process to overcome some of these factors.
- Using a mix of theory and practical examples, introduce learners to fractures and cracks and highlight the difference between them. You could start by showing how cracks propagate from residual stress and strain concentrations, and then develop into the different fracture types (brittle or gradual). This will lead into destructive and non-destructive testing, which could be demonstrated through a mix of practical examples and theory.

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

- Build on the previous theory to explain to the learners the requirements of successfully creating welding components: i.e. the structural integrity, the effect of heat-affected zones and the requirement for a lack of distortion.
- Your initial input will be a familiarisation of the welding bay, housekeeping and safety precautions.
- Use a practical demonstration to explain the tools and equipment used during the welding processes: i.e. the correct connecting cables, wire size, nozzles and electrodes. Explain how different electrodes are used for different materials and thickness.
- Use a practical demonstration to demonstrate welding parameters and settings. For example, when MiG welding, ensure that learners understand the relationship between material thickness and amperage (to use the related wire size). Ensure that learners understand that voltage determines the height and width of the bead, and that the wire feed speed needs to be set appropriately.
- Learners can then start to develop their understanding of the necessary paperwork in the form of drawings, weld procedure specification and other reporting and recording documentation.
- Learners could start practical welding in small groups or individually by creating short weld runs. These will need to be checked (e.g. for bead size, integrity of the weld and porosity).
- Give learners plenty of opportunities to develop their confidence and skills by welding different materials using different processes. They could further develop their skills by welding in different positions, such as flat or vertical. This could be linked to the practical destructive and non-destructive testing.
- Explain any quality control checks that will be required and where and how to record them. Learners will need to record the safe working practices that were applied throughout their welding tasks.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

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

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

For this unit, learners must have access to appropriate:

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

Textbooks

Various textbooks are available for the welding processes. The sample shown below ranges from covering the basic practical skills to the underlying science and metallurgy.

- Davies A C –*The Science and Practice of Welding*, *Vol. 1, 10th edition* (Cambridge University Press, 2008) ISBN 9780521435659.
  This book examines the science and metallurgy behind the welding process, examining the chemistry and physics applied to welding. The book also examines destructive and non-destructive testing.
- Davies A C – *Science Practice of Welding, volume 2*, *10th edition* (Cambridge University Press, 2008) ISBN 9780521435666.
  This book examines the practical aspects of Welding. It describes various welding process from MMA to resistance welding.
- Thaddues M Welding – *A Practical Guide to Joining Metals* (The Crowood Press Ltd, 2010) ISBN 9781847971890.
  This book introduces various different welding processes and is aimed as an introduction to the welding processes.
- Timings R – *Fabrication and Welding Engineering*, 1st edition (Routledge 2008) ISBN 9780750666916.
  This book has a bias towards fabrication, but still provides a good level of welding material for Level 3 learners.

Websites

There are many links available on the internet on welding processes but a good starting point is 'TWI' or its underlying institute 'The Welding institute'.

- www.theweldinginstitute.com
- www.twi-global.com

Unit 14: Electrical Installation of Hardware and Cables

Delivery guidance

Approaching the unit

You should deliver this unit in as realistic and practical a way as possible, stressing the importance of safe working practices and the need to be aware of and apply statutory regulations and professional guidelines. You should develop learners' knowledge and skills of domestic and industrial installations through practical exercises (possibly already developed from other qualifications) before challenging them to construct, test and report on an installation appropriate to their own situation. For example, a commercial installation would be more relevant than a domestic one to an apprentice maintenance engineer.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

It is important to take a practical approach to the unit, whilst impressing upon learners the need to understand and comply with the theoretical aspects, including regulations and guidance, in order that they work safely at all times.

Learning aims A and B form the background theoretical knowledge relating to standard lighting, power and some specialist electrical installations found in domestic and commercial applications. They also promote the development of analytical and practical skills. You should look for opportunities to demonstrate how the regulations are applied in real installations. For example, the learners could observe the circuit protection requirements for their home and compare them with the centre workshop (and other areas which can be easily visited), relating the differences to current legislation.

You could then build on this by introducing typical domestic and commercial installation schematics to highlight the requirements and formalise the layouts. It is important that you select circuits that allow learners the opportunity to investigate straightforward circuits that they are likely to find in common installations. The learners should build an installation containing the required circuits (probably working in pairs) one circuit at a time, developing skills and knowledge. A practical approach can provide you with opportunities to monitor progress and identify any common areas that you can address to a group. You should build in plenary sessions, at appropriate stages, to summarise key learning points from each circuit.

Working in pairs provides learners with an opportunity to develop confidence in practical skills, interpretation of schematics, identification of consumables and test equipment, whilst limiting the resources required. Analysing one installation should allow the learners to transfer the knowledge gained to another scenario.

You should reinforce understanding of how the circuits comply with regulations (principally, BS 7671:2008 incorporating Amendment no. 3:2015) and how to use professional guidelines (eg Institute of Engineering and Technology (IET) On-Site Guide (BS 7671:2008 Wiring Regulations, incorporating Amendment

3:2015)) taking advantage of interest generated from hands-on experience. It would be interesting for learners to visit a site to see an installation in progress, to gain an appreciation of the expected standard.

Learning aims C and D combine to allow learners to apply the knowledge and skills they have gained to analyse a given schematic and to plan and implement its construction and testing. You will need to supply an installation schematic that contains the requisite number of circuits, and this may be an opportunity to link with industry. For example, a construction company may be prepared to supply schematic layouts for completed schemes provided that they are anonymised. You need to make regulations and on-site guides available as well a range of resources, such as catalogues and manufacturers' data.

Learning aim	Key content areas	Recommended assessment approach
A Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations	**A1** Types of electrical installation **A2** Statutory and non-statutory regulations **A3** Reducing the risk of electrical shock **A4** Circuit protection methods	A report detailing the requirements of appropriate statutory and non-statutory regulations, circuit protection methods and identifying areas of increased risk.
B Interpret lighting and power circuit diagrams for domestic and commercial applications	**B1** Lighting circuits for domestic installations **B2** Power circuits for domestic installations **B3** Circuits for commercial installations	A report analysing given domestic and commercial electrical installations in terms of the suitability of components to meet the requirements of regulations and guidance relative to the application.
C Select materials and documentation for an electrical installation	**C1** Cables **C2** Connectors **C3** Wiring enclosures **C4** Sustainability	Safe construction of an electrical installation (preferably wall mounted) together with a log detailing construction, testing, calculations, circuit layout and construction plans, photographs, one or more observational witness statements and a formal assessment of the final installation, with reference to how sustainability issues have been considered.
D Develop an electrical installation that incorporates different types of circuits in compliance with current regulations	**D1** Safe working practices **D2** Safe working procedures **D3** Circuit testing	

Assessment guidance

There should be no more than three summative assignments for this unit. Assessment for learning aims A and B will take the form of a written report. You should ensure that the statutory and non-statutory regulations relating to domestic and commercial electrical installations investigated for learning aim A relate directly to the circuits explored experimentally for learning aim B so that learners can appreciate the importance of identifying them and working to them. You need to select the lighting and power circuits for both domestic and commercial installations so that they allow learners to explore the regulations and guidelines that they are most likely to encounter in a working environment. Learning aims C and D provide summative evidence, requiring learners to interpret a schematic diagram, select appropriate materials, construct and then test the installation safely to appropriate standards. You will need to provide sufficient resources to allow learners to meet all the requirements. You should encourage learners to collect evidence such as sketches, photographs, text, calculations and detailed observation records as they progress.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 14: Electrical Installation of Hardware and Cables

Introduction

You could introduce this unit to your learners using a demonstration rig to illustrate the purpose of different electrical systems and components in lighting and power circuits.

You could link the demonstration to the requirements of the learning aims, highlighting the need to develop knowledge and practical skills to ensure that all work is completed safely and in compliance with appropriate regulations. During this you could lead a discussion on potential hazards inherent when working with electricity and the necessity for regulations and guidelines to control them.

Learning aim A – Examine safety requirements based on statutory and non-statutory regulations when working with electrical installations

- You could start with whole-class teaching, through:
    - a discussion on the hazards associated with working with electricity in commercial and domestic environments
    - a walkabout of the workshops to identify elements of the electrical installations and provisions for different applications
    - learners comparing their findings with their home installation as a homework exercise (observation only).
- Introduce relevant legislation through whole-class discussion, for example:
    - IET wiring regulations, BS 7671:2008 incorporating Amendment 3:2015, and relevant guidance notes
    - The Building Regulations 2010: Approved document P; Electrical safety-dwellings
    - The Electrical Equipment (Safety) Regulations 1994 (and/or other relevant international equivalents).
- Whole-class teaching on types of circuit protection devices, such as:
    - switchgear
    - over-current protection devices
    - circuit protection methods
    - cable size (eg from tables for current loading and thermal constraints)
    - protection from mechanical damage (eg armoured cable, cable trunking, cable).
- You could then give pairs of learners a circuit diagram for an individual circuit, for example a simple lighting or power circuit for a domestic or commercial premises for which they could identify:
    - relevant regulations and guidelines
    - protection devices and cable sizes needed to safely construct the circuit (at least one pair could work on a scenario that includes an area of increased risk of electrical shock).
- Learners could feed back to the rest of the group through explaining their choices and how they satisfy the requirements of the regulations and guidelines.

- You could then lead a plenary session to summarise the outcomes from the learner presentations and identify any areas not sufficiently covered for learners to complete a report on their investigation of statutory and non-statutory issues and regulations relating to electrical safety for given electrical installations. You should guide learners to evaluate the requirements of at least four statutory and non-statutory regulations for given domestic and commercial premises, including the suitability of circuit protection devices and any special requirements related to areas of increased risk of electrical shock.

Learning aim B – Interpret lighting and power circuit diagrams for domestic and commercial applications

- You could get pairs of learners to swap circuits and ask them to identify:
  - all components and materials needed to construct the new circuit
  - tools and test equipment necessary to complete construction
  - how they meet the regulations and guidelines.
- Learners could feed back to the rest of the group through explaining their choice of materials and how they satisfy the requirements of the regulations and guidelines.
- You can then lead a plenary session to summarise the outcomes from the learner presentations and identify any areas not sufficiently covered. You could then guide the learners to use the gathered information to analyse the design of two lighting and two power circuits, each for domestic and commercial installations, justifying the suitability of the specified components for the given applications.

Learning aim C – Select materials and documentation for an electrical installation

- Learning aim C is the planning stage of constructing a domestic or commercial installation. You can begin by providing individual learners with the circuit diagram for a complete domestic or commercial installation. It is expected that these installations incorporate elements investigated earlier, but each should be a unique combination to minimise the potential for plagiarism. There is potential to use business contacts to provide sample installation drawings to generate realistic scenarios. You should ensure that learners carry out the planning stages before commencing any construction.
- Encourage learners to collect evidence as they proceed and to consider environmental and sustainability issues when making their choices. You may find it profitable to ask learners to provide a bill of materials (BOM) before allowing them to progress to the construction stage.

Learning aim D – Develop an electrical installation that incorporates different types of circuits in compliance with current regulations

- Learning aim D provides a platform for learners to demonstrate their skills in safely constructing an accurate, effective and efficient electrical installation containing at least five circuits. It is important that this is as realistic as possible, so should, preferably, be completed on walls in a typical wiring booth.
- It is simpler for you to provide the correct materials etc. for the construction if the learners create a BOM when carrying out their planning for learning aim C. Learners need to demonstrate that they are working within appropriate regulations and guidelines at all times. You need to provide detailed observation/witness statements (who, what, where, when, how) for the construction.
- You should carry out a visual inspection of each installation before allowing learners to carry out inspection and testing. Any issues should be resolved before testing takes place. This could form the basis of an observation/witness statement.

- Learners should carry out appropriate test and inspection measurements and produce a report documenting the results, using forms compatible with sector guidance. You need to check that this is carried out safely and should provide a detailed observation/witness statement for the inspection and testing.
- The evidence that learners provide for learning aims C and D could contain:
  - a safely constructed electrical installation (preferably wall mounted)
  - a log detailing construction, testing, calculations, circuit layout and construction plans, photographs and observation/witness statements
  - a formal assessment of the final installation
  - reference to how sustainability issues have been considered.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 15: Electrical Machines*
- *Unit 16: Three Phase Electrical Systems*
- *Unit 18: Electrical Power Distribution and Transmission*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- The IET – *IET Wiring Regulations 17th Edition (BS 7671:2008 incorporating Amendment number 3:2015)* (IET, 2015) ISBN 9781849197694.
  This book contains the most current regulations relating to electrical installations.
- The IET – *Student's Guide to the IET Wiring Regulations* (IET, 2015) ISBN 9781785610783.
  This book provides explanations of the full regulations for students.
- The IET – *On-Site Guide (BS 7671:2008 Wiring Regulations, incorporating Amendment 3:2015)* (IET, 2015) ISBN 9781849198875.
  Standard guidance for how to apply the regulations on-site.

Unit 15: Electrical Machines

Delivery guidance

Approaching the unit

In this unit, your learners will investigate both the safe operation and operating principles of alternating current (AC) and direct current (DC) electrical machines, ie generator, electric motor and transformer. There is a considerable theoretical element to this unit. Practical exercises will bring the theory to life. It would be an advantage to give learners working examples of electrical machines and their associated control gear. This will allow the learners to design and install various control circuits and carry out measurement and tests. A full range of approved and fully calibrated test equipment will also be required. Reading voltage and current will enable learners to see for themselves the effects of starting torque and rotor speed on current, and in the case of the star-delta starter, the change of voltage from 230V to 400V.

Of course there will be safety issues to consider, as the terminals of these machines will be live and there may be moving parts, so risk assessment is of vital importance and will give a 'real-life' scenario on which to base the assessments for learning aims A and B. You will need to supervise closely to ensure safe practices are adhered to. Machine safety is divided into electrical, that is the hazards posed by the electrical supply to the machines themselves, and mechanical, particularly in the case of generators and motors. Mechanical processes are those that either operate, or are operated by, the machine. In addition, associated regulations and other health and safety documents need to be made available, either as actual documents or accessible online.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

There are three main parts to learning aim A:

- regulatory requirements
- safe operation of machines
- risk assessment.

Make clear that there are two main areas of safety consideration: electrical safety, which is concerned with the prevention of fire and shock and mechanical safety, which is concerned with the prevention of injury from the equipment operated by the electrical machine. Try a research exercise requiring learners to find as many regulations applicable to the safe use of electrical machines as they can and to draw up a table showing the main points of these regulations.

A risk assessment must be drafted by each learner. This must cover running, and taking electrical measurements from, live machines. It should cover both electrical and mechanical hazards. The risk assessment needs to include a likelihood and risk level calculation. Familiarity with the safe isolation procedure is also required.

Although the focus of learning aim B is DC machines, first establish the difference between AC and DC electrical supply. An explanation of DC generation is a logical next step, as it gives learners a basic model of electromagnetic induction, and the relationship between electrical and mechanical energy. Explain the working principles, and uses, of the DC generator and motor.

Magnets and conductors, connected to a voltmeter are a simple way to demonstrate the effect of electrical induction. Making simple generators and machines is an enjoyable and effective way to introduce a learner to their basic construction and operating principles.

Theoretical aspects must be dealt with here: electromagnetic induction, calculations such as speed and torque, B = ElV and F = BIl, and loss calculations such as $P = I^2R$. Describe and practise Fleming's right and left hand rules.

Examine the components of a DC motor and a generator. Enhance this examination by making a motor available to learners. This can then be dismantled by learners to reveal components in their working context. Cutaway or exploded diagrams will also be an advantage, as it is often difficult for a learner to visualise these components. Point out and explain features such as cooling fins, and the way field windings are bedded into the iron core to increase magnetic flux and reduce eddy currents. Losses and back EMF are also important issues with electromagnetic machines such a generators and motors.

State the types of dc motors – series, shunt and compound. The learners can research these motor types, including their construction, advantage and disadvantages, and their uses. The research can be summarised in PowerPoint form and presented by the learners to their peers.

The study of DC starting and control equipment gives an opportunity for learners to design, install and test control circuitry and components for test bed motors. The learners should take measurements of voltage, current and power, to establish the effect of speed control and torque.

Learning aim C is focused on AC electrical machines – generators, motors and transformers. Learning aim B explains the basic principles of electromagnetic induction and its use in generating electricity. Explain the difference between the DC and AC generator and demonstrate its output. An oscilloscope is the ideal instrument with which to show the sine wave visually. The relationship between the rotation of the armature windings and the structure of the sine wave is an important point to cover with learners.

The essential AC motor is the induction type, both three-phase and single-phase versions. Before tackling the induction motor, it may help to explain the operating principles of the three-phase generator, in particular the relationship between the three phases and the effect of this relationship in creating a rotating magnetic field. Synchronous speed, rotor speed and slip calculations should be set. Explanation of the operating principles for single-phase induction motors will require a knowledge of leading and lagging AC circuits. A recap of these principles will be beneficial. This gives scope for research and the summary of findings into an explanatory guide or PowerPoint presentation for peers.

As with the DC motor, explore starting and control. This will be in terms of external control of the motor, for example undervoltage protection and reduced start-up currents. Again, practical design, installation, test and measurement are invaluable tools for gaining an understanding of the complexities of the AC motor.

The other AC machine is the transformer. For this, describe the effect of mutual induction, along with calculations of turns ratio and inversely proportional voltage and current. Transformers also suffer from losses and highly reactive windings, which result in back EMF and eddy currents. A working transformer would be useful so that measurements can be taken and calculations set, based on those readings. For example, learners can take power, voltage and current readings and calculate power factor.

A visit to an industrial installation would be highly beneficial. There, the learners could see various types of electrical machine operating in a working environment, usually on a larger scale.

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

Assessment guidance

The recommended evidence for learning aim A is a risk assessment which covers the use of a range of electrical machines. The assessment should clarify the demarcation between electrical and mechanical hazards. This is a working risk assessment because learning aims B and C require test and measurements to be taken from live electrical machines. Your learners will then explore how the assessment meets the requirements of local procedures for those machines.

Get your learners to tease out the main points of one relevant regulation and one relevant guidance note and then compare them with the practical safety measures outlined by the risk assessment. The comparison can take the form of a brief report which describes the regulation and procedure and then examines where the risk assessment conforms with these requirements and where it falls short. There are links to relevant regualtions and guides on the HSE website at www.hse.gov.uk/electricity/withequip.htm.

Learning aims B and C require a portfolio of design decisions, actual planning and design of control systems and systems operated by electrical machines. They also require results of measurements, testing and accompanying calculations. Agree a logical layout for the portfolio so that the information it contains is readily accessible and clearly presented.

A suggested project for this assessment is the design, installation and test of a series of control systems for a variety of electrical machine(s). There is a requirement to use different types of machine:

- two types of DC motor – say a series and shunt type
- a DC generator
- a three-phase AC induction motor
- a single-phase AC motor – eg a universal motor
- an AC generator
- a single-phase transformer.

This will also give a practical demonstration of the principles explored in *Unit 16: Three Phase Electrical Systems*. Other methods of presenting information could be accompanying video footage and a PowerPoint presentation that summarises the main points of the project.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 15: Electrical Machines

Introduction

This unit is concerned with the safe use of electrical machines, their operating principles and uses. It also requires the learners to carry out test and measurement procedures. Access to live machines would be beneficial, although this does present safety issues. The ideal test terminals are plug-in types that have their live parts shielded from accidental contact. Always use calibrated, professional test equipment that conforms to GS38.

Operating these machines requires a firm grounding in electrical principles, particularly electromagnetic inductance, three-phase principles (see *Unit 16: Three Phase Electrical Systems*), reactance and resistance and the effect of leading and lagging current.

A visit to an industrial installation to see electrical machines in use would also benefit the learners and present a real-life context for the theoretical aspects of the unit.

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

The safe use of machines divides into a number of separate subjects.

- Relevant health and safety legislation.
- Electrical safety:
  - Protection from shock.
  - Protection from overload.
  - Protection from fire.
- Mechanical safety:
  - Protection from physical injury.
- A good starting place would be a research exercise in which your learners look up relevant health and safety legislation. They can then create a table or matrix on which to record the main requirements of these regulations. It can also include non-statutory documents such as BS7671 and the IET On-Site Guide. While these two documents do not contain many specific requirements regarding electrical machines, they do deal with switching, isolation and possible thermal effects. This exercise will enable your learners to distil the information down into focused points covering the essential health and safety practices employed when using, testing, installing and running electrical machines. This should include both electrical and mechanical regulations. This will also give them a foundation from which to produce the report required for the assessment.
- Your learners should select the relevant test equipment and check that it conforms to GS38.
- Because the use of live machines forms part of the learning for this unit, a risk assessment for the safe undertaking of these exercises must be drawn up by the learners themselves. This would not only give the necessary analysis of the risk and hazard connected with such an exercise, but also the necessary learning associated with the assessment.

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

• A knowledge and understanding of basic principles is essential to the successful completion of this learning aim. In light of this, you might take the learners through these principles as an introductory session. They include the magnet and its properties, and the effect on a conductor subjected to changing flux and its application to:
  o the creation of electricity in the form of a generator
  o mutual induction, which lies at the heart of transformer operation.
• To avoid 'chalk-and-talk', illustrate these principles by developing a classroom-based practical exercise, in which the learners construct simple generators, using materials such as magnets and small-gauge wire. A test meter, with a scale fine enough to read low voltages and currents will be required. It would also be a good idea to connect the generator to a potentiometer to show how the direction of armature rotation affects polarity. This exercise will also demonstrate the effect of rotation speed and magnetic field strength on voltage values. As a final exercise, your learners can convert the generator to an electric motor, and, once again, demonstrate the effects of magnetic strength and polarity.
• Your learners must carry out measurements (voltage, current and power) and tests on live machines. You will need a selection of motors to facilitate this. A series, shunt and compound motor would give learners examples of the main DC motor types. Your learners will measure starting torque, start and running currents and establish the strengths and weaknesses of each type. A selection of DC motor starters and speed controllers will also be beneficial for this learning aim.
• DC motors power many industrial machines. A visit to an industrial installation will place the theory into a real-life setting. Your learners can use such a visit as an opportunity to research the machine selection criteria for a variety of mechanical processes and equipment.

Learning aim C – Explore the safe operation of alternating current electrical machines as used in industry
• Bring the principles explored in learning aim B to bear on the AC motor. An explanation/revision of three-phase is a good point from which to start this subject (see *Unit 16: Three Phase Electrical Systems*). The relationship between the phases, utilised to create a rotating magnetic field, forms the foundation of the induction motor. • From there, describe the single-phase induction motor, in terms of phase-shift created by either a resistive start winding or a capacitive one. Facilitate a research project on the principles of the AC motor. Use the output from this exercise to feed into their final report. An accompanying PowerPoint presentation can help your learners summarise and reinforce the main points of their research and findings. • A design project would give a means for your learners to explore motor control circuits. A selection of AC motors and starters and controls will be required for this. Ideas include remote start stop, inching or a number of motors starting in sequence. Your learners can measure start and run current, particularly in star-delta or autotransformer starting systems. Electronic systems, eg soft-start would also be beneficial to your learners. • Arrange a visit to an industrial installation so that your learners can see AC motors operating in a 'real-life' context (see learning aim B).

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

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

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Grimwood T and Jeffery A – *Level 2 and 3 Diploma in Electrical Installations (Buildings and Structures)* (Pearson Education, 2013) ISBN 9781447940258. Gives a thorough grounding in all electrical principles and processes, with a comprehensive chapter on electrical science.
- Wildi T – *Electrical Machines, Drives and Power Systems* (Pearson International, 2013) ISBN 9789332518537.
  A detailed, specialised book that is accessible and covers all aspects of the subject.

Unit 16: Three Phase Electrical Systems

Delivery guidance

Approaching the unit

Three-phase is, by its nature, a hazardous system involving higher voltages than those normally experienced by learners (eg 230V, 50V, 24V). It can also be a difficult concept for learners to grasp - why there are three line conductors supplying a load but only one (or no) neutral. This unit explores the principles behind the generation of three-phase and its uses. Transmission and distribution of electricity is in the three-phase format, and at varying voltages, from the 25kV at the power station up to 400kV in the Supergrid and 33kV or 11kV for distribution. Describe the local distribution transformer to learners, particularly in terms of its delta primary and star secondary winding configurations and how single-phase domestic installations are fed from the three-phase supply.

This unit examines the relationships between voltage, current and power within a three-phase system. It looks at line and phase voltages and currents, and the relationships between them. Much of this is theoretical and can be explored through a mix of classroom lectures and personal research by the learner. Measurement of three-phase systems, both balanced and unbalanced, as well as line and phase voltage and current will require a live test rig of some description. Safety during these experiments and measurement activities is of the utmost importance due to the higher voltages present.

The effects of reactive load, for example in an industrial installation, are to be explored and the components of the reactive circuit, XL Xc, R and Z require calculation. Power factor and its correction form part of the assessment for this unit, in terms of power consumption and costs. Learners will need access to tariffs and charges levied by supply companies.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A deals with the generation of electrical supply and the basic construction of the National Grid. Examine the components of the three-phase synchronous generator. If there is an example available, this will of course be advantageous. Diagrams and technical data sheets will also be useful support. Carry out calculations of synchronous speed and frequency. The transmission and distribution, and the voltages in each part of this network, can form the basis of a learner-led research exercise. Include a diagram showing the grid and its component parts.

Explain the conversion of three-phase to single-phase for domestic installations in terms of the delta primary and star secondary of the local distribution transformer. These transformers are not generally accessible to the public, but an awareness of the location of the local distribution transformer would be useful for the learners to establish. It is worth contacting your local supply company to see if they would arrange access to a transformer compound. The supply company can certainly supply other useful information relevant to the unit.

The actual three-phase system and its features and values are examined in learning aim B. Calculations will include the relationships between line and phase voltages and currents in both star and delta systems, as well as reactive and capacitive inductance, resistance and impedance. Explore the effect of balanced and unbalanced loads in terms of current and power. A test rig would give a means of measuring these effects. The rig should feature a set of balanced, but individually switchable, loads. Supplying highly inductive discharge lighting from the rig, and introducing switchable capacitors into their circuits, makes possible the demonstration of the effects of power factor on power consumption and cost (as required in learning aim C).

Learning aim C is broken down into research, design and problem-solving. Your learners can carry out research to establish the tariffs and costs levied by two different supply companies. It may be a good idea to contact a number of these companies ahead of the learning delivery to establish that they are willing to give the information needed by the learner. Your learners can analyse various quotes from supply companies, and compare and prepare breakdowns of the costs. A 'real-life' installation would give structure to the assessment of the learning aim. Calculation of maximum demand is another learning aim requirement. The said 'real-life' installation would be an ideal subject for this calculation, and subsequent diversity decisions.

Power factor correction is an essential part of cost effective electrical supply within an industrial installation, which will consist of highly inducting loads such as discharge lighting and electrical machines. The learning aim B test rig can give the means for measuring and proving the effect of power factor.

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Learning aim	Key content areas	Recommended assessment approach
A Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity	**A1** Construction and operation of synchronous generators **A2** Transmission and distribution networks **A3** Safety considerations on high-voltage transmission systems	A written report examining the infrastructure of the national grid (or similar), to include generation transmission, distribution and protection.
B Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally	**B1** Connection methods for three-phase power circuits **B2** Electrical calculations for three-phase power circuits **B3** Electrical measurements for three-phase power circuits	An experimental report based on physical measurements and theoretical calculations, exploring the relationship between currents voltages and powers in three-phase power circuits.
C Investigate the cost of using three-phase electrical power systems in typical industrial applications	**C1** Supply considerations **C2** The cost of using electricity	A written report investigating the cost of using electricity, including tariff structures and power factor correction.

Assessment guidance

The recommended assessment method for learning aim A is a report that examines the national grid infrastructure. This report needs to show how power is generated and the voltages present in various parts of the network. The generator and its components should be described. Calculation showing synchronous speed and frequency should be present. Research tools such as textbooks and internet availability will be needed. Contact with a generating company may well prove a useful source of information.

An experimental report based on physical measurements and theoretical calculation is the suggested assessment approach for learning aim B. The values in a three-phase system are to be explored and calculated. A test rig should be available for the learner to carry out experiments and measurements. The rig will be a means to prove the theoretical assumptions, particularly in the realms of load balancing, and line and phase voltage and current.

A subject installation would be invaluable for completion of learning aim C. This could be part of the training centre or college, or it could be a workplace attended by the learners during the rest of their week, or an installation created as a subject for the research. Tariff and costs for electricity consumption need to be calculated and analysed. Learners should explain power factor and its correction, and the effects of uncorrected and corrected circuits on power consumption and cost. It may be helpful to visit an industrial installation to research the supply and power factor correction system installed.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 16: Three-Phase Electrical Systems

Introduction

Structured differently from the traditional circuit, the three-phase supply can be a confusing concept for your learners to grasp. In the three-phase system, there are three line conductors, which not only carry voltage and current separately but are also linked to one another in a relationship created at the generator and used to power three-phase machines. The absence of a neutral in the network side of electrical supply, as well in the supply to three-phase motors, is a further puzzling aspect of this type of system. Even learners who may be working in the electrical industry may not have a full grasp of the principles behind three-phase supplies and systems. Three-phase needs to be fully explained and you need to be certain that your learners have grasped its principles before moving on.

Much of this subject is inevitably theoretical, so to prevent its delivery as a series of dry lectures give thought to exercises, both academic and practical, to add variety and to aid comprehension of the subject. Take great care with any practical tasks related to this unit because three-phase is extremely hazardous and therefore should be treated with respect.

Learning aim A – Examine the construction and operation of a national grid, which safely connects power stations and substations to supply electricity

- Start at the generator. Understanding the operation and principles of the three-phase generator will help make the relationship between the phases clear to your learners. Once the principles of its generation are established, move onto transmission and distribution of this electrical supply from the power station to the user. Emphasise that power is transmitted and distributed as a three-phase supply. There is no neutral. Power distribution begins at the power station, is transmitted nationally via the Supergrid and National Grid then distributed to local transformers. This gives scope for a learner-led research project – the extent, make-up and components of the grid. The learners can research the various voltages and its hierarchy from the Supergrid to local supply. They can produce a block or family tree type diagram, which shows the elements, and voltages that make up the network. The learners will need to be able to describe individual components, such as HV switching, arc suppression and other safety devices.
- Your learners will research the safe operation and testing of HV systems. They will find information in the relevant regulatory documentation. Encourage the learners to contact supply company technical representatives. They will have knowledge of national and local HV procedures. The learners can also investigate the training necessary for those carrying out HV work.
- The key to distribution is the local transformer, which converts an incoming supply of 33kV or 11kV to 400V. The transformer has delta-wound primary and star-wound secondary windings. Neutral is created at the star point. A visit to a local transformer compound would be beneficial. Entry into the compound would be even better, however, access being granted is unlikely due to the stringent safety procedures surrounding high voltage systems. It is worth contacting the supply company, because it may result in information, a visit by a technical expert or access to the compound. Ask your learners to locate their own local transformer.

- This leads onto:
  - supply of single-phase to domestic installation from the three-phase mains
  - three-phase load balancing
  - calculation of line and phase voltage and current.
- The learner could gather these elements together into a report, written in a coherent and informative style. An accompanying presentation would act both as a summary and as reinforcement of the main principles of three-phase generation and distribution.

Learning aim B – Explore the operation of three-phase power circuits which form the majority of electrical infrastructures globally

- Three-phase is a form of AC supply, and as such, subject to reactance, capacitance, resistance, impedance and their subsequent effect on power. These effects can form the basis of the learner's experimental report for assessment. If your learners have already studied these effects as part of other units, then a minimum of teaching will be required. If they are not familiar with them, then basic grounding on the subject will be necessary. Calculations will reinforce the elements of this subject.
- Use an oscilloscope to:
  - show a 'live' representation of the three-phase sine wave
  - demonstrate the relationships between current and voltage in inductive, capacitive and resistive circuits.
- You must also ensure that learners can explain the following:
  - R, X and Z
  - kVa, kW and kVAr
  - power factor.
- Load balancing is vital where the circuits in an installation are supplied by both three and single-phase supplies. Your learners must be able to describe the need for load balancing, particularly in terms of third harmonics (neutral current). Encourage your learners to contact an electricity supply company. The technical department of a supply company will have information on the effects of an unbalanced supply.
- Make a test rig available to prove the effects of unbalanced loads in a three-phase system. This rig needs to give a safe means of taking voltage current and power readings. A set of separately switched lamps, evenly distributed across the phases will give a simple method of putting the system in and out of balance. The rig should also give a method for measuring line and phase voltage and currents.
- Your learners can then record and comment on the results of these measurements.

Learning aim C – Investigate the cost of using three-phase electrical power systems in typical industrial applications

- There are three main elements to this learning aim. These are:
  - maximum demand
  - power factor correction
  - costs of electrical supply.
- Define maximum demand – the absolute maximum amount of current used by an installation. Get your learners to calculate it for your department of your training

establishment (or their own workplace). Are the main fuses or other protective devices of a sufficient rating for the installation? Your learners can now calculate diversity, by referring to the diversity allowances stated in the IET On-Site Guide.

- Your learners can also find out which supply company supplies power to their subject installation and the tariffs imposed by that company. What other tariffs are available? Your learners can obtain quotes. Draw up an analysis comparing the quotes and making recommendations. The analysis can also show the make-up of the quote. Which part of it is payment for actual power used and which is a standard charge? Are there cheaper rates at certain times of the day?
- Power factor has a significant effect on power consumption, particularly where an installation's loads are highly inductive (eg a factory or workshop full of electrical machines and illuminated by discharge lamps). Learning aim B includes the suggestion for a three-phase test rig. If the lamps supplied by the rig are a high-inductance, discharge type, installing switched capacitors in the circuits will give a means of proving the effect of capacitance on power.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 15: Electrical Machines*
- *Unit 18: Electrical Power Distribution and Transmission*

National Diploma in Electrical Installation (Levels 2 and 3)

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Grimwood T and Jeffery A – *Level 2 and 3 Diploma in Electrical Installations (Buildings and Structures)* (Pearson Education, 2013) ISBN 9781447940258. Gives a thorough grounding in all electrical principles and processes, with a comprehensive chapter on electrical science.
- *IET On-Site Guide (BS 7671:2008+A3:2015): Incorporating Amendment No. 3 (Electrical Regulations)*, Institution of Engineering and Technology, ISBN 9781849198875.
  A practical application of the IEE Wiring Regulations. Includes an appendix showing diversity allowances for various installation types.

Unit 17: Power and Energy Electronics

Delivery guidance

Approaching the unit

The emphasis of this unit is the increasing application of power electronics to areas such as renewable energy, electricity generation and supply, transport systems and industrial processes along with the consideration of issues arising from their use.

You should ensure that learners focus on the practical development of skills and knowledge of the structure and applications of power electronic devices using a variety of circuit prototyping methods. The unit content builds upon the knowledge and skills developed in *Unit 19: Electronic Devices and Circuits*. Learners may be studying this unit alongside *Unit 20: Analogue Electronic Circuits* and/or *Unit 21: Electronic Measurement and Testing of Circuits*, both of which contain knowledge and skills that are complementary to this unit.

Learners need to investigate the construction and operation of power electronic devices, by building circuits to discover their function and typical applications. For example, you could ask learners to investigate direct current (DC) motor speed and direction control in the context of propulsion for a remote controlled vehicle or an industrial drive system. There is potential for using links with local industry to provide realistic scenarios for investigations.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

For example, if possible, you could arrange a visit to investigate sustainability and renewable energy considerations and the role of power electronics in addressing them.

Delivering the learning aims

This unit combines theoretical knowledge and practical skills, and requires learners to identify common types of power electronic devices, their construction and characteristic behaviour.

Learning aim A introduces the types of device. It is important that learners investigate the characteristic switching behaviour of each type, using a prototyping system and/or pre-prepared kits of components that allow learners to make changes quickly to assist their investigations. You could encourage learners to supplement a report on their investigations for learning aim A with manufacturers' and catalogue data. It is important that any inclusions are referred to in the report and are relevant..

Learning aim B is flexible enough to allow pairs of learners to investigate the applications in no particular order. It would reduce the resource requirements, therefore, if pairs were working on different activities, progressing in a planned sequence. The investigation of the inverter circuit is likely to be theoretical at this stage due to the potential complexity of the switching circuitry. Learners need to collate their evidence as they generate it and each individual learners needs to produce their own report.

Learning aim C has the potential for close working with industrial partners for learners to investigate sustainability and environmental issues in two power electronics applications. If possible, invite an expert speaker to talk with the learners and provide challenges for the focus of investigations into sustainability issues. Learners can become very involved in these applications and develop ideas about how they may progress and extend the tasks. It is important, while fostering their interest, that you encourage each learner to consider how they will manage to complete each investigation in the time available.

Learning aim	Key content areas	Recommended assessment approach
A Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy	**A1** Construction and operation of different types of power electronic device **A2** Characteristics of power electronic devices in switching circuits	A logbook collating practical experiment reports exploring the operation of common power electronic devices in relation to device construction.
B Explore applications of common power electronic devices that are used to modify a form of electrical energy	**B1** DC motor control circuits **B2** Voltage conversion circuits	A logbook collating practical experiment reports exploring applications of power electronic devices.
C Investigate sustainable applications of power electronics	**C1** Applications of power electronics **C2** Sustainability issues relating to power electronics **C3** Regulations relating to power electronics	A written report investigating power electronic applications in each of the four sectors, exploring one of them in greater depth.

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Assessment guidance

There should be no more than three summative assignments for this unit. This is a practical unit in which learners should investigate the switching behaviour of semiconductor devices and how they can be used in power applications. It is envisaged that the circuits for the unit will be constructed using rapid development systems, as listed in the Resources section of the unit specification, or pre-assembled kits of components. If pre-assembled kits are used, then the assessor should give each learner additional components to allow for the selection of the most appropriate values. Learner evidence should include circuit diagrams, brief explanations of each purpose of each circuit, evidence of testing, and brief explanations of how the circuits work. The learners should use simple semiconductor theory to analyse the materials used and the physical construction of power electronic devices to demonstrate how they relate to the component circuit symbol.

You could provide detailed observation records confirming the practical activities carried out. You may need to guide learners to keep all of the evidence for each device together, so that they build up a database of information.

Learners need to evaluate the operation of power electronic devices in DC motor control and voltage conversion circuits using test results and theory. They should explore speed and direction control of a DC motor using bipolar junction transistors and MOSFETs in circuits using more than one active device. They will need low voltage DC motors, such as 12V DC motors suitable for toys or model cars.

Learners should evaluate the operation of voltage conversion circuits, comparing the measurements taken from each physical circuit with theoretical behaviour. For example, using voltage waveforms from oscilloscope traces of a thyristor rectifier circuit to demonstrate how the output voltage is controlled by the firing angle. It is unlikely that learners will be able to examine inverters practically, so this could be a theoretical topic, which could be advantageous in managing resources.

Learners need to write a report on two contrasting potential applications of power electronics. Learners may be stimulated to investigate an area triggered by ideas introduced by a guest speaker. You could prime the guest speaker to present suitable challenges to the learners.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 17: Power and Energy Electronics

Introduction

It is important that learners understand the variety and uses of power electronic devices in everyday applications. You could start by demonstrating some applications, for example motor speed and direction control using remote controlled vehicles such as cars, helicopters or drones. You could also consider sustainability and renewable energy applications, such as solar and wind power generators, and the potential of visits to and/or from local industries/experts to foster interest in the subject.

Learning aim A provides the basis for learners to understand the construction and operation of typical power electronic devices along with some of the underpinning theory. It is important that you provide the learners with an opportunity to carry out practical investigation of the device types, especially the switching behaviour, as that is an important aspect of many applications.

Learning aim B allows learners to carry out practical investigations into applications of power electronic devices. You could organise a carousel of activities with a theoretical inverter investigation acting as a buffer between practical investigations to allow learners to complete each practical activity.

The investigations for learning aim C offer an opportunity for learners to develop transferable skills such as:

- the ability to learn independently
- the ability to research actively and methodically
- reading technical texts
- effective writing
- analytical skills.

Learning aim A – Explore the construction and operation of common power electronic devices that are used to modify a form of electrical energy

- Learning aim A introduces power electronic devices in terms of their construction, operation and switching characteristics. You could introduce the concepts by demonstrating applications of power electronics such as:
  - motor speed and direction control
  - solar and wind power generation.
- You may also consider the potential for an industrial visit for learners to see applications of power electronics.
- Learners need to explore the switching behaviour of each of the devices and relate it to the internal structure and semiconductor theory. The unit content develops from simple pn junction diodes to more complex internal structure, and it is advisable for learners to progress through the devices in sequence of complexity, so that they can build up understanding of the underpinning semiconductor theory.
- Learners could record the results of their exploration of devices by creating a portfolio (or logbook), gradually building up information on each system as they

progress through the practical exercises. For learning aim A learners could relate the :

  - standard circuit symbols (IEC 60617, BS 3939) to the internal structure of each device.
  - observed switching behaviour to the internal structure and that expected from semiconductor theory.
  - observed values with published data.
- You could give each group of learners responsibility for presenting their findings for one of the devices, identifying:
  - the device investigated
  - its circuit symbol
  - the observed switching behaviour
  - how the observed behaviour compares with that expected from theory
- This would also help in developing intrapersonal skills: communicating, working collaboratively, negotiating and influencing and self-presentation.
- You could summarise the information by leading a plenary session to collate the outcomes from the learner presentations and identify any supplement areas not covered in sufficient detail for learners to be able to complete their report on their investigations.
- You could guide learners to organise their portfolios/logbooks.

Learning aim B – Explore applications of common power electronic devices that are used to modify a form of electrical energy

- Learners should use the knowledge gained meeting the requirements for learning aim A to carry out a series of practical exercises to investigate practical applications of each of the power electronic devices. You could organise a carousel of activities to cover the unit requirements, so as to minimise the resources required. It is important that you monitor progress carefully as learners are likely to complete activities at different rates. You may decide to arrange for a theoretical inverter investigation to act as a buffer between practical investigations.
- Learner records could include data such as:
  - circuit schematics
  - waveform sketches
  - accurate measurements
  - explanations of the circuit behaviour.
- Learners could feed back to the rest of the group through explaining:
  - the function of a given application
  - how they measured signals at key test points
  - how the measurements relate to the underpinning theory.
- This would also help in developing intrapersonal skills: communicating, working collaboratively, negotiating and influencing and self-presentation.
- You could then lead a plenary session to summarise the outcomes from the learner presentations and identify and supplement any areas not sufficiently covered.
- You could also guide the learners to organise their reports logically and use correct technical engineering terms.

Learning aim C – Investigate sustainable applications of power electronics

• Learners need to complete investigations into two contrasting applications of power electronics. You could prime learners to prepare for the requirements of learning aim C by looking at potential areas of investigation within their own workplace, or to base their choice on a work placement or local issue before the start of the unit. For example, they could base one of the applications on a proposal to build a wind farm, supply homes with photovoltaic panels or increase the sustainability of a planned extension to the school/college buildings.
• It is important that investigations are sufficiently rigorous to allow learners access to the full range of assessment, but they should not so complex as to be unfeasible in the time allowed.
• You should set the parameters for each investigation so that learners are set unique targets to minimise the potential for plagiarism.
• There is potential to use business contacts to provide realistic scenarios for learners having difficulty finding one for themselves.
• Learners should include diagrams, charts and tables of data. They should identify the purpose of each application and include specific details of the required technology, reviewing the current ability to implement it.
• You should encourage learners to comment on potential issues related to the sustainability of the application. For example, concerns raised by the proposed construction of a solar-farm on a brown-field site should contain comment on environmental impact, ethics and relevant regulations.
• You could organise a poster competition for learners to summarise their research into one of the areas as an A3 poster. Learners could provide peer appraisal to select the winner(s). This exercise can also develop the interpersonal skills of:
  ○ self-management
  ○ adaptability and resilience
  ○ self-monitoring and development.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 3: Engineering Products Design and Manufacture*
- *Unit 5: A Specialist Engineering Project*
- *Unit 15: Electrical Machines*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 21: Electronic Measurement and Testing of Circuits*
- *Unit 23: Digital and Analogue Electronic Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Rashid MH – *Power Electronics: Devices, Circuits, and Applications, 4th edition* (Pearson, 2013) ISBN 9780273769088.
  This text is aimed at undergraduate level, but gives a good introduction to devices and applications. The more analytical content means that the text will continue to be useful for further study.

Websites

- www.electronics-tutorials.ws
  Basic Electronics Tutorials for beginners and beyond, Basic Electronics Tutorials Site by Wayne Storr. Very well presented information covering a wide range of electronic subjects.
- http://powerelectronics.comOnline industry magazine, Penton Media Inc.
  This has industry-focused articles pitched at a high level. It gives an indication of the direction in which the industry is moving.

Unit 18: Electrical Power Distribution and Transmission

Delivery guidance

Approaching the unit

Transmission and distribution systems run on high voltage (HV – 1000V or greater) and are covered by their own stringent regulations. Because of this, the scope for practical exercises is limited. However, try working with transmission and supply companies. The technical departments of these organisations may be able to make the expertise and information necessary available to complete this unit. Visits to HV installations are also problematic, but contact with supply companies may result in access to some of these installations.

Many renewable generation plants have visitor facilities, and although the focus of this unit is not renewable energy supplies, it will still give context, and first-hand information, on factors such as electrical output, transformers and connections to the grid.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A focuses on the power station. A visit to a power station would be beneficial. If this is not possible for a major location, it may be possible to visit a local power plant. A number of large industrial parks are now supplied from their own local power stations. A speaker from a power generation company would also be a good source of technical information. This is very much a research project, so access to information is vital. This guide lists a number of websites that contain relevant data and are gateways to further information sources.

An analysis of the design of the supply network is the focus of learning aim B. This will require the cooperation of a supply company. A visit to a control centre would be advantageous. These control centres monitor grid status and switch supplies to areas of greatest need. A visit would give an overall view of the working of the network. Permission is not required for a visit to a pylon, as long as the land on which it stands is not private.

The network is more than a collection of components. Demand and resilience are key factors in the design decisions behind its construction. There are also aesthetic factors. Few people welcome the construction of a row of electricity pylons across their landscape. Again, technical expertise from the supply companies themselves will be a welcome support for this learning aim. Access to the original planning applications and related material for a particular section of the network would give a view to the factors that contributed to its final approval and installation.

Learning aim C leads on from the previous one. The information gathered on an existing supply system can be utilised for the design of a new supply and distribution network for a client. This client can be real, or a mythical one devised for this unit. An actual installation would be beneficial because it gives a 'real-life' context to the work. Of course, your learner will have to seek

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permission and cooperation of the client, who will have to reveal information about their current demand and power needs. Consider diversity as a means of reducing costs, in terms of current demand and the resulting cable size and transformer rating.

In the delivery phase, your learners could design a supply system from scratch and ignore any supply components already in place. They should use their own research and apply this to the project. They should build redundancy into their system so that supplies are maintained in the event of maintenance shutdown or accidental power failure. The design documentation could include drawings, calculations and justifications that will lead well into the assessment of this learning aim.

Learning aim	Key content areas	Recommended assessment approach
A Investigate the operation of thermal and water-cooled nuclear reactor power generation that supplies electricity to the national grid	**A1** Thermal power generation **A2** Nuclear power generation **A3** Comparisons between the two generating methods	A report detailing the operation and construction of nuclear and thermal power stations and the perceived benefits and drawbacks of each.
B Examine the design of a typical transmission network used to supply electricity	**B1** Transmission networks **B2** Transmission network design features **B3** Design of overhead power transmission	An analysis of a given transmission network, which details the relevant sections and why certain decisions have been made.
C Design a distribution system to meet customer requirements for a new electrical installation	**C1** Network design **C2** Power distribution **C3** Distribution substations	The design of a distribution network for a given customer requirement that justifies all choices made and costs incurred.

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Assessment guidance

Delivery and assessment of this unit is limited in that working with HV requires specialised training. HV is extremely hazardous to life, so laboratory experiments and exercises are not possible. This means that the unit will be largely theoretical and research-based.

Supply and transmission companies may donate examples of the components used in an HV system. Investigate the purchase of these components. You can invite speakers in to deliver specialist lectures and demonstrations. Visits may be possible but this will depend on the organisation approached and the level of hazard involved.

The learning aim assessments for this unit consist of a report, an analysis and a design. The report is of the processes within a nuclear power station and requires research and technical advice. Access to power stations is limited but it is always worth trying. Approach the generation companies from the angle that this qualification is a training route for future electrical engineers. Again, visits from technical experts are vital because pure research cannot give a 'feel' for the subject or reveal localised procedures or individual aspects of particular power stations. *Unit 15: Electrical Machines* and *Unit 16: Three Phase Electrical Systems* contain the principles of electricity generation and three-phase supply, but a refresher session on these principles would be beneficial before assessment.

Learning aim B, the analysis of an industrial supply and distribution network, gives the necessary foundation for learning aim C. Many industrial installations contain a number of voltages and often include equipment directly fed by HV. A ring main may be in place to provide redundancy and a transformer system to provide the required voltages. *Unit 16: Three Phase Electrical Systems* includes maximum demand calculation. It also explores the consumer supply side of a real installation. This unit's analysis and design assessments could be a continuation of that project. In this unit, the external supply of that same installation can be analysed.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 18: Electrical Power Distribution and Transmission

Introduction

The suggested assessments are a report, an analysis and a design. The hazardous nature of HV precludes the use of experimental equipment in the laboratory and limits fieldwork. However, liaison with technical experts and representatives from generation and supply organisations will bring a level of expertise into the scope of the learners.

A real-life supply distribution system is to be analysed and an industrial installation would prove a good model for this analysis. Explore the components, voltages and layout of the system. Make contact with industrial partners and local firms to facilitate this. Designing a supply network around the need of a real life installation will give the learners a structure on which to hang their learning aim C assessment.

This unit depends a great deal on the cooperation and help of local businesses and gives an opportunity for contact and partnership. Look into the possibility of internship or work experience for learners within the supply industry as a way for them to gain the knowledge and experience necessary to complete the unit, and also to introduce them to working in that industry. A mutual benefit would be for the learner to gain employment from this arrangement.

Learning aim A – Investigate the operation of thermal and water-cooled nuclear reactor power generation that supplies electricity to the national grid

- The assessment requires a report on the operation of a thermal, water-cooled, nuclear power station. Research is the key to this assessment. Remind the learners of the basic principle of electricity generation. Describe the electromagnetic principles that underlie this process (*Unit 15: Electrical Machines*). Remind them of the operation of the three-phase generator (see *Unit 16: Three Phase Electrical Systems*). Give a basic description of the process of generation of heat within the reactor, which heats water to the super-heated 'dry' steam used to power the turbine, which in turns drives the generator. Your learners should describe the two main types of reactor – boiling water and pressurised water. Other discussion issues include types of uranium, heating control and power output.
- Learners could research detailed documents that cover aspects of the process. There are numerous resources (see the next section of this guide) but you should also invite representatives from a generation organisation, eg Powergen, to speak and offer technical information and advice. Use this speaker for assistance with the other units.
- A visit to a power station would be advantageous, Not many nuclear power stations offer this facility, but a smaller, local power station might willing to accept a visit. The essential principles will be the same, the conversion of heat energy to mechanical energy and thence to electrical energy.
- Your learners should also research and discuss proposals to build new nuclear power stations in the UK. How much will this increase output? What is the cost of this, what is the philosophy behind this? Again, a speaker from the industry would be able to put flesh on the bones of these proposed projects.

Learning aim B – Examine the design of a typical transmission network used to supply electricity

- The main supply network for the country is the National Grid. Introduce the network. Give your learners some guidance on the aspects of the network they need to research and explore.
- Use a large installation, such as larger industrial sites and industrial parks which require their own distribution systems. There may be differing voltages on these sites, including HV. Your learners should describe such features as ring mains, employed to feed a series of transformers and providing redundancy in the event of maintenance, shutdown or faults. What are the prospective fault current and external earth fault loop values? Your learners should look at the cables – what size are they and what type? What are the features of the cables? Are they earthed-concentric? Are they single core, aluminium or copper? Drawing and schematics of the system will be required. A series of C codes regulate this equipment. Explore the philosophy behind the design. Get your learners to create a checklist of the features and information they need for their analysis. They must be clear on what they need to find out before undertaking the research task.
- Liaise with local businesses to arrange access to their sites. Arrange to meet a supply company representative on site, someone who can describe the components of the network. Your learners should gather information on current demand and any particular power needs. Work experience with a supply company would be of a great advantage, giving an inside view into supply networks.

Learning aim C – Design a distribution system to meet customer requirements for a new electrical installation

- Draw up a list of requirements before design can begin. There are a large number of practical items to consider, for example:
  - demand
  - redundancy
  - voltages
  - system (single or three-phase).
- Your learners will need to research the hardware. What type of cable will be used? Will they be run overhead or underground? A survey of local residents would give guidance on the overhead/underground decision. Would the residents approve of a set of overhead lines run in their locality? On the other hand, how do they feel about the disruption of cable trenching? They should decide on the rating and type of transformers. Calculate cost and consider logistics. Base this on the knowledge gained while working on learning aim B.
- The assessment needs careful planning before the learners get started. One suggestion is to hold a brainstorming session to draw up a list of requirements. Get your learners to list all the items needed for the execution of this project. Sort into those that can be researched online and in textbooks, and those requiring site visit and liaison both with the 'client' and with the supply companies. Once you have your shopping list, give the project structure by turning into a Gantt chart or other type of project plan. This will give a systematic approach to guide your learners through the process. Arrange progress tutorials throughout the period taken up by this assessment. These can take the form of project meetings, in which learners can condense outstanding tasks into action points with set deadlines. The purpose of this approach is to take a mass of requirements and information and give it structure. This approach can of course be used on other assignment tasks, but this one, in particular, requires support. This is because of its scope and size, and the challenge of taking a blank sheet of paper and producing a final design.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 15: Electrical Machines*
- *Unit 16: Three Phase Electrical Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Websites

- www.edfenergy.com/energy/nuclear-new-build-projects
  EDF Energy information on nuclear new build projects.
- www.onr.org.uk/new-reactors/faq.htm#q3
  Generic Design Assessment information from the Office for Nuclear Regulation.
- www.bbc.co.uk/schools/gcsebitesize/science/add_ocr_gateway/radiation/fissionrev2.shtml
  How power stations work.
- www.nei.org/Knowledge-Center/How-Nuclear-Reactors-Work
  Nuclear Energy Institute information on how nuclear reactors work.
- www.namrc.co.uk/intelligence/uk-new-build-plans
  The Nuclear Advanced Manufacturing Research Centre
- www.energynetworks.org/electricity
  How the transmission grid works.
- www.energynetworks.org/modx/assets/files/electricity/engineering/engineering%20documents/G81/ENA_ER_G81_Part_1_Issue_2_Amendment_1_080109.pdf
  Local distribution design information.
- www.bbc.co.uk/search?q=Power+to+the+People
  Power to the People – a series of BBC documentaries about power generation and supply.

Unit 19: Electronic Devices and Circuits

Delivery guidance

Approaching the unit

In this unit, learners will explore the processes that are used by engineering organisations to develop both analogue and digital electronic circuits. They will investigate the various stages of designing, simulating, constructing and testing circuits using practical tasks. They will develop their understanding of how electronic components are used in a range of applications, from domestic home entertainment systems through to the control systems for nuclear power stations and aircraft.

There is an opportunity to develop links with appropriate local engineering organisations where learners could see how electronic systems are integrated into a very wide range of engineering products. This could also allow learners to experience safe working practices for circuit construction on an industrial scale.

In this unit, learners will also develop the skills necessary to simulate and construct a range of electronic circuits, considering how these circuits function and analysing results from tests.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could introduce learners to the working practices that will be required in order to work safely whilst carrying out both the construction and testing of electronic circuits. This could involve the use of simulations of emergency procedures that will need to be carried out in the event of an emergency situation. You should make sure that learners are aware of the location of isolators for both power and heat sources, along with the procedures for raising alarms or evacuation if necessary.

Once learners have a good understanding of safe working practices, they could be introduced to a range of analogue devices including diodes, transistors and operational amplifiers. You could approach this using a theoretical introduction to each type of component, followed by practical tasks where learners would gain experience of how each type of device operates within a circuit. At this stage, it would be appropriate to introduce learners to the conventions for representing electrical circuit drawing standards BS8888 and BS3939 so that they are able to correctly note the circuits that they construct.

Circuit construction could then be completed using a prototyping board or stripboard. In addition to constructing prototype circuits, you could give learners with the opportunity to simulate their circuits virtually in order to gain data that they can use for comparative purposes. Finally, you could introduce learners to the skills that they will require to carry out tests on physical analogue circuits, including the safe use of multimeters and other items of test equipment. Data collected from tests could then be compared to those obtained theoretically from simulations.

For learning aim B, you will introduce learners to the theory of logic gates, including the symbols used for the different types of logic gates. You will also develop learners' ability to produce circuit schematics for digital circuits and introduce them to the methods of testing that are used for physical digital circuits.

You could initially consider truth tables for the standard logic gates, and how Boolean algebra can be used to describe the outcomes of different types of logic gate based upon their inputs.

Once learners have an understanding of the different types of logic gates and how the operation of these gates can be represented using Boolean algebra, you should introduce learners to how Boolean algebra is applied to combinational logic circuits and methods which can be used to minimise combinational logic circuits. Learners should also be given the opportunity to construct prototype logic circuits using a suitable prototyping method. This can be followed by introducing learners to sequential logic circuits and the prototyping of circuits that employ bi-stable devices.

For learning aim C, you will encourage learners to reflect on their explorations of circuit construction, including methods in which they have represented their circuits using schematics, methods of simulations and testing of completed circuits.

You should encourage learners to reflect on their skills and experiences in each of the areas they have studied whilst completing the unit. This should include health and safety, the practical skills related to manufacturing circuits and their engineering skills in general. Learners need to consider the lessons that they have learnt throughout the process, and their performance whilst carrying out the various practical activities.

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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 circuit **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 learnt 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.

Assessment guidance

The assessment of this unit is most likely to be in the form of two assignments, one for learning aim A and a second for learning aim B. Evidence to support the award of criteria that address learning aim C will be drawn from the evidence contained within these two assignments. For learning aim A the evidence would normally be presented in the form of a written report containing schematic diagrams for circuits, calculations, results from simulations and tests along with comparisons of these results to those obtained from circuits that they have constructed. For learning aim B learners will present a further report that evaluates logic circuits, including reference to truth tables and schematic diagrams for sequential circuits. In both assignments, learners would be expected to demonstrate relevant behaviours and engineering skills to a professional standard whilst also providing a balanced review of practical activities.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 19: Electronic Devices and Circuits
Introduction This unit offers the opportunity for learners to gain the skills necessary to be able to simulate, construct, test and evaluate a range of transistor and diode based analogue circuits, along with digital circuits that feature sequential and combinational logic. There is significant opportunity for learners to carry out a range of practical activities that could be based on either stripboard or breadboard construction techniques. You will prepare learners for this by appropriate teaching and learning activities covering safe working practices along with the functions and applications of a range of discrete electronic components. This unit offers the opportunity for you to develop links with engineering organisations so that visits could take place, which could be used to emphasise safe working procedures along with how electronics is integrated into products produced by a range of engineering sectors. You should encourage learners to develop the skills required to carry out practical activities safely, and to then to reflect on the activities they have completed to identify lessons they have learnt and the processes they carried out in order to complete tasks within an appropriate time scale and safely.
Learning aim A – Explore the safe operation and applications of analogue devices and circuits that form the building blocks of commercial circuits
• Learning aim A initially gives the foundation of knowledge that is required for learners to be able to carry out practical electronics work safely. This should include methods to isolate power or heat supplies, reporting procedures to follow during emergencies and the importance of following instructions in such situations. • Once learners have a good understanding of emergency procedures, you should demonstrate to learners the methods of safe working during the construction and testing of electronic circuits. • Having gained the knowledge and understanding required to work safely during construction and testing of circuits, you should start to introduce learners to a range of analogue components that feature in a wide range of electronic applications. You should take a similar approach when introducing learners to each of the components, including diodes, transistors and operational amplifiers. For each type of component, you should allow learners to investigate the specific components which are named in the unit specification, and how each of these components functions within a circuit. Subsequently, for each, learners should be given the opportunity to investigate a number of different circuits that make use of the specific components. This could be approached using either a prototyping board or strip boards. The relevant skills to construct circuits using these methods will also need to be demonstrated to learners. • Whilst carrying out activities to construct circuits, learners will be developing their ability to work with others, as it is likely that there will be some paired work during the prototyping of circuits with resources being shared between learners. It would be beneficial to learners if they also had the opportunity to construct circuits using both prototyping board and strip board.

- Alongside the investigations into the functions and use of the analogue components, you should be equipping learners with the skills that they will need to be able to represent these circuits schematically. You should make sure that learners are able to produce circuit schematic diagrams that are to recognised standards such as BS3939.
- You could then introduce learners to methods for testing circuits, both physically and using simulations. This will include the use of equipment such as multimeters, oscilloscopes and other test equipment that learners will need to be instructed how to use safely. Learners should be taught a range of methods to take measurements, and then be introduced to the calculations which need to be carried out on these test results. This should include transistor current gain, circuit voltage gain and determining the cut off frequency for op-amp filters. These values could also be determined using simulations of circuits where measurements and data should be extracted from virtual test instrumentation.
- Once learners have developed the skills needed to be able to simulate, construct, test and analyse circuits safely, you should give them the opportunity to complete their first assessment. You should allow learners the opportunity to evaluate a range of circuits, including at least one diode, one transistor and one operational amplifier circuit. Learners should construct these circuits safely, testing the function of the circuit and comparing their results to those obtained through the use of simulation. Learners should be encouraged to produce a range of different types of evidence within their report, including circuit schematic diagrams, annotated photographs of circuits, tabulated results, calculations, screenshots and sketches. Further supporting evidence could be given in the form of witness statements or observation records.

Learning aim B – Explore the safe operation and applications of digital logic devices and circuits that form the building blocks of commercial circuits

- Learning aim B is designed to give learners an insight into how logic devices can be used within commercial electronic circuits, including how the use of Boolean algebra is used to indicate the outcomes that are produced by these devices.
- Initially, you should introduce learners to the six main types of logic gates that form the building blocks of logic circuits. For each of these, you should give learners the opportunity to develop their understanding of the relevant truth tables for each type of gate. They should also be able to apply the correct gate symbols when representing logic gates in schematic diagrams.
- Once learners have a good understanding of the six main types of logic gates, you should move on to considering the different types of logic family, including transistor-transistor logic (TTL) and complementary metal oxide semiconductor (CMOS) logic. For each, you should make sure that learners are aware of the characteristics of each logic family and have an understanding of their functions.
- With a good understanding of the types of logic gates that are used within digital circuits, learners then should have the opportunity to develop the skills required to apply Boolean algebra to combinational logic circuits. You should introduce learners to the rules of Boolean algebra. This should include the expressions for the sum of products along with the truth tables for Boolean expressions. You could then progress to explain to learners the methods that can be applied to minimise combinational logic gates, with reference to both Karnaugh maps and De Morgan's theorem.
- This knowledge should then be expanded upon by introducing learners to a range of sequential logic circuits, including flip-flops, counter circuits and shift registers. You should again ensure that learners have the opportunity to construct the aforementioned types of circuit using either prototyping board and/or strip board. The circuits themselves should make use of a range of bi-stable devices.

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- As with analogue devices, learners will need to be equipped with the skills necessary to be able to represent digital circuits using circuit schematic diagrams. Again, you should make sure that learners are able to produce these schematic diagrams to a recognised standard.
- Learners should again be taught how to use test equipment safely, including the safe use of logic probes and analysers. As with analogue circuits, you should also ensure that learners have the necessary skills to carry out simulations on digital circuits so that the logic states for inputs and outputs can be extracted. You should also give learners the opportunities to carry out calculations using Boolean algebra and truth tables.
- Following revision of each of the topics, and further practical tasks learners should complete their second assignment for the unit, which is targeted at learning aim B. You should give learners the opportunity to evaluate the operation of at least one combinational logic circuit and two sequential bidirectional logic circuits. Learners should construct these circuits safely, testing the function of the circuit and comparing their results to those obtained through the use of simulation. Learners should be encouraged to produce a range of different types of evidence within their report, including circuit schematic diagrams, annotated photographs of circuits, tabulated results, calculations, screenshots and sketches. Further supporting evidence could be given in the form of witness statements or observation records.

Learning aim C – Review the development of analogue and digital electronic circuits and reflect on own performance

- You could introduce learning aim C simultaneously with learning aims A and B as the nature of the learning aim is to develop the reflective skills of learners whilst they carry out a range of practical electronic activities. You should encourage learners to evaluate the skills that they have either gained or developed whilst carrying out the construction of electronic circuits, including those skills related to health and safety, development of circuits and any potential impact on the general engineering skills of the learners. It is important that learners are able to explain how they have been able to apply these skills whilst carrying out practical activities and can identify where they may need to develop these skills further.
- You should encourage learners to develop and improve appropriate behaviours when carrying out practical tasks. The time planning and management skills that they may have applied in other units could be applied to practical activities in this unit. You should encourage learners to consider the order in which activities will need to be carried out when solving problems that relate to either analogue or digital circuits. Furthermore, transferable skills such as those related to communication and literacy should be refined with reference to electronic devices. An awareness of the transferable nature of many of the skills used in this unit should be encouraged.
- It would be appropriate to allow learners the opportunity to carry out a number of practical activities as a part of the teaching and learning for the unit, which can then be evaluated by learners with reference to the previously identified skills, and also the engineering behaviours that they should be able to demonstrate whilst carrying out practical tasks.
- Evidence to address learning aim C could be partially generated via the assignments that cover learning aims A and B. The nature of the assignments should be such that there is opportunity for learners to reflect on the tasks that they have carried out. It is likely that some of the evidence will be found within the written reports that reflect on practical work. It may be appropriate for learners to use the heading 'lessons learnt' within the two reports. You should encourage learners to present their work with a balanced view, considering actions that they have taken in order to comply with the behaviours expected of an engineering professional.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Gibson J – *Electronic Logic Circuits* (Routledge, 2013) ISBN 9781136076695.
  Includes combinational and sequential logic, along with truth tables.
- Bird J – *Electronic Circuit Theory and Technology* (Routledge, 2010)
  ISBN 978-1136072697.
  Sections about diodes, transistors and Op Amps.

Websites

- www.allaboutcircuits.com
  Web-based resource that covers many analogue and digital components, along with Boolean algebra.
- www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
  Boolean logic and De Morgan's theorem.

Unit 20: Analogue Electronic Circuits

Delivery guidance

Approaching the unit

In this unit, learners investigate the relationship between theoretical, simulated and actual operation of single function analogue circuits. Although there is an apparent increasing focus on digital devices, the continued relevance of analogue electronics is ensured since the world we live in is analogue. For example, a few years ago, a mobile phone had one important analogue sensor: a microphone. Today's mobile phones feature cameras, accelerometers, touchscreen sensors, proximity sensors and more.

The learners will prototype circuits, building up the level of complexity as they develop, comparing the outcomes with those obtained from a software schematic capture and simulation package and semiconductor theory. The package needs to be sophisticated enough to provide analysis tools such as Bode plots. The prototyping system used should allow learners to make rapid changes to circuits and work reliably. Proprietary plug-in systems would be suitable.

Learners could benefit from working on the practical exercises in pairs, but it is important that they generate their own individual reports.

The skills developed in this unit are in high demand in a wide range of industries including aerospace, automotive, audio and video, wireless communications, industrial controls and factory automation, all of which employ analogue electronic engineers.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

It is important that you build on the behaviour of individual components covered in other units to develop knowledge of their application in single function circuits that can be used to form the building blocks of more complex systems. One of the main intentions of the unit is the need for technicians to build up a 'database' of knowledge of common components and the types of circuit in which they are used and to understand how that knowledge helps in the synthesis of new applications.

Learning aim A provides the underpinning knowledge of the features and functions of analogue circuits, which are divided, for convenience, into six categories. It also introduces the use of schematic capture and simulation software to investigate the predicted behaviour of each type of circuit. The learners will need access to circuit diagrams for working circuits that they can simulate and build for learning aim B. It is important that the chosen component values are available and that they give repeatable performance. Learners should be continuously reminded of the need to save evidence as they generate it.

Learning aims A and B are closely linked. They provide opportunities for the development of knowledge of components and their representation in circuit diagrams. Learners should be encouraged to compare the outcomes of simulation and practical investigation with theoretical behaviour, selecting appropriate test equipment and using it safely and accurately. You should consider using prototype circuits in kit form, which can be modified simply, without requiring a total rebuild, to maintain the pace of development. It would be logical to carry out the practical investigation of a circuit type in tandem with the theoretical and simulation investigations, rather than carry out simulations and circuit construction and testing in isolation.

Learning aim C allows the learners to demonstrate how they can apply the knowledge and skills developed to modify one of the circuit types investigated to meet a given specification. It assesses cognitive and problem-solving skills (using critical thinking, approaching non-routine problems by applying expert and creative solutions, using systems and technology). You will need to provide individual scenarios and sufficient resources to allow learners to meet all the requirements of the assessment criteria. You should encourage learners to collect evidence such as sketches, photographs, text, calculations and detailed observation records as they progress. It might help learners organise their evidence if you provide a standardised set of documentation to record findings.

Learning aim D involves self-reflection, which is an important attribute for professional engineers. It is an opportunity for learners to develop interpersonal skills (self-management, adaptability and resilience, self-monitoring and development). It is also enables learners to develop skills in précising information into a summary of what went well, what improvements could be made and what would be done differently next time.

Learning aim	Key content areas	Recommended assessment approach
A Investigate through research and simulation the operation of single function analogue electronic circuits	**A1** Applications and characteristics of single function analogue circuits **A2** Simulation of single function analogue electronic circuits	A developmental log supported by observational witness statements. The log should contain circuit diagrams, photographs, tables of results, sketches, screen shots, calculations and an evaluation of the physical and simulated circuits.
B Safely explore the operation of single function analogue electronic circuits that form the building blocks of commercial circuits	**B1** Construction of single function analogue electronic circuits **B2** Testing single function analogue electronic circuits **B3** Calculations for analogue circuits	
C Modify a single function analogue electronic circuit to meet given parameters, as widely undertaken in industry	**C1** Component selection **C2** Simulation of a modified analogue electronic circuit **C3** Construction and testing of a modified analogue electronic circuit	A developmental log detailing the design, construction and testing of prototype circuits. Evidence should include: calculations, component selection, schematic capture, simulation, circuit layout and construction plans, one or more observational witness statements and a formal assessment of the final permanently constructed circuit.
D Review the development of analogue electronic circuits and reflect on own performance	**D1** Lessons learned from exploring analogue electronic circuits **D2** Personal performance while exploring analogue electronic circuits	The evidence will focus on what went well and what did not go so well when exploring analogue electronic circuits, reviewing the processes and reflecting on own performance. Portfolios of learners' evidence generated while exploring analogue electronic circuits and when reviewing the processes and reflecting on own performance.

Assessment guidance

There should be no more than three summative assignments for this unit. This is a practical unit with learners investigating the relationship between theoretical, simulated and actual behaviour of analogue circuits. Learners should include evidence of simulations, for example screen shots, brief explanations of each purpose of each circuit, evidence of testing and brief explanations of how the circuits work. You could provide detailed observation records confirming the practical activities carried out. Learners should be guided to keep all of the evidence of one type of circuit (theory, simulation and measurements) together, so that they build up a database of information.

For learning aim C, learners can demonstrate the skills and knowledge developed in the unit by designing, constructing and testing a modification to one of the circuit types to meet a new specification. It is important that individual targets are set, and that the parameters given are achievable within an acceptable tolerance. Learners need to provide evidence of planning, implementation and testing of their modified designs. The evidence may include calculations, circuit diagrams, simulations, results of measurements and the modifications the learners made to more closely meet the design specification.

Learning aim D provides a vehicle for learners to reflect on technical lessons learned in terms of the operation of analogue circuits and their dependence on component values, as well as on their own performance and personal development in prioritising, planning and working to deadlines. Learners should identify areas of strength and those requiring further development. They should include suggestions for what they would do differently in future.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 20: Analogue Electronic Circuits

Introduction

You could introduce the unit by identifying the characteristics and applications of analogue devices and circuits. You could have a number of working circuits to demonstrate the different types of circuit and the types of measuring instrument.

Learners would benefit from early introduction to practical activities and the schematic capture and simulation package would be a good way to make a start into exploring circuit behaviour. This could be revision of skills developed in earlier units in preparation for extending learners' range of skills in this unit.

It is intended that learners should build up a working knowledge of the behaviour of each of the circuit types, and develop an appreciation of the value of simulation and the expected level of accuracy. They should then use this knowledge to modify one of the circuit types, by calculating component values to meet a given specification, simulating the circuit and building a prototype to measure the outcomes. The simulation and build can be iterative to achieve a result close to the design criteria.

Reflection is an important skill for engineers, and learners need to distinguish between what went well and what could be improved from the technical viewpoint They should also consider what transferrable skills have been developed as a result of carrying out the tasks.

Learning aim A – Investigate through research and simulation the operation of single function analogue electronic circuits

- Learning aim A requires you to introduce six types of circuit to the learners, including their configurations, functions and signals:
  - power supplies
  - passive filters
  - transistor amplifiers
  - operational amplifier applications
  - oscillators
  - communications applications.
- You could build up understanding of the way in which the components are used in each of the circuits through the use of schematic capture and simulation software to enable learners to:
  - identify component circuit symbols
  - build schematic diagrams using international drawing standards
  - use simulation techniques and virtual instrumentation to identify signals at key test points for each circuit type.
- Learners could record the results of their exploration of the circuit types by creating a portfolio (or logbook) that provides the background data to be explored practically for learning aim B. For each circuit investigated in learning aim A, learners could:
  - identify the function
  - include screen prints of circuit schematic diagrams
  - record signal values and characteristics taken at test points.

- You could summarise the information by leading a plenary session to collate the outcomes from the learner investigations and to identify and supplement any areas not sufficiently covered for learners to complete their report on their investigation.
- You could guide learners to organise their portfolios/logbooks so that they can add material at each stage, as they progress through the unit.

Learning aim B – Explore the operation of single function analogue electronic circuits safely that form the building blocks of commercial circuits

- For learning aim B, learners could use the knowledge gained when meeting the requirements for learning aim A to carry out a series of practical exercises to investigate each of the circuit types, This should allow the learners to demonstrate their ability to research actively and methodically.
- You may prefer learners to carry out practical investigations in small groups to make effective use of resources.
- You could introduce a variety of construction methods for learners to use, as appropriate to the circuit type. For example, the development of amplifier types might use a plug-in method, whereas communication applications could use prefabricated circuits. It is unlikely that all learners will work at the same rate, so you will need to monitor progress carefully, and have sufficient resources to allow them to proceed when ready, to retain their interest.
- Learners need to develop skills in selecting and using measurement equipment correctly and accurately, so it is important that they spend as much time as possible working practically.
- Learners could append their records for each circuit with:
  - notes on circuit operation
  - photographs of constructed circuits
  - measurements of signals at key points
  - calculations of theoretical values for the component values used, eg voltage gain of an inverting amplifier (development of analytical skills)
  - comparison of circuit performance through theoretical calculations and results from safely conducted tests and simulations.
- You could give each group of learners responsibility for presenting their findings for one of the circuit types, identifying the:
  - system function
  - theoretical operation
  - signals at key points
  - necessary calculations
  - comparison of theoretical, simulated and measured values.
- This would help in developing intrapersonal skills (communicating, working collaboratively, negotiating and influencing, self-presentation).
- You could summarise the information by leading a plenary session to collate the outcomes from the learner investigations and to identify and supplement any areas not sufficiently covered for learners to complete their report on their investigation.
- You could guide learners to organise their portfolios/logbooks so that they can add material at each stage, as they progress through the unit.

Learning aim C – Modify a single function analogue electronic circuit to meet given parameters as widely undertaken in industry
• Learners need to select components to modify one of the types of analogue circuit to meet a given client brief, provided by you. They should systematically simulate, test and fault-find it so that it operates as intended. The report should contain details of all stages of the process. • Suitable circuits for learners to develop could include a 555 timer oscillator of given frequency, a Wien bridge oscillator using an operational amplifier, a passive filter or a stereo amplifier for a mobile phone/mp3 player using a commercial integrated circuit. You could give each learner a different circuit type/client brief to avoid the potential of plagiarism. • Learners should: o plan a modification to one of the six types of analogue circuit to meet the client brief o confirm the operation of the modified circuit through schematic capture and simulation, construction and systematic testing o make further modifications to refine the operation of the circuit in relation to the client brief o produce a permanently constructed final circuit o record all stages of the development. • You could require learners to give a short demonstration of their developed circuit by comparing theoretical, simulated and measured values; this would help in developing intrapersonal skills (communicating, working collaboratively, negotiating and influencing, self-presentation). • You could guide learners to organise their portfolios/logbooks so that they can add material at each stage, as they progress through the unit.
Learning aim D – Review the development of analogue electronic circuits and reflect on own performance
• Learners need to review and reflect on the practical activity to investigate and explore analogue circuits by preparing a 'lessons learned' report. The report should explain how health and safety, electronic and general engineering skills were used to design, construct and test analogue circuits, including an explanation of the importance and use of appropriate behaviours (eg time management). • You could help the learners structure their reflections so that they: o review and reflect on the activities that have been completed and make notes about what went well, what improvements could be made and what would be done differently next time o analyse the notes they have made and differentiate between facts and opinions o produce a professional report. • In reflecting on their activity, learners should consider the transferable skills they have used, eg the ability to: o learn independently o research actively and methodically o give presentations and be active group members.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 5: A Specialist Engineering Project*
- *Unit 10: Computer-aided Design in Engineering*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 21: Electronic Measurement and Testing*
- *Unit 22: Electronic Printed Circuit Board Design and Manufacture*
- *Unit 23: Digital and Analogue Electronic Systems.*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Floyd TL and Buchla DL – *Electronics Fundamentals: Circuits, Devices and Applications*, *8th edition* (Pearson, 2013) ISBN 9781292025681.
  This is an in-depth text with good illustrations. This text will remain relevant for further study.
- Storey N – *Electronics: A Systems Approach*, *5th edition* (Pearson, 2013) ISBN 9780273773276.
  This is the updated edition of a long-standing text, which takes a systems rather than a component focus.

Journals

- *Everyday Practical Electronics* (Wimborne Publishing Ltd)
  This is the number one magazine in the UK for hobby electronics enthusiasts. As well as practical constructional projects, each issue contains advice, special features and adverts from specialist electronics suppliers.

Websites

- www.electronics-tutorials.ws
  Basic Electronics Tutorials for beginners and beyond, Basic Electronics Tutorials Site by Wayne Storr. This contains well-presented information covering a wide range of electronic subjects.

Unit 21: Electronic Measurement and Testing of Circuits

Delivery guidance

Approaching the unit

In this unit learners will investigate the equipment that is used by engineering organisations in the testing of both analogue and digital electronic circuits, including discrete and integrated circuit components. Learners will gain an understanding of how testing equipment is used to fault-find, and become familiar with the procedures that should be followed when identifying faults in electronic circuits.

They will gain an understanding of the skills that are needed to diagnose faults, including the production of a test plan that they will implement through measurement and testing of circuits to diagnose faults. Learners will reflect on their own performance when carrying out fault-finding activities, considering their own personal performance and also the lessons they have learnt.

Learners will also develop the safe working practices and skills in fault-finding that they could apply in a range of sectors where electronic devices feature in either the manufacture or operation of plant and equipment. They will recognise the importance of accurate reporting and record keeping, understanding that such skills are transferable to a wide range of engineering activities.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could begin by introducing learners to the range of measurement devices that they will encounter during the practical activities associated with this unit. You could use either demonstrations or small group practical tasks to introduce the operational functions of multimeters and the procedures that should be followed in order to determine values for a range of quantities such as current, voltage and resistance. You could then discuss with learners the methods that should be employed to read accurate measurements from analogue meters to avoid inaccuracies caused by parallax.

Once learners are secure in their understanding and application of multimeters, you should progress onto more complex pieces of equipment including oscilloscopes and spectrum analysers. For both of these, you should make use of practical activities wherever possible so that learners are able to gain first-hand experience of the equipment. In addition, they should be able to explain the features of an oscilloscope that are used whilst performing fault-finding activities. Similarly, you should give learners the opportunity to become familiar with using the digital test devices that they will use when fault-finding digital circuits. This will include both logic probes and logic analysers.

Once learners have an understanding of how logic probes are used, they should develop their knowledge of the points at which logic states change, and the responses a probe would give when between the two states.

In learning aim B you will begin to prepare learners for practical fault-finding activities by introducing learners to the tests that they should carry out on electronic circuits. You should introduce learners to the procedures of carrying out visual inspections. This could be approached by giving learners a range of different circuits that have faults which could be identified visually. You could then follow this by considering input-to-output tests and the half-split technique. As with visual inspections, it would be beneficial for learners to be given the opportunity to practise these techniques using circuits where the diagnosis of faults will vary in complexity. Once learners are competent with these techniques, you could progress onto systematic diagnostic techniques including circuit substitution and symptom-to-cause methods of fault-finding. Finally, you should introduce learners to a top-down technique for diagnosing faults in complex electronic systems. With each of these methods, learners should be given sufficient practical opportunities so as to be able to hone the skills necessary to arrive at an accurate diagnosis of faults within circuits.

Once equipped with the skills necessary to identify a range of faults within electronic circuits, you should consider with learners the resources that they will need to be able to plan tests, including the diagrams, datasheets and charts that relate to specific circuits. You could discuss with learners the location within a circuit where they will take measurements, and the readings they would expect to be given at these points should a circuit be functioning correctly. You should then explain to learners how they should make use of resources and expected readings in preparing a test schedule.

You could lead learners through procedures for reporting faults, including appropriate documentation onto which they should be able to record details of the fault and methods by which the problem could be rectified. As with the testing methods, it would be appropriate for learners to gain hands-on experience of completing documentation whilst they are carrying out fault-finding activities in preparation for their assessments.

Learning aim C will draw together learners' theoretical understanding of a range of test equipment along with the procedures for fault-finding. You could initially consider safe working practices that must be observed when fault-finding electronic circuits in a workshop environment. You should refer back to learning aim A where learners were introduced to a range of test equipment, refreshing learners' understanding of how to use the aforementioned equipment safely. Once learners have been equipped with the knowledge and skills to work safely, you could explain the importance of measuring signal conditions from circuits that do not have faults in order to make comparisons with circuits where there are faults to be identified. You could then give learners an opportunity to carry out fault-finding activities on circuits during which they should follow their fault-finding plan in order to identify faults.

Finally, learning aim D should give learners an opportunity to reflect on their performance when measuring and testing electronic circuits. You should encourage learners to view their performance critically. You could initially give learners a framework around which they could build their self-evaluation but as learners progress through tasks and develop their evaluative skills they should be encouraged to review the lessons they have learned more independently.

Learners should also review the skills that they developed whilst testing electronic circuits. You should encourage learners to consider a range of personal traits including time planning, communication and problem-solving. Learners could be given an opportunity to carry out reviews of each of the tasks completed whilst developing their skills in testing circuits.

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits</td><td>A1 Operational features of measurement devices
A2 Operational features of test devices</td><td>A written report exploring the operational features of typical measurement and testing devices. Learners will explore the measurement and test devices in the laboratory and through research.</td></tr>
<tr><td>B Explore fault finding techniques and test plans used when measuring and testing electronic circuits</td><td>B1 Fault finding techniques
B2 Preparation for testing and test plans</td><td rowspan="2">A test plan to analyse each electronic circuit, detailing the fault finding techniques to be used and preparation tasks to be undertaken. It will also explain the rationale behind the application of different techniques.
A logbook and fault finding record for the circuits, detailing tests undertaken, symptoms and final identification of the faulty components in analogue and digital circuits. One or more observational witness statements.</td></tr>
<tr><td>C Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely</td><td>C1 Safe working practice
C2 Practical fault finding on analogue and digital circuits</td></tr>
<tr><td>D Review the measurement and testing of electronic circuits and reflect on own performance</td><td>D1 Lessons learned from measuring and testing electronic circuits
D2 Personal performance while measuring and testing electronic circuits</td><td>Evidence will focus on what went well and what did not go so well when testing and measuring electronic circuits, reviewing the processes and reflecting on own performance.
A portfolio of evidence generated while measuring and testing electronic circuits and reviewing the processes and reflecting on own performance.</td></tr>
</table>

Assessment guidance

The assessment of this unit is most likely to be in the form of three assignments, one for learning aim A, the second for learning aims B and C and a final assignment for learning aim D. For the first assignment the evidence would normally be presented in the form of a written report that explores a range of typical measurement and test devices. This report should be based around practical experience of using test equipment along with research tasks. For assignment 2, learners will produce test plans to fault-find two analogue and two digital circuits and each plan should have no more than four stages. Learners will then implement their plans, recording their actions in both logbooks and fault-finding records. Assignment 3 will evaluate the measuring and testing activities that they carry out, considering what went well and where they need to develop their skills.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 21: Electronic Measurement and Testing Circuits

Introduction

This unit offers the opportunity for learners to develop a range of skills that will enable them to carry out fault-finding activities on both analogue and digital circuits. They should be given the opportunity to develop these skills through practical investigations, improving their understanding of how equipment operates and how to use it safely. Learners will gain skills that are transferable to similar activities, including the ability to maintain accurate records of activities, and analytical skills that will improve their cognitive and problem-solving abilities. Learners should also be given the opportunity to recognise the strengths and weaknesses of their own skill set, with a view to improving their interpersonal skills such as self-management.

Learning aim A – Explore the operational features of common electronic test devices used to measure and test signals in electronic circuits

- Learning aim A gives learners the background for carrying out fault-finding activities on both analogue and digital electronic circuits. You should introduce learners to at least six different devices that are used for measuring or testing electronic circuits. You could approach this by giving learners sufficient background knowledge to be able to understand the function and purpose of devices. It would be beneficial for learners to gain practical experience of using these devices to take measurements from circuits that are without faults. This would give learners an insight into the accuracy of each piece of equipment so that they could carry out comparisons between them.
- You should give learners the opportunity to either use or research measurement devices, including digital and analogue multimeters, a dual beam oscilloscope and a logic probe, and two test devices. These could be a stabilised power supply and a signal generator. For each, you should ensure that learners are able to identify an appropriate application. This could be through group activities where they could develop their interpersonal skills either by using equipment or by researching applications using suitable resources. You could discuss with learners the relative merits of analogue and digital measurement devices, making reference to both accuracy and ease of use.
- Once learners have demonstrated that they have a good working knowledge of test and measurement devices, and that they are able to evaluate the suitability of each piece of equipment, learners should work on their first assessment. This will require them to evaluate the features of test equipment and how effective each piece of equipment is when taking measurements from either analogue or digital circuits. Learners should present their work in the form of a report that is both logical and technically accurate.

Learning aim B – Explore fault finding techniques and test plans used when measuring and testing electronic circuits

- Learning aim B gives learners the knowledge and understanding of fault-finding techniques that they will need in order to be able to plan and then carry out fault-finding activities on a range of analogue or digital circuits. This could be approached through a range of demonstrations and practical tasks that would allow learners to initially gain an understanding of the procedures that should be followed, and then an opportunity to apply this knowledge when identifying faults in circuits. At all times you should ensure learners are aware of the safe working practices that should be observed throughout.

- Learners should understand that there are a range of different fault-finding techniques that could be used when identifying faults, and that generally it is good practice to carry these out in a specific order.
- You could first consider the visual inspection of circuits, highlighting to learners common faults that they are likely to encounter, such as components in the incorrect place, or examples of badly soldered joints, short circuits or overheating of components. Learners could then work collaboratively to apply these skills to identify faults in given circuits which could include incorrect components, incorrect orientation of components or bridging of tracks.
- This could then be followed by introducing learners to further diagnostic activities, including the input-to-output and output-to-input technique, the half-split technique and circuit substitution technique. In each case, you could follow a similar approach to that for visual inspections, with demonstrations being followed by either individual or group diagnostic activities. You could give learners faults of varying complexity so that they can develop a deeper understanding of the processes involved with pre-built analogue and digital circuits with switched faults, eg fixed voltage regulated DC power supply, 2-stage class A amplifier with test points accessible, single stage active filter, position controller (servo), a combinational logic circuit such as a 4-bit adder or decision making circuit, a sequential logic circuit such as a traffic light circuit or ripple-counter.
- At this stage, it would be appropriate to introduce learners to methods of recording faults and how they have been rectified. You should introduce learners to standardised fault-finding record sheets that will include information relating to the devices under test, initial symptoms, test devices used (including serial numbers or other identification for traceability), tests carried out, observations and conclusions and the identification of the root cause of the problem.
- You should emphasise to learners the importance of accuracy in such record-keeping as technicians often use a technique known as symptom-to-cause where historic test data is used to identify potential faults. You could give learners an exercise where they could develop their problem-solving skills by interpreting data to identify likely causes of circuit failure.
- To conclude you could introduce the top-down technique that is used for more complex electronic systems, similar to those that learners are most likely to encounter within a work environment. This technique will often draw together aspects of the previously covered diagnostic methods in order to find the subsystem and then the component that is the root cause of the fault.
- Once learners have a good understanding of fault-finding techniques, and the practical skills to apply them successfully, you should introduce learners to the procedures that they should follow when producing a test plan for a given circuit.
- You should consider the range of fault-finding aids that learners are likely to use whilst identifying faults. There is an opportunity for learners to carry out some independent study to gain a deeper understanding of the information that each document is likely to contain and how this can assist in planning activities.
- You should review the various pieces of test equipment that learners are likely to use, and discuss with learners where readings and measurements should be taken on both analogue and digital circuits. You could then demonstrate to learners how to synthesise this information in order to create a test schedule. This could then give a framework that learners can use as a basis for the production of their own test plans, initially relating to circuits that they have already inspected, and then for further and potentially more complex circuits and systems.

- To complete the learning aim, you could then introduce learners to a range of methods used in the reporting of faults and potential solutions to the problem. It would be appropriate to consider the use of standardised forms where learners could complete information themselves.

Learning aim C – Carry out measurements and tests on analogue and digital electronic circuits to identify faults safely

- Learning aim C is most likely to be addressed in a workshop environment, where there will be significant numbers of practical tasks being carried out. You should first review safe methods of working with learners, in particular safety rules and the behaviours that are expected when using devices safely. You could approach this through either demonstrations or practical investigations, including methods for interpreting risk assessments and then identifying control measures that need to be applied.
- You should emphasise the importance of working safely whilst learners follow fault-finding plans. Initially, you could give learners appropriate test plans that include a number of different stages and testing methods. As learners grow in confidence, they should begin to show an understanding of how to select the most appropriate approach for each fault diagnosis problem that they are presented with.
- You should give learners an opportunity to plan and carry out testing activities on both analogue and digital circuits. Whilst carrying out these tests, learners should be encouraged to record their actions using standardised documentation. You could at this stage reinforce the need for learners to record measurements from both measuring devices and logic probes and stress that these readings should be used in conjunction with predicted values when systematically tracing faults in circuits or systems. As learners increase in confidence and accuracy with testing activities, you could give them circuits that become increasingly complex. This would give them appropriate experience in readiness for the assessment of learning aims B and C.
- With a good understanding of safe working practices and effective methods of carrying out fault-finding tasks on both analogue and digital circuits, learners would be suitably equipped to complete their second assignment.
- Learners should produce a report and logbook in which they produce fault-finding plans for two analogue and two digital circuits. Learners should attempt to optimise these plans based on their prior experiences of testing similar types of circuit. They should produce suitably detailed plans that justify their choices of test procedure whilst also comparing the testing techniques. On completion of planning, learners should work safely and effectively to correctly identify faults in two analogue circuits and two digital circuits, one of which should be a combinational logic circuit, whilst the other should be a sequential logic circuit. Learners should record in full the results of their tests, suggesting appropriate solutions in order to resolve faults.

Learning aim D - Review the measurement and testing of electronic circuits and reflect on own performance

- Many of the activities associated with learning aim D will be carried out at the same time as those for learning aims B and C due to the reflective nature of the learning aim. You will need to make sure that learners have the interpersonal skills needed to be able to consider the lessons that they have learned during activities, whether these relate to safe working practices, or to the actual measurement of values and testing circuits. To achieve this, it would initially be appropriate to give learners frameworks for carrying out their reflection, however you should encourage learners to reflect on their experiences at the earliest opportunity as this is most likely to result in them identifying those skills where development may be needed. You should encourage learners to evaluate their own performance whilst carrying out tasks, and record their thoughts in their logbook.

- You should highlight to learners the importance of reviewing their personal performance while measuring and testing electronic circuits. In particular, you should relate this to the development of their interpersonal skills including self-management. Learners should be encouraged to be critical of their own performances, identifying those aspects of the measurement and testing processes that they could improve.
- The work submitted by learners to address learning aims B and C should give sufficient evidence of the engineering skills that learners have applied. These skills should be demonstrated to a professional standard, and present a balanced view on the actions taken by learners during fault-finding activities.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 16: Three Phase Electrical Systems*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 20: Analogue Electronic Circuits*
- *Unit 23: Digital and Analogue Electronic Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Morris J – *Digital Electronics* (Routledge, 1992) ISBN 9780415502894.
  Digital fault-finding is covered in detail in chapter 7.
- Pain R – *Practical Electronic Fault Finding and Troubleshooting* (Newnes, 1996) ISBN 9780750624619.
  Introduction to fault-finding methods using multimeters and an oscilloscope.
- Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006) ISBN 9780750669238.
  Safe working practices, fault-finding.

Videos

- www.youtube.com/watch?v=LClnIbUTZXY
  Safe use of multimeters; similar videos available for taking voltage and current measurements.
- www.youtube.com/embed/2nQ_pqbb1Tg
  First of a series of 5 videos showing methods of fault-finding.

Websites

- www.allaboutcircuits.com
  Troubleshooting and fault-finding techniques.
- www.circuitstoday.com/category/testing-components
  Techniques for testing circuit features at a component level.

Unit 22: Electronic Printed Circuit Board Design and Manufacture

Delivery guidance

Approaching the unit

In this unit, learners will investigate the industrial processes and procedures that are associated with the design and manufacture of electronic products and more specifically sustainable printed circuit boards (PCBs). Learners will develop their understanding of the function of PCBs as not only a method of connecting components together, but also the potential for integrated user-interfaces to be included on the PCB.

They will gain an understanding of the different types of PCB that can be used in electronic devices, including through hole, surface mount and flexible PCBs. Learners should become familiar with the typical applications of different types of PCB and the reasons why specific types of PCB are more appropriate for certain applications. Learners will also develop the skills necessary to represent both AC and DC circuits using suitable computer-based software packages that should also be used to simulate the function of such circuits.

With the skills necessary for the design and manufacture of PCBs having been gained, learners should then develop their ability to interpret circuit schematic diagrams so that designs for PCBs can be produced. Learners will develop the safe working practices and skills in fault finding which they could apply in a range of sectors whilst producing their own single-sided PCBs.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could begin by introducing learners to the basic principles of printed circuit boards before giving them research activities to explore typical applications of PCBs, including the technologies and characteristics of the PCBs associated with each application. You could approach this in a number of ways, although there is potential to carry out some disassembly activities with learners working in either pairs or small groups to disassemble a range of small electronic devices in order to extract the PCBs and then describe their features. Groups could then feed back to the class, giving learners background knowledge that relates to a range of applications and PCB characteristics.

Following on from exploring applications of PCBs you should consider in detail the different types of PCB that are employed in industrial applications. You should ensure that learners are familiar with the technologies associated with the range of PCB types listed within topic A1. Where possible, learners would benefit from hands-on experience of each type of PCB. This would then allow learners to evaluate design features critically and objectively as they progress through to the assignment related to learning aim A.

You should then consider with learners the characteristics of the different PCB technologies that they have investigated, considering factors such as the materials used, density of components and the ability to rework PCBs as may be appropriate. There is an opportunity to link several aspects of the subject content together when considering PCB manufacturing techniques, as the application of the circuit will influence the amount of heat generated whilst in use and subsequently the approach taken to dissipate heat.

This could be followed by introducing learners to the stages involved in the mass manufacture of PCBs, including those stages where there could be alternative methods employed, for example in producing artwork. Learners should be introduced to relevant standards that apply to the manufacture of PCBs, including those set by the Institute for Printed Circuits. You could consider sustainability issues related to PCB production at this stage, or as a discrete topic after quality control. Whichever approach is taken, you should consider the environmental considerations not only of the materials and processes, but also of the end product during its lifecycle.

Finally, you should consider quality control methods that are applied to the manufacturing of PCBs. You should consider techniques used for batch production and mass production and also those employed for one-off and small batch production. At the smaller scales, it would be appropriate to apply practical inspection methods to physical PCBs and completed circuits. This allows learners the opportunity to gain the hands-on experience that will be required when completing their assignments.

In learning aim B you will begin to prepare learners for producing their own PCBs by developing the skills necessary to firstly capture schematic circuit diagrams using software packages and then to simulate the function of both AC and DC circuits prior to the actual physical manufacture of circuits.

You could approach this learning aim by making reference to tasks carried out in other units, for example in *Unit 2: Delivery of Engineering Processes Safely as a Team* or *Unit 10: Computer Aided Design in Engineering* where computer-aided design packages have been used for the production of circuit diagrams. You should make sure that learners have the opportunity to develop the skills necessary to produce circuit diagrams that meet relevant drawing standards and represent both AC and DC circuits, either separately or in one more complex drawing. You should encourage learners to make sure that they represent components with sufficient detail to allow for a circuit to be constructed with accuracy.

Upon completion of the production of schematic diagrams, you should introduce learners to the methods and theories relating to simulation of AC and DC circuits using a range of software simulation packages. You could initially introduce learners to the methods that they should employ for simulating circuits through the use of relatively simple circuits, progressively increasing complexity. You should give learners the opportunity to develop the skills necessary to extract data and measurements from the software in order to verify correct circuit operation.

Learning aim C will develop learners' theoretical understanding of circuit design in order for them to develop the skills necessary to produce their own designs for single-sided PCBs. You could initially review the methods for capturing circuit schematics before introducing learners to the various factors that need to be considered when designing a printed circuit board. You could approach this using some relatively simple circuits with only a limited number of components in the first instance. This could allow learners to gain an understanding of the requirements that different types of component have when being fitted onto a PCB. You could then move on to consider aspects such as tracks and pads, considering their sizes and the spacing required for insulation.

You could consider the practical manufacturing of PCBs. You should initially explore hazardous materials that are encountered during the production of PCBs, including refering to the handling of materials and related regulations. You should make sure that learners know about the safe working practices that must be observed when producing PCBs in a workshop environment. Learners could then be guided through the process of carrying out a risk assessment for the production of a single-sided PCB. Once learners have been equipped with the knowledge and skills to manufacture a single-sided PCB safely, they should be given the opportunity to produce their own PCBs for a given circuit which they will then populate with appropriate passive, active and mechanical components.

Finally, learning aim D should give learners an opportunity to reflect on their performance when designing and manufacturing a single-sided PCB. You should encourage learners to view their performance critically. You could initially give learners a framework around which they could build their self evaluation but as learners progress through tasks and develop their evaluation skills, they should be encouraged to review the lessons that they have learned more independently.

Learners should also review the skills that they developed whilst manufacturing PCBs. You should encourage learners to consider a range of personal traits including time planning, communication and problem-solving. Learners could be given an opportunity to carry out reviews of each of the tasks completed whilst developing their skills in manufacturing PCBs.

Learning aim	Key content areas	Recommended assessment approach
A Examine the design and manufacture of printed circuit boards that are widely used in industry	**A1** PCB types, technologies and applications **A2** Characteristics of printed circuit boards **A3** Heat gain and thermal management **A4** Manufacturing processes **A5** Quality control methods **A6** Sustainability and environmental considerations	A written report or formal presentation detailing the PCB technology, characteristics and thermal management techniques employed in electronic products, including a description of the relevant manufacturing processes and quality control methods.
B Explore how computer software is used for schematic capture and simulation of an electronic circuit	**B1** Schematic capture **B2** Circuit simulation	Evidence of computer based activities capturing and simulating direct current (DC) and alternating current (AC) circuits, or a complex circuit containing DC and AC elements; witness statements accompanied by annotated screen shots, print outs and data generated.
C Develop safely a printed circuit board to solve an engineering problem	**C1** PCB design **C2** Health and safety requirements when manufacturing a PCB **C3** Risk assessment **C4** Manufacture of a single-sided PCB	A reflective developmental log detailing the design, manufacture and testing process undertaken. This should be accompanied by one or more observational witness statements, photographic evidence, a formal assessment of the final circuit board and relevant behaviours applied. The portfolio of evidence learners' generate while developing a printed circuit board and reviewing the processes and reflecting on own performance.
D Review the development of the printed circuit board and reflect on own performance	**D1** Lessons learned from developing a PCB **D2** Personal performance while developing a PCB	

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Assessment guidance

The assessment of this unit is most likely to be in the form of three assignments, one for learning aim A, the second for learning aim B and finally a third assignment to address learning aims C and D. For the first assignment, the evidence would normally be presented in the form of a written report or a presentation that evaluates two significantly different types of electronic products, including the manufacture of printed circuit boards, quality control methods and potential further developments for the products. For assignment 2, learners will produce a range of evidence, including screen dumps, witness statements and associated printouts for both AC and DC circuits along with simulations of the circuits to confirm the operation of each. The third assignment, which addresses learning aims C and D, should be a project log for a design and manufacture activity to produce a PCB from a given circuit schematic. Learners are expected to present a range of appropriate evidence that should include annotated photographs, risk assessments and quality control documentation along with design documents. Learner Observation Records and Witness Statements should be used to support the assessment of practical activities.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 22: Electronic Printed Circuit Board Design and Manufacture

Introduction

This unit offers the opportunity for learners to develop a range of practical electronic circuit design and manufacturing skills that will enable them to represent both AC and DC electronic circuits schematically and then produce their own single-sided printed circuit boards. They should be given the opportunity to develop these skills through practical investigations and making activities, improving their understanding of how to produce their own PCBs safely.

Learners will gain skills that relate to safe working practices and the production of risk assessments that are transferable to other practical activities. They will also build upon experiences from other units through the use of computer-aided design packages to produce circuit schematic diagrams. Learners should be given the opportunity to recognise the strengths and weaknesses of their own skill-set with a view to improving their interpersonal skills such as self-management.

Learning aim A – Examine the design and manufacture of printed circuit boards that are widely used in industry

- Learning aim A gives learners the background knowledge that they will need to be able to design and manufacture their own single-sided PCBs. You could initially introduce learners to the different types of PCB in order to give them a foundation upon which they can build whilst carrying out investigations into small electronic devices to determine the features and characteristics of the PCBs around which they are based.
- You could then give learners a collaborative learning experience that would involve either pairs or small groups of learners disassembling an electronic product to identify the nature of the PCB contained within. The activity should be designed to allow learners to gain knowledge of the various types of PCB such as through hole, surface mount and mixed-technology boards. There should also be opportunity for learners to investigate the various different types of substrate that are used for PCBs. Where it is not possible for learners to be able to gain first hand experience of each of the different types and variations of PCB construction, you should give learners a supplementary research activity to investigate these additional types of PCB.
- You could then further expand upon learners' understanding of the various types of PCB by considering in detail the characteristics of different types of PCB technology. You could again approach this through the use of practical investigations, with learners examining given PCBs to identify, and subsequently justify, characteristics of the circuit boards such as density of components, size and shape of the PCB, the materials used for the substrate along with methods which are employed for connectivity between boards and external components and how the PCB has been designed for ease of mass manufacture. You could give learners a framework upon which to initially base the results of their investigations, with more complex circuit boards and applications being introduced as learners' depth of knowledge and understanding is increased.
- There is then an opportunity to consider with learners some of the factors which can affect the performance of a circuit board, in particular the consequences of excessive heat, or thermal cycling. You should first consider the causes of heat generation with regards to PCBs. This could be approached through the use of individual research tasks which would develop learners' interpersonal skills in self-

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management. Learners could also research the effects of excessive heat gain, or thermal cycling. The results of these investigations could then be shared with other members of the class in the form of a presentation.

- You could then present methods in which thermal management can be employed to reduce the consequences of heat gain to learners. For example, you could initially focus on methods such as heat sinks and the use of these for dissipating heat from processors on computer motherboards. This could be followed by a brief discussion of other methods of dissipating heat prior to setting learners a collaborative activity to explore these methods, considering both applications and the ways in which they manage heat dissipation. This could lead into further discussions about how to arrange components on the PCB in order to improve the heat efficiency of the board or by considering the nature of the enclosure for the board. To complete the consideration of thermal management, learners could be tasked with an activity to research thermal rating conventions and then find typical values for simple heat dissipation devices.
- This could be followed by an examination of the construction methods that are employed during the mass manufacture of PCBs. It may be appropriate to consider aspects of topics A5 and A6 where these relate directly to aspects of topic A4. It would be appropriate to demonstrate the mass manufacturing of PCBs through a visit to an appropriate engineering organisation, where some of the placement and soldering techniques may be observed. Otherwise, an external speaker who has experience of industrial manufacture of PCBs could be invited to speak to learners using appropriate audio-visual resources. Learners should explore the various different approaches that can be taken at each stage of the manufacturing process, producing a presentation or research report to examine the processes thoroughly. At each of the relevant stages of the process, learners should consider the quality control checks that are put in place and also any sustainability and environmental considerations that apply at each stage. This should include consideration of hazardous materials in addition to the materials and consumables used during PCB manufacture and population.
- Finally, you should consider the quality control methods that are applied to the mass manufacturing of PCBs in fuller detail. Again, there is opportunity for you to make effective use of any industry partners who it may be possible to visit, or from whom a speaker could be invited. Learners should have a good understanding of the differences between the quality control methods that are employed for large scale manufacture and those for smaller scale production, which they will themselves employ in their own PCB manufacture. Any further sustainability related issues could also be considered at this point, either through the use of class discussion and demonstration, or through learner investigations.
- Learners should be given the opportunity to complete their first assessment to address learning aim A. You should give learners an assessment instrument that allows them the opportunity to investigate and evaluate at least two printed circuit boards that will cover a range of factors including the complexity of the circuit, construction methods and physical factors. The selection of products should be such that there is opportunity for learners to consider the potential changes which may be made to the products and the impact which this could have on the design of the PCBs.

Learning aim B – Explore how computer software is used for schematic capture and simulation of an electronic circuit

- To address learning aim B you could first review the activities that learners have carried out when working through *Unit 2: Delivery of Engineering Processes Safely as a Team*, *Unit 10: Computer Aided Design in Engineering* and/or *Unit 19: Electronic Devices and Circuits* where they will have gained some experience of producing schematic diagrams for electronic circuits. You could then introduce a number of exercises where learners could reproduce given circuits, developing the complexity of circuits as learners develop their skills. You should give learners the opportunity to select components that are appropriate, along with the suitable values and device models.

- You could then make further independent tasks where learners will develop the skills to represent circuit network connections such as those found in modular systems available. You should give learners the opportunity to develop their computer-aided drafting skills to be able to produce drawings that meet the standards of either BS8888 or BS3939 depending on the application. This will give learners transferrable skills that can be used in other areas of CAD work. Learners should also be given the opportunity to enhance their self management skills whilst producing drawings within given timescales.
- Learners should be given the opportunity to produce schematics for both AC and DC circuits and, where appropriate, circuits that involve a combination of both. Where this is the case, they should be able to represent connections and crossovers to recognised standards.
- You should then give learners a selection of AC and DC circuits that they can simulate using software packages. You could demonstrate this to learners in the first instance, explaining how to use the packages to confirm that a circuit is operating as expected and then how to extract data and measurements from the simulation software.
- Once learners have the skills necessary to accurately capture circuit schematics for both AC and DC circuits, and subsequently simulate circuits to confirm the operation of circuits, learners should be given their second assignment to address learning aim B. You should give learners DC and AC circuits, or a complex circuit that combines features of each, from which they are to independently produce their circuit schematics and then carry out simulation activities to confirm the operation of the circuits.

Learning aim C – Develop safely a printed circuit board to solve an engineering problem

- Learning aim C is most likely to be addressed through a combination of theoretical and practical tasks that would take place in a workshop environment, where the construction of PCBs will take place.
- You could begin by reviewing how circuit schematics are captured and how circuit function is simulated using software. This would then offer a starting point from which you could introduce the factors that influence the design of PCBs. You could give learners an exploratory task in which they could investigate a number of PCBs to identify features such as the layout and width of tracks, pads for attaching components and how components are arranged on the PCB. This could be achieved through a further disassembly task, where learners will not only consider the PCB but also the casing in which it is contained. Initially, learners could investigate products such as remote controls for TVs or hand-held electronic toys. Circuits should be selected to allow learners to identify a range of the factors that influence designs of PCB.
- You could then set learners a task to carry out research to investigate the details of PCB design, encouraging them to consider a range of different approaches which can be taken both in the routing of tracks and placement of components along with methods of mounting PCBs into casings.
- This could be followed by a group activity to design a PCB for a circuit that contains only a limited number of components, possibly a sensor circuit. Learners can work through the process of designing a PCB, including the generation of artwork, materials lists and other related documentation.

- You could then consider the practical manufacturing of PCBs. You should initially explore hazardous materials that are encountered during the production of PCBs, including reference to the handling of materials and related regulations. You should make sure that learners have the knowledge of safe working practices that must be observed when producing PCBs in a workshop environment. Learners could then be guided through the process of carrying out a risk assessment for the production of a single-sided PCB. Once learners have been equipped with the knowledge and skills to manufacture a single-sided PCB safely, they should be given the opportunity to produce their own PCBs for a given circuit, which they will then populate with appropriate passive, active and mechanical components.
- You should introduce learners to the processes involved in the physical manufacture of PCBs. You should emphasise the importance of working safely whilst learners produce their PCBs. Learners should be guided through the procedures for carrying out risk assessments. Such knowledge and understanding will be transferable to other units of the qualification, and will include skills that learners can build upon as they either continue their studies or begin work in an engineering setting. Learners should be given the opportunity to produce their own risk assessments for the production of PCBs. You could give learners a template to complete their risk assessments, with learners being encouraged to make reference to regulations and HSE guidance in their assessments.
- With a good understanding of safe working practices and the processes for manufacturing a printed circuit board, learners could manufacture the PCB that they have previously designed. This could be completed in small groups, developing learners' interpersonal skills and their ability to work as a member of a team. Learners should gain the skills necessary to firstly produce the PCB, including associated quality control checks. Once manufactured, the PCB should be populated, with learners selecting the appropriate components, preparing them and then soldering them safely onto the PCB.
- With learners then competent with the procedures to be followed to design and manufacture PCBs, they should complete their third assignment that addresses learning aims C and D. Learners should be given a circuit schematic diagram from which they are to design and manufacture a single-sided PCB. The task should be designed so that learners will follow the processes for producing a one-off PCB, including simulation of the circuit, designing and manufacturing the PCB and the subsequent assembly and testing of the completed circuit. Learners should keep a log to record the activities they have carried out, which will include all production documentation including design work, manufacturing documentation, risk assessments, quality control plan and results. This is likely to be supported by observational witness statements and photographic evidence.

Learning aim D - Review the development of the printed circuit board and reflect on own performance

- Many of the activities associated with learning aim D will be carried out at the same time as those for learning aim C due to the reflective nature of the learning aim and the subsequent evidence learners will need to produce as a part of their portfolio of work. You will need to make sure that learners have the interpersonal skills needed to be able to consider the lessons that they have learned during the designing and making of the single-sided PCB, whether these relate to safe working practices, or to the actual designing and making of the PCB. To achieve this, it would initially be appropriate to give learners specific questions to answer when reflecting on their work. You should encourage learners to reflect on their experiences at the earliest opportunity as this is most likely to result in them identifying those skills where development may be needed. You should encourage learners to evaluate their own performance whilst carrying out tasks and to record their thoughts in their logbook.

- You should highlight to learners the importance of reviewing their personal performance while developing a PCB. In particular, you should relate this to the development of their interpersonal skills including time planning and management. Learners should be encouraged to be critical of their own performances, identifying those aspects of the measurement and testing processes which they could improve.
- The work submitted by learners to address learning aim C should give sufficient evidence of the engineering skills that learners have applied. These skills should be demonstrated to a professional standard, and present a balanced view on the actions taken by learners during the design and manufacture of a PCB.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 5: A Specialist Engineering Project*
- *Unit 10: Computer Aided Design in Engineering*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 21: Electronic Measurement and Testing of Circuits*
- *Unit 23: Digital and Analogue Electronic Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Tooley M – *Electronic Circuits: Fundamentals and Applications, 3rd Edition* (Routledge, 2006) ISBN 9780750669238.
  Circuit simulation methods are covered, including SPICE.
- Boothroyd G et al – *Product Design for Manufacture and Assembly, 3rd Edition* (CRC Press, 2010) ISBN 9781420089271.
  Chapter 6 covers the design of PCBs or manufacture and assembly.
- Brindley K – *Newnes Electronic Assembly Handbook* (Newnes, 1993) ISBN 9780750616300.
  PCB manufacturing processes, soldering and testing methods described.

Videos

- www.youtube.com/watch?v=VJNfnstUw40
  UK based PCB manufacturer, demonstrating aspects of PCB production.
- www.youtube.com/watch?v=2qk5vxWY46A
  Covers SMT and THT manufacturing and testing.
- www.youtube.com/watch?v=sIV0icM_Ujo
  Multilayer PCB construction methods as used for small scale and prototype manufacture; processes will be similar to those carried out to produce a single-sided PCB by learners.

Websites

- www.ipc.org
  Institute of Printed Circuits, includes downloads of standards.
- www.eipc.org
  European Institute for Printed Circuits.
- www.allaboutcircuits.com
  Includes sections on low volume production of PCBs.
- www.eurocircuits.com/making-a-pcb-pcb-manufacture-step-by-step
  Step-by-step guide for manufacturing PCBs.
- www.electricstuff.co.uk/pcbs.html
  Small scale PCB production, considers all stages.

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Unit 23: Digital and Analogue Electronic Systems

Delivery guidance

Approaching the unit

Your approach to this unit should be as practical as possible, using pre-fabricated circuits with a choice of switched faults for each required complex system. This unit builds upon the knowledge of components and circuits developed in other units to see how they are incorporated into more complex systems; complex systems being taken as electronic systems with more than one interconnected section, eg a regulated low voltage supply is made up of transformer, rectifier, filter and regulator.

You should plan a logical progression from circuit analysis through measurement of correctly operating systems to diagnosing faults in a system containing a known and predetermined fault. Learners in small groups should analyse systems by breaking them down into simpler functional blocks (block diagrams). They can then explore how the functions combine and signals flow through them by taking measurements and observations on working systems, before completing fault-finding exercises. Learners would probably benefit from completing the investigation of one system before progressing to the next allocated system.

Learners should develop measurement and analysis skills, becoming confident in the selection and correct use of measuring equipment for both analogue and digital systems.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

It is important that you build on the behaviour of individual components and circuits that form the building blocks of more complex systems covered in other units. Consumer and industrial products such as smartphones, high definition television and leisure equipment are sophisticated electronic systems. Engineers use a range of common analogue and digital modules to design them. One of the main intentions of the unit is the need for technicians to build up a 'database' of such modules. Learners should develop a systematic approach to gathering data from working systems, which they can apply to the diagnosis of faults in electronic systems.

Learning aim A introduces the concept of analysing electronic systems by breaking them down into their simpler functional blocks and how these can be represented in block diagrams. These show how the individual functions combine and how signals flow through them. The focus is on what the systems do rather than how they do it. The knowledge required by learning aim A should not be treated as isolated theory, but develop from the practical investigations of analogue and digital systems carried out in tandem for learning aim B. You will need to have a range of circuits and corresponding schematic and block diagrams that cover the learning requirements. It is very probable that you already have a range of circuits with switched faults from previously delivered units developing fault-finding skills in digital and analogue circuits. The unit content gives an indication of the level of complexity of the systems that learners could investigate.

A regulated dc power supply is a good example to use as an analogue system as it can be broken down into easily identified modules – rectifier, filter, regulator, load. You could use a low voltage alternating current supply rather than a transformer to avoid exposing learners to mains voltage. A motor speed or servo system would be a good example of closed-loop control, giving learners the opportunity to investigate transducers, comparators and power drives.

Learners need to appreciate the difference between combinational and sequential circuits, but also recognise that complex systems utilise both. For example, a car alarm system uses combinational logic such as (door open) AND (alarm set) to trigger the alarm, and sequential logic in exit/entry delay when arming/disarming.

The type of faults introduced should not be immediately obvious from visual inspection. They could include open-circuit resistor, short-circuit capacitor, open-circuit diode, transistor base-emitter short-circuit, transistor base-emitter open-circuit, open-circuit ic pin, 'stuck-at' digital level.

Learning aim C is aimed at giving learners an opportunity to use the knowledge and skills gained to carry out fault-finding techniques on the circuits explored. Learners would benefit from carrying out practical work in pairs, and completing the investigation and fault finding on a particular system before progressing to the next.

Learners can explore the expected signals then fault find on the same circuit if each has built-in switched faults. Switched rather than permanent faults on each circuit can limit the number of resources and reduce the possibilities of plagiarism.

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Learning aim	Key content areas	Recommended assessment approach
A Examine the principles of analogue and digital electronic systems as applied in industry.	**A1** Characteristics of analogue and digital signals **A2** Block diagrams and hierarchical design **A3** Open- and closed-loop systems	A written report exploring the characteristics of analogue and digital signals, system blocks, block diagrams, open-loop and closed-loop control systems, with supporting calculations.
B Explore the characteristics of analogue, digital and mixed systems, and the role of signal conversion in control applications.	**B1** Testing electronic systems safely **B2** Analogue systems **B3** Digital systems **B4** Analogue to digital conversion (ADC) **B5** Digital to analogue conversion (DAC)	A logbook summarising practical experiments and reports exploring the sub-systems that make up complex analogue and digital systems, the measurement of signal flow through them, and the use of signal converters in mixed electronic systems.
C Carry out fault finding safely on complex electronic systems as applied in industry.	**C1** Fault finding techniques **C2** Fault finding in analogue, digital and mixed systems	A logbook recording fault finding in analogue, digital and mixed electronic systems with a single fault. The evidence should include block diagrams, fault finding plans identifying techniques and selection of instrumentation, test points, test reports, results and conclusions. The evidence should also contain observation records/witness statements.

Assessment guidance

This is a practical unit with learners investigating the structure and operation of analogue and digital systems in terms of typical functional modules. Learners should include evidence of circuit and block diagrams, brief explanations of system function, and evidence of testing. You should provide detailed Observation Records confirming the practical activities carried out. You could guide learners on how to keep all of the evidence for each system together so that they build up a database of information.

Learners can demonstrate the skills and knowledge developed in the unit by systematically finding single faults for each system. It is important that learners produce individual reports even when working in pairs or small groups. They need to give evidence of planning and structure when carrying out fault finding. You could give a structure for learners to complete their fault-finding reports. The learner evidence may include results, measurements, deductions and conclusions.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 23: Digital and Analogue Electronic Systems
Introduction It is important that you make the focus of the unit what the functional blocks do, rather than detail how they do it in terms of the behaviour of individual components. You should encourage learners to understand the value of analysing complex systems in terms of functional blocks and how those blocks can be combined in hierarchical designs. For example, a 4-bit adder from 4 separate full adders, each of which is made from half-adders and other gates. One of the underpinning principles of the unit is the need for technicians to build up a 'database' of knowledge of circuits and systems, which they can use when faced with investigating a system new to them. Learning aims A and B give formative evidence, requiring learners to interpret schematic and block diagrams, select appropriate test equipment and use it safely and accurately. Learning aim C is a summative, testing how well the learners can apply the knowledge and skills developed to identify typical system faults. You need to give sufficient resources to allow learners to meet all the requirements and encourage learners to collect evidence such as sketches, photographs, text, calculations and detailed Observation Records as they progress. It would help learners organise their evidence if you gave them a standardised set of documentation to record findings.
Learning aim A – Examine the principles of analogue and digital electronic systems as applied in industry
● Learning aim A introduces the concept of functional blocks, the way they can be defined in terms of analogue and digital signals and how they can be combined in open- and closed-loop control systems. You may have systems fabricated for previous qualifications that would be suitable for this unit. You could introduce the concepts by demonstrating: ○ the systems that form the basis of each assessment and ○ the type of equipment used to test them so that learners can appreciate the importance of identifying the functions and how they affect system performance to carry out fault finding effectively. ● You need to select the systems so that they allow learners to: ○ explore them logically and safely ○ build knowledge and skills that they can use in fault finding. ● It is not essential that all learners explore the same systems simultaneously. The unit content is flexible enough for groups of learners to progress around the available systems in no particular order, though it may be simpler to administer if all groups work on the same type of circuit (eg analogue or digital) at the same time. ● Learners could record the results of their exploration of the available systems by creating a portfolio (or logbook), gradually building up information on each system

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as they progress through the exercises. For learning aim A learners could:

- differentiate between the properties of analogue and digital signals in each system
- relate circuit schematics and block diagrams of complex analogue and digital systems identifying the nature of the expected signals at key test points
- define whether the systems are open- or closed-loop, determining the expected output for each system from given input signals.

- You could then give each group of learners responsibility for presenting their findings for one of the systems, identifying:
  - the system function
  - the functional block diagram
  - whether the system uses open- or closed-loop control (where applicable)
  - the type of signal at key points
  - the test equipment that could be used to investigate the system.
- This would also help in developing interpersonal skills – communicating, working collaboratively, negotiating and influencing, self-presentation.
- You could summarise the information by leading a plenary session to collate the outcomes from the learner presentations and identify any areas not sufficiently covered for learners to complete their report on their investigation. You could guide learners to organise their portfolios/logbooks so that they can add material for each system as they progress through the unit.

Learning aim B – Explore the characteristics of analogue, digital and mixed electronic systems and the role of signal conversion in control applications

- Learners can use the knowledge gained meeting the requirements for learning aim A to carry out a series of practical exercises investigating the block structure of, and signal flow in, complex analogue, digital and mixed electronic systems, which incorporate signal conversion.
- It is a good idea to organise the work in blocks of system type, eg analogue, digital or conversion, though as stated above it is not essential that all learners explore the same systems simultaneously. It is unlikely that all groups will work at the same rate so it is important that you monitor progress carefully and have sufficient resources to allow each group to proceed when ready to retain their interest.
- Learners could append their records for each circuit with:
  - notes on the operation of the systems
  - signals at key test points systematically

  for the given analogue, digital and signal conversion systems. (The intention is that learners develop an appreciation of the importance of building up the information on each system so that they have a useful archive for future use.)
- Learners could feed back to the rest of the group, explaining:
  - the function of a given system
  - how they measured signals at key test points.
- This would also help in developing interpersonal skills – communicating, working collaboratively, negotiating and influencing, self-presentation.

- You can lead a plenary session to summarise the outcomes from the learner presentations and identify any areas not sufficiently covered. You could then guide learners to organise their portfolios/logbooks so that they can append the additional material for each system as they progress through the unit.

Learning aim C – Carry out fault finding safely on complex electronic systems as applied in industry

- Learners need to complete fault-finding exercises using the pre-prepared complex analogue, digital and mixed electronic systems analysed for learning aims A and B. The intention is that they use the data collected in previous exercises to help them identify a single fault in each type of system. It is logical for learners to complete the fault-finding exercise on a system upon completion of the investigation for learning aim B. This reduces the chance of a system being used by a different group when needed for testing. You could give each group a different switched fault on a system to reduce the risk of plagiarism. Learners could append their records for each system with:
  - a fault-finding plan, which includes safe working practice for the system under test
  - details of the selection and use of fault-finding techniques to identify faults in each system using standardised fault-finding documentation
  - identification of the fault for each of the required systems.
- This exercise can also develop interpersonal skills – self-management, adaptability and resilience, self-monitoring and development.
- You could guide learners to organise their portfolios/logbooks so that they can append the additional material for each system as they progress through the unit.
- It is important that learners are given clear deadlines for the submission of evidence for each learning aim if this holistic approach is taken to avoid the potential for learners leaving everything to the last minute, which could limit their access to the higher grades. The process of data gathering needs to be completed for learners to have the necessary information to perform fault finding effectively.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 20: Analogue Electronic Circuits*
- *Unit 21: Electronic Measurement and Testing of Circuits*
- *Unit 32: Computer Systems Principles and Practice*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Pain R – *Practical Electronic Fault Finding and Troubleshooting* (Newnes, 1996) ISBN: 9780750624619.
  Good coverage of a wide range of fault-finding techniques. Slightly dated, but the basics are still relevant.
- Storey N – *Electronics: A Systems Approach, 5th edition* (Pearson, 2013) ISBN: 9780273773276.
  This text uses a systems rather than a component approach to electronics. It does not cover all the unit content, but it is an excellent resource, offering a good basis for further study.
- Tomal DR, & Agajanian AS – *Electronic Troubleshooting*, *4th edition* (McGraw-Hill Education, 2014) ISBN: 9780071819909.
  Covers a wide range of analogue and digital circuits, some of which go beyond the scope of this unit, but could be useful for the future.

Journals

- *Everyday Practical Electronics* (Wimborne Publishing Ltd) www.epemag3.com
  Magazine for hobby electronics enthusiasts that contains practical constructional projects for the hobbyist, special features, advice and adverts from specialist electronics suppliers and more besides.

Websites

- www.electronics-tutorials.ws
  Basic Electronics Tutorials for beginners and beyond, Basic Electronics Tutorials Site by Wayne Storr. Very well presented information covering a wide range of electronic subjects.

Unit 24: Maintenance of Mechanical Systems

Delivery guidance

Approaching the unit

The unit is designed to be an informed introduction into the maintenance of mechanical systems that will inspire learners to enter into the exciting world of engineering. Learners should be given the opportunity to experience the unit content through active learning, by exploration and by doing.

The unit covers many of the general areas of maintenance without being too specific. There is an overall emphasis on the safety considerations that need to be appreciated and carefully applied to what may be relatively unique situations for the maintenance engineer.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A relates to the lubrication of mechanical systems. It is important to maintenance engineering because the failure of the system can lead to catastrophic failure of the mechanical system and the system of lubrication is one that is often overlooked. Therefore, the emphasis is on the learners seeing these systems stripped down so that they can see, touch and understand them. When the systems are stripped down, it is possible to show the learners the actual movement that is required to be lubricated in order to understand the conditions, the forces, the movement and the physical conditions generally. This will help them understand the requirement of the lubricant and the technology of the different lubricants. Again, the emphasis needs to be on experiencing the lubricants, their physical properties and appearance.

It would be useful to have either a guest speaker or an industrial visit at this point, as the topic area is expansive and technical. To achieve this, you could approach a local company, particularly one that uses a process to produce its product and therefore is one where there is an emphasis on the maintenance of the plant. The maintenance manager would be a useful contact. Stockists of lubricants may also be willing to provide a visiting speaker and suitable samples, and they will be able to speak in detail about the application of their products.

Learning aim B is concerned with common consumable items to be found in mechanical systems that need to be replaced at regular intervals to ensure the correct function of the system. The emphasis is on giving the learner hands-on experience of touching and fitting these components safely and in the proper way. The learners need to be exposed to as many different consumable items as possible. These are readily available in many workshop environments. A motor vehicle could also offer these types of opportunity to renew consumable items, although the emphasis should not be solely motor vehicle based.

Again, an industrial visit will be very useful, as it will give the learners a good opportunity to see these activities carried out in an industrial context. Having good contact with a large company through the maintenance manager will potentially offer the greatest opportunity for the learners to be exposed to a variety of contexts that may include some very interesting experiences. It may be very difficult for the company to provide this opportunity on an on-going basis, so these visits may need to be planned to coincide with maintenance periods or with breakdowns. A short opportunity for work experience may exist with some companies and this is well worth exploring, making sure that you follow the usual work experience measures and procedures.

Learning aim C is closely related to learning aim B and could be considered alongside it, particularly due to the knowledge that the learners get from the practical elements, the industrial visits and the potential work experience. The emphasis is on the learners being able to see how a mechanical system is performing its intended function. It is a very good opportunity to relate practice with the theory that should be delivered as part of this learning aim. The emphasis is on power transmission and should include any system that does this. Many of these systems modify in some way the power that is transmitted, which may, for example, be slowing down or speeding up, changing the direction or the type of movement from rotational to linear or increasing the mechanical advantage.

One approach to delivering this learning aim would be to expose learners to a mechanism and then ask them to determine what is happening. They should then describe this in detail, either within a small group or a presentation to the whole class. You can introduce the relevant theories as the opportunities arise during the discussion.

In learning aim D, learners should consider both the sustainability of the maintenance function within a company and how to maintain the safety of the environment in which they are working. Safety should be emphasised throughout the unit – both personal safety and safety in respect of others – and this should be related to the specific task that the learners are performing. Learners should also focus on the wider issues.

In respect of sustainability, the learners should understand the need to examine carefully the materials that are being used and how they are disposed of. The learners should understand the relevant costs, as well as the need to care for the wider environment. They should also understand the need to order just what is required – and not to order spares – and that stock should be kept at a minimum – zero if possible. The learners need to understand that some items can be reused if they can be cleaned properly and that some parts can be reconditioned and used again. The learners need to understand that some of the materials that have been used traditionally have been superseded by safer and more environmentally friendly materials and that these should be used where available.

Whilst safety should be emphasised throughout, learners need to understand and consider wider issues such as the need to create a safe environment for themselves and for others. This will include:

- the isolation of systems, hydraulically, pneumatically, electrically and mechanically
- the need to perform safety checks on the equipment that they will use for the maintenance task, such as lifting ropes, slings and chains, hoists, overhead cranes, hydraulic and mechanical lifting devices and low voltage hand tools
- making the area safe by using tape to seal off the area that they are using
- physical isolation of systems
- ‘do not use’ notices.

Throughout this learning aim, the learner must be exposed to legislation that covers the whole realm of the maintenance including:

- working at height
- working in confined spaces
- working with dangerous materials;

- permission to work permits
- the need for good, relevant and documented training.

This is clearly a very large area of knowledge and experience to cover and you are not expected to cover everything. However, the learners need to understand their responsibilities to perform tasks safely, and to understand that where they do not have relevant data or knowledge that it is their responsibility to find out.

Again, a guest speaker, an industrial visit or suitable work experience would be useful to develop the necessary understanding and awareness.

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics of lubricants and their application in mechanical systems	**A1** Lubricant characteristics **A2** Lubrication of mechanical systems	A report about the characteristics of lubricants and their application in two mechanical systems.
B Investigate the characteristics and applications of common consumable components used in mechanical systems	**B1** Mechanical seal characteristics and common applications. **B2** Bearings characteristics and common applications **B3** Fastener characteristics and common applications	A report about the characteristics, maintenance considerations and applications of common consumables and the operation and maintenance considerations of power transmission components used in mechanical systems.
C Investigate the characteristics and applications of common consumable components used in mechanical systems	**C1** Gear train function and operation in power transmission systems. **C2** Typical function and operation of other power transmission components	
D Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system	**D1** Safe working practices when undertaking routine maintenance. **D2** Routine maintenance tasks on mechanical systems	Practical activity to complete maintenance tasks safely. Evidence will include: a record of the procedures followed, observations records and correctly completed documentation, with witness signatures against each completed task.

Assessment guidance

This unit requires three assignments: learning aim A has one assignment; learning aims B and C have one joint assignment; and learning aim D has one assignment.

For assignment one (learning aim A) the learners are presented with two different mechanical systems and are asked to examine the system carefully, thoroughly and safely. There is no requirement for the learner to dismantle or reassemble, although a little may be required in order for them to conduct a thorough examination. If possible, the learners should be presented with different systems but some duplication may be necessary.

Having examined the systems and the process of lubrication, the learners must produce a report for assessment that includes the elements identified in the specification. It will be necessary for the learners to have access to the data concerning the lubricant that is being used currently, or lubricant that could be used.

The report can be in any format but it must evidence all of the required elements. If the report is presented using PowerPoint, a copy of the presentation must be submitted and either a video taken of the presentation or a witness statement must be presented by the assessor that details what the learner did and comments on the outcomes achieved; this should then be signed and kept. If a video is made, it must be saved and must be accompanied by a statement from the assessor detailing the outcomes achieved.

In assignment two (learning aim B and C) the learners are presented with two different mechanical systems and are asked to examine the systems carefully, thoroughly and safely. There is no requirement for the learner to dismantle or reassemble, though a little may be required in order for them to conduct a thorough examination.

It is important that the systems are chosen carefully by the centre because they collectively need to present the learners with three different types of consumable and must utilise three different types of power transmission.

If possible, the learners should be presented with different systems but some duplication may be necessary.

The learners can produce their evaluation in any format but it must evidence all of the required elements. If the evaluation is presented using PowerPoint, a copy of the presentation must be submitted and either a video taken of the presentation or a witness statement must be completed by the assessor that details what the learner did and comments on the outcomes achieved; this should then be signed and kept. If a video is made, it must be saved and must be accompanied by a statement from the assessor detailing the outcomes achieved.

In assignment three (learning aim D) the learners are presented with a mechanical system on which they can perform two routine maintenance tasks. If possible, the learners should be presented with different systems but some duplication may be necessary.

The assessment is concerned with the actual maintenance task and how each learner undertakes that task (see the specification for the detail), but the learner will need to refine the process they use to perform that task and evidence that they have refined the process. This should be done in the form of a brief document that can be followed by others, so that they can perform the task in the refined manner.

There will need to be evidence of what the learners have done and the outcomes they have achieved. This could take the form of a witness statement, completed by the assessor, that details what the learner did and comments on the outcomes achieved; this should then be signed and kept. The learners could also video themselves performing the task. The video must be saved and should be accompanied by a statement from the assessor detailing the outcomes achieved.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 24: Maintenance of Mechanical Systems

Introduction

The delivery of the unit should give the learner the opportunity to experience many different aspects of maintenance through discovery and by doing. However, there is a small part of the content that is unsuitable for this approach (eg health and safety issues).

The unit should allow the learners to gain experience of maintenance engineering that a prospective employer would find attractive. The learner should already have some experience of handling mechanical systems and some limited tools, and in addition, they should be able to describe in detail the function of some systems and the rationale for some of the processes necessary for the maintenance of some mechanical systems. This unit should enable learners to develop their cognitive and problem-solving skills.

In addition to the practical aspects, the intention of this unit, and the assessment, is to prepare learners for a university degree course because it requires the learners to think independently about systems and their function. Learners are required to undertake some independent research in respect of technical data and to write technically concerning their research, having carefully analysed the appropriateness of the detail. The assessment requires learners to present their work in the form of a report, which could be delivered as a presentation.

Learning aim A – Examine the characteristics of lubricants and their application in mechanical systems

- You could begin this topic with a group discussion on the purpose of lubrication.
- The initial discussion should enable the learners to understand the purpose of lubrication:
  - what it does
  - how it does this
  - what the consequences of this system failing are.
- You could then show them practical examples of lubricants being used within mechanical systems by visiting a laboratory or workshop. You may need to dismantle some mechanical systems for them to be able to see clearly.
- You could use group discussion followed by an exploration of the systems for the two other aspects of this learning aim.
- You could use a group discussion, followed by a safely conducted learner exploration of suitable mechanical systems to introduce the different methods used to deliver lubrication. Again, being able to view a variety of systems will be useful so that the learners can contextualise the concepts. It will also facilitate some discussion concerning the operating conditions of systems in industry.
- This topic would benefit from a visit to a suitable maintenance facility in a local company. Companies that are involved in producing a product via a process are most suitable.
- The third topic involves the learners exploring the various lubricants available, and it would also benefit from an explorative approach. A visit from a speaker would help motivate learners. This could be a representative of a lubricant supplier, who may be able to show learners an extensive range of different lubricants.

Learning aim B – Investigate the characteristics and applications of common consumable components used in mechanical systems
• You could follow the approach described for learning aim A in this outcome. • You could introduce each of the three items that are the concern of this aim (i.e. seals, bearings and fasteners) with a group discussion. You could follow this with an examination of these items, and then show them to learners *in situ*. Expose learners to as wide a range of contexts as possible. • You will need to give learners some instruction regarding the application of the components and again it will always be better if the learners can view the items *in situ*. Any discussion on their application will need to reference relevant data (this will be available from various suppliers via the internet). • A suitable industrial visit, or a visiting speaker, or both would be of benefit in this learning outcome.
Learning aim C – Investigate the operation and application of power transmission components used in mechanical systems

• Once again, the approaches described previously could be used for this outcome.
• You could introduce the topic using a group discussion. You could then follow it by showing learners the various applications of the mechanisms that are used to transmit and transfer power.
• It is important that learners appreciate how power is transmitted and the nature of the resulting power. It is therefore an opportunity for learners to understand:
    o mechanical advantage and velocity ratio
    o respective gear and belt speeds
    o the geometry of gears
    o movement given by cams
    o the movement offered by linkages
    o the respective speeds of the various parts of those linkages.
• Again, this will require some reference to data for the various factors.
• An industrial visit or speaker would be beneficial to put the learning in context.

Learning aim D – Carry out routine maintenance safely and sustainably to help ensure the continued operation of a mechanical system
• This learning aim is concerned with exposing the learners to some practical work, to demonstrate the correct manner and processes for performing some simple maintenance tasks whilst giving them an awareness of the underlying reasons for performing tasks in a particular manner. • The learning aim is used to give a wide perspective on safety considerations including the legislation that covers various types of operation and the need to follow very specific safety procedures for specific types of working environment. This would need to include measures that mitigate against the hazards. • You need to introduce the learners to considerations of the environment and financial considerations concerning the maintenance of mechanical systems. • The practical work needs to be delivered by a suitably qualified person (who could be a guest) and in a suitable environment. The learners need to be able to perform all tasks safely and in the correct manner. • Careful observation of the learners whilst performing the tasks is very important as this will form the basis of the assessment for the learning outcome.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 11: Engineering Maintenance and Condition Monitoring Techniques*
- *Unit 12: Pneumatic and Hydraulic Systems*
- *Unit 15: Electrical Machines*
- *Unit 25: Mechanical Behaviour of Metallic Materials*
- *Unit 28: Dynamic Mechanical Principles and Practice*
- *Unit 29: Principles and Applications of Fluid Mechanics*
- *Unit 46: Manufacturing Joining, Finishing and Assembly Processes*
- *Unit 50: Aircraft Gas Turbine Engines*
- *Unit 53: Airframe Mechanical Systems*

Resources

The Maintenance of Mechanical Systems is generic and spans all of the engineering disciplines, therefore general maintenance resources are listed, but many more resources are available under the headings of the specific engineering disciplines or under the heading of the specific equipment or task.

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Kibble R T and Stenerson J R – *Mechanical Principles and Systems for Industrial Maintenance*, (Prentice Hall, 2005) ISBN 9780130494177.
  This is a broad based textbook and a good introduction for learners.
- Jeffrey D – *Principles of Machine Operation and Maintenance* (Routledge, 2011) ISBN 9780750602938.
  This book explains how rotating machinery works, and the role of the maintenance engineer in ensuring its proper operation.
- Mobley K – *Maintenance Fundamentals* (Elsevier Butterworth-Heinemann, 2004) ISBN 9780750677981.
  This covers the fundamentals for maintenance.
- Mobley K (editors) – *Maintenance Engineering Handbook*, 8th edition (McGraw-Hill, 2014) ISBN 9780071826617.
  This book focuses on proven best practices for maintenance, repair, and overhaul (MRO), inventory management, root-cause analysis, and performance management.
- Shine B – *Maintenance & Facilities Management* (Original Writing Ltd, 2011) ISBN 9781908282514.
  This book looks at the key multi-functional engineering building blocks required for implementing proper maintenance and facilities management.

Journals

- www.theiet.org
  The *Journal of Engineering* is a reasonable online journal that is free to access.

Videos

- www.youtube.com/watch?v=45Uni_m4aHM
  'Titan Airways Boeing 757 – Maintenance by Monarch Aircraft Engineering'.
- www.youtube.com/watch?v=fM_Ff9q1o6M
  'Japan Bullets Trains' maintenance routine – clip from NHK World documentary'
  This clip is good for giving an appreciation of preventative maintenance.

These video clips are good for giving a general appreciation of maintenance routines and give the learners insight into areas that they may never gain real-life access to.

Websites

- www.engineeringtoolbox.com
  A useful general web site for engineering, searchable and it contains material on the majority of topics at all levels.

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Unit 25: Mechanical Behaviour of Metallic Materials

Delivery guidance

Approaching the unit

The unit content is structured so that your learners will be able to apply the principles of mechanical behaviour of metallic materials to real-life situations. This will involve investigating the design of metallic components and thinking about why they are made from particular materials. To stimulate enquiry and investigation, your learners should combine theoretical studies with significant amounts of laboratory work, for example tensile and harness testing. One of the key elements of this unit is to encourage your learners to think about the sometimes difficult decisions a design engineer will have to make when selecting a metallic material for a product. They usually have to make a reasoned compromise between raw material cost, manufacturing cost, strength, durability and availability of supply. This is particularly important when designing products for the mass consumer market, for example domestic motor vehicles.

Learning aim A investigates the classification of metallic materials and how their mechanical properties are defined. It then moves on to investigate the microstructures of ferrous and non-ferrous metals and the effect these have on mechanical properties. You then move on to take your learners through some of the basic processing techniques that are used to modify the mechanical properties of metals, for example cold working and heat treatment.

Learning aim B provides lots of opportunities for you to carry out experimental work with your learners and, in this respect, it links well with *Unit 27: Static Mechanical Principles in Practice*, in particular the beam stress and strain analysis and the design optimisation of a complex structure. Some of the time will be spent on material identification based on data gathered from testing.

Learning aim C covers the major failure modes that can occur in metallic components and should be approached from an investigative angle. You could start delivery by explaining the failure mechanisms and then follow this up by looking at, and spot testing, actual components.

You can use a range of delivery methods in this unit, such as:

- formal teaching
- individual and small-group investigation
- video clips and images
- case studies
- laboratory testing.

There are also numerous opportunities to link with engineering employers who may be prepared to provide metallic component samples (including components that have failed) with associated documentation and relevant test data.

You should make your learners aware that formal teaching will be supported by a significant amount of practical work involving the use of test equipment. During their investigations, your learners will consider a range of materials and assess their mechanical properties based on evidence gained from visual inspection (microstructure/surface appearance) and strength/hardness testing. As you deliver the formal teaching, you should make topics more accessible to your learners by showing them short video clips (YouTube is a really good resource).

Throughout delivery, you should consider the use of materials in real-life situations.

For learning aim B your learners will be collecting test results and processing them. Encourage them to put numerical data into spreadsheets so that it can be manipulated easily and findings can be presented graphically. Your learners will require access to published data about the mechanical properties that relate to the materials they test; this can be in hard-copy format or accessed online. Do encourage your learners to find this information independently.

If your programme also includes *Unit 26: Mechanical Behaviour of Non-metallic Materials*, it is worth considering running the two units in parallel because they have similar learning aims and there is a lot of common terminology. You will have to set separate assignments, but there is scope to save time when carrying out practical investigations because equipment would only need to be set up once; for example when carrying out tensile testing.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Before starting delivery, it is important to gather together a really good selection of ferrous and non-ferrous metals. As a starting point, these can just be off-cuts of metal but, as you move into the theoretical aspects of mechanical behaviour, you will need to have available metal specimens of known composition and provenance/processing history. Some of the grading criteria require your learners to evaluate test results against published data; to do this they need to know what type of material they are working with. These identifiable specimens will include surface prepared, mounted specimens for micro-examination and test pieces that conform to the relevant British Standard. As stated above, links with engineering employers could be highly advantageous in this regard.

For learning aim A, introduce the topic by showing your learners components made from mild steel, stainless steel, aluminium, brass and titanium. Discuss the choice of materials in terms of strength, mass, durability, surface finish, aesthetics, cost and processing history. Then home in on processing history. Ask the question: 'How do we determine the history if we don't have access to manufacturing documentation?' Explain that good ways to do this would be to cut samples from the component and look at them under the microscope and also to carry out mechanical testing such as tensile/compressive and hardness. Explain why it is important to correctly understand the mechanical properties of materials when designing and making products.

You can then move on to consider the grain structure of metals and microscopy. Show your learners images of crystals either as photographs or displayed on screen from a microscope. This is where you really need access to resin mounted specimens that have been polished; putting them under the microscope in this condition usually reveals nothing. Explain to your learners that you need to reveal the grain boundaries. You can do this yourself using an etchant (typically dilute acid) or, if health and safety does not allow this, then use a specimen that has been pre-etched. All will now be revealed. Start with a mild steel specimen that has been normalised, then move to one that has been cold rolled and discuss what effect this has on the shape of the grains. Having established that metals are crystalline structures you can move into the theoretical aspects of grain structures (topics A4 and A5).

For learning aim B, introduce the topic by telling your learners that here will be lots of demonstrations and hands on experimentation. You could start with a relatively simple demonstration that links this learning aim back to the previous one. Get hold of a component that has been case hardened; a good one is the metal cutting disc from a circular saw. Carry out a series of hardness tests across its surface starting from near the centre and moving out to the teeth; show how the hardness increases towards the teeth. You can then discuss why the teeth are hard (for cutting) and the inner disc is less brittle (so it does not shatter). This leads into a discussion about in-service requirements.

You can now move on to demonstrate a range of destructive test procedures, using standard specimens to start with. To add interest, it is worth spending some time investigating duralumin; if you have access to an engineering workshop it is possible to make a basic 4% copper specimen that is age hardened. When tested against a piece of plain aluminium (eg roof flashing) a significant increase in hardness and tensile strength will be seen. The analogy here is adding a pinch of salt when cooking to bring out the flavour. Staying with duralumin, you could go on to discuss why high strength aluminium alloy skin panels on aircraft are riveted not welded; again, reinforce the link with learning aim A, topic A5.

Having set the scene, most of the rest of this unit will be delivered through learner investigation involving the use of destructive and non-destructive test equipment. This will require careful supervision but it is important to allow learners to develop their testing skills.

For learning aim C, you could introduce the topic by discussing the procedure followed if a product fails in service and members of the public are involved – the collection, preservation and analysis of evidence during the course of investigation. When trying to find out what went wrong, a first step would be to see if there is metal failure caused by, for example, overloading or fatigue. There are a number of well-documented case studies that you could overview, for example turbine blade-off in an aero engine or engine crankshaft fatigue failure.

There is plenty of scope, when delivering this learning aim, to look at images of components that have failed and to identify what caused this failure. A starting point would be to look at a component that has failed due to fatigue and to identify the burnished and crystalline areas on the fractured surface. When investigating a gear wheel (for example) that has failed, you could check for fatigue cracks using dye penetrant (which links back to non-destructive testing).

The final topic in this learning aim is about considering design strategies to prevent component failure. It pulls together all of the unit content and is best delivered in the form of case studies. A simple one to start with is improving the design of a stepped shaft that has failed due to stress raising caused by a sharp radius. This could lead to a discussion about why commercial aircraft have round or oval shaped cabin windows.

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.

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Assessment guidance

This unit is internally assessed and you should use three assignments that will require time to be spent in a materials science laboratory. It is essential that each assignment covers a complete learning aim and is not split into sub-tasks per criterion.

Your learners must independently generate hard-copy evidence presented as a portfolio that contains written narrative, images, calculation and plotted results. Do encourage your learners to present numerical data using spreadsheets so that load/extension and stress/strain graphs can be easily plotted. If you are using test equipment that features self-plotting this is fine; learners can make printouts directly. Encourage your learners to take photos and video clips of what they are doing and back this up with observation records to support their evidence (which must be individual).

There will be safe working requirements when operating some of the test equipment and it is important that your learners confirm are made aware of the dangers and know what to do in an emergency – your observation record should confirm this action. The wearing of eye protection should be mandatory for any of the impact and tensile/compressive tests. Your observation record must also contain comments about how each learner approached practical tasks, set up equipment, took measurements and processed them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 25: Mechanical Behaviour of Metallic Materials

Introduction

Before starting delivery, it is recommended that you gather together samples of the materials listed in the unit content so that they can be passed around to your learners. They should also be shown actual components that have been in service, including some that have failed due to corrosion or fatigue. The aim is to make delivery of the unit very 'hands on' for both you and your learners.

Begin by introducing the unit to your learners through a group discussion about the range of metallic materials available for use by engineers. This is best done by considering materials in the context of engineering design; explain why it is important to the correct material for a particular application. The discussion should include references to specific product groups such as motor vehicles, aircraft and boats. Touch on aspects such as strength to weight ratio, corrosion resistance and aggressive operating environments such as high temperature, high stress and dynamic loading. Explain that if a designer chooses the wrong material for a particular application and a component fails in service, then there could be serious repercussions; perhaps open out the discussion to include thoughts about corporate liability.

Explain to your learners that they will be carrying out experimental work that involves setting up test equipment, carrying out tests and evaluating results against published figures taken from data sources. From their previous studies your learners will have experience of carrying out science experiments, usually with the aid of a laboratory task sheet. The intention in this unit is that, when learners are carrying out experimental work, they are given an overall objective to be achieved but the way that they approach the task(s) is up to them; some will need guidance, others may not (differentiation within the group). For each learning aim the thematic nature of the assessment criteria provides scope for your learners to show initiative and the experiments become true investigative activities.

Throughout your teaching of this unit, maintain the link with *Unit 27*: *Static Mechanical Principles in Practice* (if possible/appropriate), in particular, the beam stress and strain calculations (learning aims B and C) and the design optimisation of a complex structure (learning aim C).

Most of the test equipment is expensive and it is worth thinking about trying to use the facilities of a local engineering employer or a higher education establishment. There is great benefit in being able to take your learners into an industrial environment to see mechanical testing in practice, for example quality assurance of raw materials and finished products and the inspection/testing of failed components to find out what went wrong.

Learning aim A – Investigate the microstructures of metallic materials, the effects of processing on them and how these effects influence their mechanical properties

- Using a formal presentation, you could overview the metallic materials that your learners will be investigating.
- Show your learners engineered components and then have a whole class discussion about what the components are made from – type of material and why chosen, for example mild steel for a shelving system because it is easy to stamp out, form and surface coat. An interesting discussion would follow from the question: 'Why are car bodies not made out of stainless steel? It seems the obvious choice to use as it

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does not rust.' This allows you to bring in the manufacturability constraints when choosing a material.

- Learners could then work in small groups to research the mechanical properties of metallic materials.
- Use a formal presentation to lead learners into thinking about the internal structure of materials (grain structure) and the effect that internal structure has on mechanical properties. Support this teaching with images of microstructures.
- You could then demonstrate the use of a metallurgical microscope and the capturing of grain structure images – hard copy or 'e' format. Compare the images with reference ones and identify material types.
- Give a formal presentation about thermal equilibrium diagrams.
- Learners could then work in small groups to investigate the effects that processing (for example heat treatment) has on mechanical properties.
- In preparation for the assessment activity you could guide your learners through:
    - researching the effects of processing history on the mechanical properties of metallic materials
    - completing a macro investigation of sample materials and recording observations
    - using a metallurgical microscope to record images of microstructure of sample materials and identify features of the structure, for example grain boundaries, pearlite and ferrite
    - comparing the recorded images against the images presented in micrographs
    - investigating a range of samples to assess mechanical properties and processing history and to identify the materials.

Learning aim B – Explore safely the mechanical properties of metallic materials and the impact on their in-service requirements

- Using a formal presentation, you could overview in-service requirements (operating envelope) for a range of components and then identify the materials that they are made from.
- You could then have a class discussion about the benefits and limitations of destructive and non-destructive testing.
- Learners could investigate the different types of test equipment available; they should be given a steer on what to look for to prevent them spending too much time doing online research. Clipped images and brief commentary are what is required.
- For a given range of materials (ferrous, non-ferrous, plain, alloy) your learners could investigate the best ways to test them.
- You could then demonstrate how to carry out materials testing safely.
- Learners should then work in small groups to carry out testing.
- In preparation for the assessment activity you could guide your learners through:
    - completing safely a series of destructive tests on metallic materials (ferrous and non-ferrous) to determine their mechanical properties
    - carrying out non-destructive tests to identify defects in metallic materials (ferrous and non-ferrous)
    - presenting and evaluating findings in a technical report
    - evaluating how the mechanical properties of different metallic materials affect their behaviour and suitability for different applications, comparing the results from safely conducted experiments with accredited data sources
    - selecting test pieces of known material composition and processing history, and comparing their mechanical properties found by experimentation with those given in an accredited data source.

Learning aim C – Explore the in-service failure of metallic components and consider improvements to their design

- Using a formal presentation, you could discuss failure modes and present exemplars.
- Learners could be shown a range of components (and/or images) that have failed in service due to corrosion/fatigue/creep and be asked to identify the failure mode.
- You could demonstrate a creep test on a piece of lead or show this using a video clip.
- In preparation for the assessment activity, you could guide your learners to investigate at least three components to determine why they have failed in service and suggest improvements to prevent failure. At least two components should have failed in service due to a mechanical fault and at least one due to corrosion. Learners should:
  - carry out a visual examination of the components
  - carry out appropriate mechanical test(s) (typically a spot hardness test)
  - research the processing history of the components and make reference to a properties of materials database
  - on the basis of the visual examination, testing and research, evaluate how each component failed in service and recommend a design solution from a range of alternatives so that failure in service can be prevented in the future or the consequences of failure reduced.
- Suitable examples to investigate include:
  - a turbine blade operating at high temperature and stress levels that have prompted dimensional changes due to centrifugal force
  - a wheel stub axle on a piece of farm equipment; the random stress reversals produced by the wheel bumping across ruts in the ground causing crack propagation at a stress raiser point (eg change of cross section) and failure due to fatigue
  - a valve body that has suffered galvanic corrosion
  - an aircraft undercarriage pintle bolt or wing skin and stringer assembly that has suffered fretting corrosion.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Delivery and assessment of this unit requires specialist materials testing equipment including:

- Access to materials properties data sources:
  - www.matweb.com
    MatWeb: Online Materials Information Resource.
  - Howatson AM, Lund PG and Todd JD – *Engineering tables and data, 2nd Edition* (Kluwer Academic Publishers, 1991) ISBN 9780412389702.
    The physical and mechanical properties of metallic materials presented in these tables are up to date even though this second edition has been around for some time.
  - Metal samples of known composition and processing history. A good source is the Institute of Materials, Minerals and Mining IOM^3. A boxed set of specimens can be purchased from their website.
- Hardware equipment, including:
  - magnifiers, metallurgical microscopes
  - tensile testing, hardness and impact testing equipment
  - non-destructive test equipment, eg dye penetrant, magnetic particle, ultrasound, eddy current
  - creep and fatigue test equipment (preferred, but can be replaced by simulation software).

Textbooks

- Darbyshire A – *Mechanical Engineering* (Newnes, 2008) ISBN 9780750686570.
  Useful general resource for tutors.
- Bolton W and Higgins RA – *Materials for Engineers and Technicians* (Routledge, 2014) ISBN 9781138778757.
- Timings RL – *Engineering Materials, Volume 1* (Longman, 1998) ISBN 9780582319288.
  This book is relevant, though it has not been not updated since 1998. It covers all of the metallic materials in this unit.
- Boyce A, Cooke E, Jones R, Mantovani B, Roberts D and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241.
  This matches exactly to the 2010 QCF specifications but has content that is very relevant to this unit. It contains learner support activities.

Videos

There are many video clips available on video-sharing websites. Materials Science 2000 has produced some good videos, with clearly presented UK-based commentaries.

- www.youtube.com/watch?v=D8U4G5kcpcM
  Tensile test – lasts about eight minutes and shows equipment being set up, load application, result plotting on a computer screen and explanation of how to calculate the various strengths properties (SI units).
- www.youtube.com/watch?v=RJXJpeH78iU
  Brinell hardness test – lasts about three minutes and links on to the Rockwell test.
- www.youtube.com/watch?v=xEK-c1pkTUI
  Dye penetrant test – lasts about three minutes.
- www.youtube.com/watch?v=qpgcD5k1494
  Magnetic particle inspection – lasts about three minutes.

Websites

- www.iom3.org
  The Institute of Materials, Minerals and Mining (IOM^3). This is a very useful site because it has an area specifically for schools and colleges. Standard membership of the schools affiliate scheme is free of charge and provides support and access to resources to enhance and enrich the teaching of materials, minerals and mining related topics in the 11–19 curriculum. Premier and Premier Plus membership (by subscription) provide access to extra materials, school visits and conferences for tutors.

Unit 26: Mechanical Behaviour of Non-metallic Materials

Delivery guidance

Approaching the unit

In this unit, your learners will explore the mechanical behaviour of non-metallic materials. It is important to note that it will not be possible for the unit to cover the full range of non-metallic materials. Only polymer, ceramic and composite materials should be considered.

Your delivery of the unit content should involve a mix of theoretical and practical activities to engage learner interest and prepare them for the unit assignments. Learners will need an understanding of the types, structure, mechanical properties and engineering applications of polymer, ceramic and composite materials. Whole class teaching, group work and independent research activities will help them to achieve this. Once you have established the required theoretical understanding of material behaviour you can introduce the use of non-destructive testing, to identify flaws in material microstructure, and destructive testing, to directly measure a range of key mechanical properties. Learners will be required to carry out safely a range of destructive test procedures. You must ensure that there is appropriate test equipment and material samples available to your learners as these are an essential requirement for the delivery of this unit.

In addition, you will need to explore with learners some common causes of in-service failure of non-metallic materials. To deliver this learning aim, you must ensure that you have appropriate examples of components that have failed in service. You will also need supporting case study material identifying the materials used, in-service operating conditions, etc. Learners must develop the observation skills necessary to examine failed components and identify signs that characterise particular failure mechanisms. They will also need to apply their analytical skills to identify key factors that contribute to component failure. Learners will need deep knowledge and developed evaluation skills in order to investigate how recurring problems can be avoided and to consider potential solutions.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

As the content of learning aim A is primarily theoretical, you should have a range of material samples, components and other physical resources available to use as a focus in teaching activities. Incorporating as many hands-on activities as possible will enhance learner interest and engagement with the unit content.

An important aspect of this learning aim is that you should guide your learners to develop the analytical skills necessary to link the microstructure of a material to its mechanical properties and so assess its suitability for use in different applications. You might choose to establish cross-curricular links with science subjects in your institution during the planning and delivery of this learning aim.

Inviting colleagues who teach similar topics in chemistry and physics to deliver content in these areas will help illustrate the close relationship that engineering maintains with science subject specialists. It would certainly be of use to share teaching materials with your science colleagues who are likely to have tried and tested resources covering areas relevant to this learning aim.

Learning Aim B requires your learners to determine the mechanical properties of a range of non-metallic materials by carrying out destructive testing. You will need to provide access to a range of test equipment. This must include apparatus to perform tensile and impact testing. Learners will gain valuable additional experience if they are also able to carry out fatigue and creep testing, although the extended duration of these tests will necessitate careful planning. You will need to provide each learner with a range of appropriately prepared material samples suitable for use with your test equipment. During assessment, a minimum of eight samples will be required but more are likely to be used in teaching and learning activities.

Pre-prepared material test samples might be available through organisations such as The Institute of Materials, Minerals and Mining (IOM^3). Alternatively, you could arrange for them to be prepared from commercially available stock forms of appropriate materials by in house technicians.

Your learners will also need an understanding of non-destructive testing techniques and the material defects that these are able to detect. It is not necessary for learners to carry out non-destructive testing for assessment purposes. However, if equipment is available in your institution, it should be used in teaching.

There is an opportunity here for you to seek the involvement of an industrial partner to enhance the delivery of this learning aim. Destructive and non-destructive testing forms a vital part of the inspection and quality assurance procedures for the manufacturers of a range of load bearing or safety critical components in a range of sectors. A site visit to see some of these procedures being carried out and to discuss their importance with industry experts would certainly be beneficial.

In learning aim C, you will need to give learners access to a range of polymer, ceramic and composite components that failed in service. These will be used in teaching and assessment activities. Each component should be accompanied by a case study providing additional contextual information and material data. It is an important aspect of this learning aim that your learners develop the knowledge and analytical skills to characterise a component failure and then identify the mechanism by which it failed.

There is scope here for you to develop links with industrial partners. You could approach local companies to provide examples of prematurely worn, fractured or degraded non-metallic components.

You will need to ensure that learners have sufficient depth of understanding to evaluate the information provided in case study material and suggest feasible component design improvements likely to prevent a recurrence of component failure. This process will model industrial practice when problems with premature wear, cracking or catastrophic component failure have to be resolved. Analysis, evaluation and a systematic approach to problem solving are key transferable skills valued by employers.

Learning aim	Key content areas	Recommended assessment approach
A Investigate how the structure of non-metallic materials influences their mechanical properties	**A1** Types of non-metallic materials **A2** Structures of non-metallic materials **A3** Mechanical properties of non-metallic materials **A4** Typical engineering applications of non-metallic materials	A report explaining the structure and mechanical properties of a range of non-metallic materials and examples of where these materials are used in an engineering and/or industrial context.
B Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them	**B1** In service behaviour of non-metallic materials **B2** Destructive test procedures to determine mechanical properties **B3** Material defects in non-metallic materials **B4** Non-destructive tests used to identify material defects	A portfolio of results gathered from tests on samples of given materials, supported by a logbook, images and observation records.
C Explore the in-service failure of non-metallic components and consider improvements to their design	**C1** Ductile and brittle fracture **C2** Creep failure **C3** Fatigue failure **C4** Degradation processes **C5** The contribution of design to prevent component failure	A report containing investigative research into the causes of in-service failure of given engineering components and suggestions as to how these might have been avoided.

Assessment guidance

The assessment of this unit is most likely to be in the form of written reports for learning aim A and learning aim C and a portfolio or logbook of test procedures, results and analysis for learning aim B. There is flexibility in the forms of evidence that are acceptable as long as the work submitted fulfils the necessary requirements of the assessment criteria and is individual to each learner.

Evidence for learning aim A is most likely to be in the form of an illustrated written report that will include appropriately referenced images and diagrams to support the text. You should encourage learners to use standard referencing methodologies such as Harvard or APA to enhance the presentation and professionalism of their written reports.

It should be noted that the Distinction assessment criteria for this learning aim makes specific reference to the use of 'vocational and high-quality written language'. This precludes the use of certain types of evidence such as a video narrated by the learner unless a transcript of the narration is also provided.

Learning aim B involves a significant amount of practical work and related data so is most likely to be presented as a portfolio of evidence that should be well organised and structured logically. Evidence should include notes, diagrams, photographs, test results and observation records relating to the destructive test procedures carried out by learners. Reference data, analysis, research and further written elements may all be required to cover the assessment criteria in full. It would be acceptable for learners to include a presentation, learner narrated video or other form of evidence as part of their portfolio.

Evidence for learning aim C will most likely be in the form of an illustrated written report that will include appropriately referenced images, diagrams and/or photographs to support the text. Observation records should be used to support evidence relating to the component inspection carried out by learners. Alternatively, evidence could be in the form of a presentation. This may include embedded video of the learner carrying out component inspection activities. Once delivered in front of an audience, a copy of the presentation, including presenter notes, should be submitted for assessment by the learner. Where presentations are used you should provide an observation record detailing their content and effectiveness. This will greatly assist you when formally assessing the evidence and during any subsequent internal verification.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 26: Mechanical Behaviour of Non-metallic Materials

Introduction

The range and capabilities of materials available for use by engineers today has never been greater. The dominance of metallic materials is reducing in a range of applications where the properties of relatively new non-metallic materials provide a variety of advantages.

You should make clear to learners that there are a vast number of non-metallic materials (which should be obvious from the definition of non-metallic, i.e. all materials that are not metals). In this unit you will only consider a manageable selection of polymer, ceramic and composite materials. The unit also focuses on mechanical properties and, although some degradation processes are considered, many other important aspects of material behaviour are not explicitly discussed (eg electrical properties). This unit is an introduction to a selection of areas that are relevant in a mechanical engineering environment.

This unit aims to give your learners an appreciation of the advantages and limitations of a range of non-metallic materials and an understanding of why and how they behave in service. It will equip them with the skills to analyse mechanical properties and explain these in terms of material microstructure. Learners will gain practical experience of working with a range of materials by carrying out destructive tests to establish key mechanical properties. They will analyse how and why materials fail in service and the design considerations that might prevent recurrent problems. Your delivery of the unit would be greatly enhanced with the involvement of industrial partners, who might help develop case study materials, provide material or component samples, or provide site visits and visiting speakers to help contextualise the unit content.

As part of your teaching, you will work with learners to develop the analytical skills necessary to form links between the different elements within each learning aim and across the unit as a whole. Under your guidance, they will develop systematic and effective research skills from a range of sources. For example, they may develop research skills not only by using web-based information but also by using appropriate reference books, technical specifications and by raising questions with industry experts during industrial visits or during conversations with visiting speakers.

Your learners will also develop practical skills and learn the importance of safe working practices when carrying out a range of destructive testing to determine the mechanical properties of non-metallic of material samples. You will find that the opportunity to work with materials 'hands on' will help to engage and retain learner interest and reinforce the theoretical aspects of the unit.

Learning aim A – Investigate how the structures of non-metallic materials influence their mechanical properties

Learning aim A will provide your learners with the theoretical underpinning for the practical activities in subsequent learning aims.

- As this learning aim is mainly theoretical, it will help to engage learners if you have a range of components, products and/or material samples to introduce during teaching. In your first lesson, you might like to use a range of material samples in group work and encourage learners to categorise them into different material groups. This will get them thinking about the visual, physical and mechanical properties that characterise them and their suitability for use in different applications. As you introduce sub-categories within each material type (eg amorphous or crystalline ceramics, thermoplastic or thermoset polymers) further categorisation of the artefacts will help reinforce learning.

- Once material types and their general characteristics have been effectively introduced, you can start to discuss the structure of the materials. This needs to consider the fundamentals of atomic and inter-molecular bonding mechanisms in polymer and ceramic materials. For composites, the structure of the fibre or particle and matrix phases should initially be considered in isolation. Learners will require an understanding of how the contrasting properties of the two phases work in combination to provide enhanced material characteristics and how this can be customised by varying the composition of the composite.
- You might consider establishing cross-curricular links with science colleagues in your institution when planning the delivery of this learning aim. It is highly likely that they will have established resources to cover many of the topics covered. They may well have molecular modelling kits that could be used during teaching. Hands-on and visual aids will help you to explain the microstructure of materials more effectively. Simple polymer molecules could be constructed by learners and, with the addition of crosslinking, these will illustrate the differences between thermoplastic and thermoset polymer structures. Models of ceramic crystal structures will help to explain why this group of materials generally exhibit high hardness. Molecular and atomic modelling is also useful when introducing more complex material behaviours (such as creep) later in the unit.
- You should give learners the opportunity to conduct independent methodical research using a range of resources during this learning aim. They should investigate the microstructures of a range of materials from each group, to see how these relate to the mechanical properties of the material and appropriate applications. The ability to work independently is an important skill and will be a key element of any future higher-level study.
- Analysis of how and why the mechanical properties of materials within the same group differ from each other is a key element of this learning aim. You should guide learners to develop effective analytical skills and emphasise the importance of communicating clearly using appropriate technical written language. These are transferable skills valued by employers and apprenticeship providers.
- When you are confident that learners have the required technical understanding and analytical skills you should issue the first assignment that covers this learning aim.

Learning aim B – Explore safely the mechanical properties of non-metallic materials and the impact of structural defects on them

Learning Aim B is primarily practical in nature. It builds upon and reinforces the skills and technical knowledge acquired in learning aim A.

- To deliver this unit you will need to provide learners with access to a range of test equipment and appropriate test samples. When carrying out mechanical destructive testing, large forces are often involved which have the potential to cause serious injury. It is your responsibility to ensure that all equipment and apparatus is safe and suitable for learners to use under your supervision. Learners will require appropriate training and must follow institutional safe working practices. You should also discuss the institutional risk assessments for the activities being undertaken during teaching. Conducting tests safely is essential and is a specific requirement of the assessment criteria for this unit.
- You should give learners the opportunity to carry out a range of destructive tests to determine the mechanical properties of pre-prepared material samples of known

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composition. Ideally, you will have the equipment to conduct a full range of destructive tests to include tensile, impact, creep and fatigue testing. The facilities to carry out tensile and impact testing are a minimum requirement for this learning aim. The use of specialist equipment may present logistical problems depending on group size and this must be carefully considered when planning the delivery of this learning aim.

- Each learner will require at least eight pre-prepared test samples. These will consist of four identical pairs from four contrasting materials. Two of the material pairs should come from the same material group (i.e. polymer, ceramic or composite) and two from another. Tests should be repeated on pairs of identical samples to ensure results are consistent. You may find it easier to obtain or fabricate polymer and composite test samples rather than ceramic ones but you could choose to use any two of the three groups.
- You should guide learners on how to maintain a logbook containing detailed notes, sketches, photographs and the results of their test activities. You will also need to complete individual observation records detailing the practical work carried out by each learner. These will be included in each learner’s portfolio of evidence for this learning aim.
- You should build on learners’ developing research and analytical skills by asking them to identify, access and interpret data from accredited sources. Here they will need to look up reference values for the mechanical properties of a range of materials from each material group (i.e. polymer, ceramic and composite) including those that have undergone testing. These could be used to determine the accuracy of the tests they have carried out and to support further analysis on how key mechanical properties affect the in-service behaviour of specific materials from each group.
- Due to the expense and potentially hazardous nature of some non-destructive testing techniques, these will not form part of the learners’ practical work. Instead, these might form the focus for independent research. If your institution has access to ultrasonic or radiographic test equipment, then, of course, these should be demonstrated and discussed during the delivery of this learning aim. It is anticipated that most institutions will not have direct access to such facilities.
- This topic presents you with the opportunity to establish links with a local industrial partner. Industries from a range of engineering sectors use both destructive and non-destructive test procedures as part of their quality assurance processes. If you could arrange an industrial visit or perhaps a visiting speaker during the delivery of this learning aim, then it will help to increase learner engagement and provide the opportunity to ask questions of an industry professional.
- It is important that you clearly explain the types of internal and microstructural faults that can be detected by non-destructive testing. This could be reinforced by carrying out destructive tensile tests on material samples where structural flaws have been deliberately introduced. For example, rods of acrylic manufactured to include internal air bubbles for decorative purposes are widely available. These could be used to help demonstrate the decrease in tensile strength caused by voids within a polymer component.

You should ensure that you have allowed for sufficiently in depth analysis and research to cover the required content before issuing the second assignment, which covers this learning aim.

Learning aim C – Explore the in-service failure of non-metallic components and consider improvements to their design

- Before you begin the delivery of learning aim C you should ensure that you have sufficient case study material and suitable examples of non-metallic components that have failed in use. This learning aim will be difficult to deliver without the involvement of industrial partners who can assist with the development of resources and supply the failed components required during learning activities and assessment. Contacting mechanical maintenance and servicing companies might be a good place to start, as these are likely to encounter failed components in a range of materials on a regular basis. You might consider approaching photocopier or motor vehicle repair specialists, aerospace or wind turbine maintenance providers, for example.

- Once you have established an appropriate set of resources you can introduce learners to the mechanisms that lead to component failure. Learners will have encountered ductile and brittle fracturing, creep and fatigue failure during the testing they carried out in learning aim B. This learning aim should expand and deepen their understanding by considering the causes of microstructural breakdown within the material that leads to failure.
- During teaching, you should discuss the features which typically characterise each type of failure mechanism taking into consideration the in-service conditions under which the component operated. This could be supported using the case study material developed for this learning aim. For instance, the brittle fracture of a component made from a known polymer could be used as an example in teaching. Through visual inspection of the fracture surface, it might be found that the ripple marks indicative of fatigue crack propagation are visible. If the case study material confirms that the component had been exposed to vibration or some other form of cyclic loading in-service, then it is reasonable to assume that this is the key failure mechanism. Learners might then discuss, in groups, aspects of the component design that might leave it vulnerable to fatigue failure and what could be done to make the component more reliable. This could lead them suggesting a change of material to one with a higher fatigue resistance or changing the shape of the component to eliminate stress raisers such as sharp corners.
- In a similar way, moisture ingress causing matrix breakdown in composites, UV degradation and associated embrittlement in polymers or thermal shock cracking in ceramics, could all be discussed and analysed.
- You will need to work with learners to develop the observation skills necessary to carry out effective visual inspections on a range of failed components. You will need to write an observation record to record these activities to support their other assessment evidence. A key aspect of this learning aim is for learners to suggest feasible solutions to help prevent recurrent problems with components that have failed in service. This will require your learners to use a combination of confidence, technical knowledge, analytical skills and a systematic approach, to link all the elements of the learning aim.
- When you are confident that your learners have developed the necessary knowledge and skills, issue the third assignment that covers this learning aim.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 25: Mechanical Behaviour of Metallic Materials*
- *Unit 45: Additive Manufacturing Processes*
- *Unit 47: Composites Manufacture and Repair Processes*
- *Unit 52: Airframe Construction and Repair*
- *Unit 53: Airframe Mechanical Systems.*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Boyce A *et al.* – *Engineering Level 3 BTEC National* (Pearson, 2010) ISBN 9781846907241.
  Pages 263–302, the chapter 'Properties and Applications of Engineering Materials' deals with several topics relevant to the teaching and delivery of this unit.
- Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units*, *3rd Edition* (Newnes, 2010) ISBN 9780080965772.
  Chapter 4, 'Properties and Applications of Engineering Materials' deals with several topics relevant to the teaching and delivery of this unit.
- Howes P and Laughlin Z – *Material Matters New Materials in Design* (Black Dog Publishing, 2012) ISBN 9781907317736.
  This book covers a wide range of materials, their applications and a qualitative description of key properties. It focuses on novel applications for modern materials including polymers, ceramics and composite materials.

Videos

- The Secret Life of Materials, DVD, ASIN B00OP2H2G4.
  A three part BBC documentary series presented by material scientist Mark Miodownik introducing the history, characteristics and applications of metals, polymers, ceramic and composite materials. An engaging way to introduce many of the topics covered in this unit.

Websites

- www.grantadesign.com/education/edupack/index.htm
  Granta Design. CES EduPack™ is a package designed to support teaching of materials, engineering, design and sustainability. It provides a comprehensive database of materials, process information and a range of other resources.
- www.iom3.org/education
  Institution of Materials, Minerals and Mining. The UK's professional body for materials engineers may be able to provide resources and support in the delivery of this unit.
- www.matweb.com
  MatWeb. A searchable database of material properties including data sheets for thermoplastic and thermoset polymers, ceramics, plus fibres, and other engineering materials.

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Unit 27: Static Mechanical Principles in Practice

Delivery guidance

Approaching the unit

This unit builds on the scientific principles investigated in mandatory *Unit 1: Engineering Principles* and hence it is suggested that it is delivered after or at the same time as *Unit 1: Engineering Principles*. The unit content is structured so that learners are able to apply static mechanical principles to the investigation of real life situations such as frameworks and beam components in bridges. To stimulate enquiry and investigation, your learners should combine theoretical studies with significant amounts of simulation and laboratory investigation. One of the key elements of this unit is to encourage your learners to mathematically model a situation, set up experimental equipment and then evaluate experimental results.

Throughout the delivery of this unit, you should relate all teaching to actual engineering situations and make it clear to your learners that what they are learning is applied as opposed to pure science. Learning aim A investigates the effects of forces on pin-jointed framed structures that are in static equilibrium; graphical and analytical techniques are covered. You will then move on to explore the effects of point and distributed loads applied to simply supported and cantilever beams (learning aim B). There is scope here to do a useful amount of laboratory investigation; when investigating bending moments in beams, your learners will need to use differential calculus techniques that could have been learnt via *Unit 7: Calculus to Solve Engineering Problems*. Learning aim C pulls everything together by allowing your learners to apply scientific principles to a design case study.

To complete this unit your learners will need access to a spreadsheet package.

You can use a range of delivery methods in this unit, such as:

- formal teaching
- individual and small-group investigation
- structured worksheets
- laboratory investigation
- computer simulation
- case studies.

Learners will benefit from access to web-based mathematics support.

You should make your learners aware that your formal teaching will be supported by a significant amount of practical work involving the use of scientific equipment. During their investigations, your learners will mathematically model situations involving static forces, set up and use experimental equipment and then bring everything together to evaluate the success of their practical work. As you deliver the unit, you may wish to carry out virtual experiments using simulation software; this is a useful teaching resource but must not replace activities involving experimental apparatus.

A significant amount of unit content involves the understanding and application of mechanical principles that have remained unchanged for many years, for example the calculation of bending stresses in beams. Your learners will be working with formulae that have been used by engineers for many years, but the way in which the numbers are processed has changed. Calculators and spreadsheets allow heavy-duty number crunching to be carried out efficiently, which, therefore, gives your learners more time to investigate the application of what they have learnt to real engineering situations. For learning aims B and C, there will be a certain amount of 'what if' analysis carried out – this is best done using a spreadsheet.

Learning aim C allows your learners to apply the principles that they have learnt to the design of structural components. They can also draw on knowledge gained in other units, for example the mechanical properties of materials, so you can now really pull everything together and consolidate their understanding.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Introduce learning aim A by showing your learners examples of framed structures. Unless they are traditionally made roof trusses, the joints will be rigid (for example a welded steel frame) and you should explain that to analyse a rigid jointed frame is too difficult to do at Level 3. Start by looking at fairly simple triangulated structures such as roof trusses and explain that the analysis will involve considering joints that are free to pivot. You could demonstrate a pin joint by using two pieces of strip aluminium and a nut and bolt. Then take four strips and build a quadrilateral; show how it collapses. Next, introduce the concept of triangulation, by adding a cross member to the quadrilateral so that it becomes stable. Your learners will now be looking at a structure that is statically determinate and in equilibrium; show your learners other examples of where triangulation produces stability, for example a Warren girder and its adaptation to structures such as lighting and sound rigs at music events.

Explain to your learners how to carry out two dimensional analysis of frameworks using graphical and analytical methods. This may require some revision of how forces are represented using vectors and the way that they can be manipulated by diagram and resolution. The aim is to lead learners into being able to work systematically through a framework by constructing space, funicular and reciprocal (vector) diagrams or by joint resolution into components that are mutually at right angles. The benefits and limitations of each method should be explained, with analysis supported by practical demonstration using laboratory equipment. You should emphasise the importance of correctly presenting the results of analysis, for example, using a tabular layout, strut or tie coding or force magnitude.

The intention is that the structures analysed in their entirety should have about twelve members and two support reactions – one a roller and the other a pin. To provide extension activities, learners could be given the opportunity to investigate the method of sections on frameworks that have more than twelve members.

You should introduce learning aim B by explaining why beams are such an important part of everyday life, and why, in most situations, they operate in a complex environment. Explore why the terminology 'simply supported' does not necessarily mean that the analysis your learners will be doing is particularly simple. In fact some of the analysis is very complex and requires your learners to apply differential calculus methods. There are documented case studies of beamed structures that failed in-service because design requirements were wrongly interpreted during construction. Perhaps use some of these to reinforce why it is important to establish the loading envelope of a beam before starting on design calculations.

Delivery of this learning aim should be supported by plenty of hands-on experimental activity by yourself and the learners. Start by working through the terminology used when carrying out beam analysis, for example hogging, sagging, sign conventions, uniformly distributed load. It is important that, when presenting evidence for assessment, your learners use correct conventions. They can then move on to investigate how different loading configurations affect the support reactions, shear forces and bending moments in a range of simply supported and cantilever beams. Theoretical beam analysis should be used to develop shear force and bending moment diagrams; from the diagrams the positions and magnitudes of the maximum and minimum bending moments can be estimated. Having done this, differential calculus can then be used to determine their exact positions and also (where applicable) the point(s) of contraflexure.

You should run practical demonstrations using laboratory equipment in parallel with the teaching of beam analysis. Your learners should have access to this equipment so that they can develop their experimental techniques and be able to make accurate judgments about how their calculated values for shear force and bending moments compare with experimental values.

Introduce learning aim C by explaining that, having determined the forces carried by structural members and beams, the stresses and strains that these forces produce need to be considered. At this point, it is worth referring back to learning from *Unit 1: Engineering Principles* and picking up on concepts such as direct stress and strain, shear stress and strain, elastic constants and tensile and shear strength. Learning aim C has much more of a design flavour because it involves investigating the effects of forces on 'real' components. Investigations will involve theoretical analysis of engineered components that are subject to axial, bending, shear and combined loading. This pulls together knowledge delivered in learning aims A and B.

The topic on bending loading involves applying the bending equation and knowledge of second moments of area. The numerical values for the second moments of areas of regular shapes can be extracted from published tables or calculated using given formulae. You would expect your learners to be able to work with basic circular, rectangular and square cross section beam shapes (solid and hollow).

To complete this learning aim, you will be drawing your learners into a design environment and they will require knowledge of the mechanical and physical properties of materials; these can be given to them in the form of data sheets.

Learning aim	Key content areas	Recommended assessment approach
A Examine how the forces acting in pin-jointed framed structures influence their structural integrity	**A1** Static parameters **A2** Analysis of statically determinate framed structures	A report containing graphical and mathematical modelling relating to the analysis of given pin-jointed structures.
B Explore safely the shear forces and bending moments in simply supported and cantilever beams	**B1** Beam parameters **B2** Theoretical beam analysis **B3** Experimental beam analysis	A portfolio of results gathered by experimentation when investigating given beam configurations, supported by a logbook, images, observation records, graphical and mathematical modelling (including differential calculus).
C Examine how axial, bending and shear loading affect the design of structural components	**C1** Axial loading **C2** Bending loading **C3** Shear loading **C4** Design considerations	A report containing mathematical modelling relating to the analysis of the stresses and strains in given structural components.

Assessment guidance

This unit is internally assessed and you should use three assignments. Learning aim A is assessed through the use of graphics and analytical methods to solve a statically determinate pin-jointed framework. Assessment of learning aim B combines an experimental activity with theoretical analysis. Your learners will be required to work independently and you will need to plan how each learner can access the laboratory equipment. Learning aim C should be based on a case study that is given to learners as pre-reading because there is a significant amount of structural design calculation and they will need to have access to published data about the physical and mechanical properties of materials, for example density and tensile strength.

Your learners must independently generate hard-copy evidence presented as a portfolio. There is no requirement for them to word process their mathematical manipulations; for most learners, hand written/drawn evidence will be the most time-efficient method of presentation. The use of still photos should be encouraged when carrying out experimental activities. For all three learning aims, learner evidence will be based on fixed tasks. Assessor signed observation records must contain comments about how each learner approached practical tasks, set up equipment, took measurements and processed them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 27: Static Mechanical Principles in Practice

Introduction

Begin by introducing the unit to your learners through a group discussion about the significance of static systems in everyday life, for example structures that remain stable and not liable to collapse. It is worth getting them to think about the difference between statics and dynamics in the context of engineering science. As it is possible that your learners will also be following *Unit 28: Dynamic Mechanical Principles in Practice*, it will help their understanding if you discuss the conditions required to achieve static and dynamic equilibrium.

Explain to your learners that there is a significant amount of mathematical content within the unit, particularly when they come to investigate the maximum and minimum loading conditions in beams through the application of differential calculus. However, it is important to emphasise that there is also a significant amount of practical investigation involving the use of science equipment. From their previous studies, your learners will have experience of carrying out science experiments, usually with the aid of a laboratory task sheet. The intention in this unit is that, when they are carrying out experimental work, learners should be given an overall objective to be achieved but the way in which they approach the task(s) is up to them; some will need guidance, others may not (differentiation within the group). For each learning aim, the thematic nature of the assessment criteria provides scope for your learners to show initiative and the experiments should become true investigative activities.

Where appropriate, use simulation packages to support your formal teaching and learner investigation, but make sure that you do not deny them proper hands-on experience with experimental apparatus. Most of what you will be teaching is applied mathematics but set in realistic engineering contexts. Emphasise that the principles that learners are being taught are used by people whose jobs involve carrying out mathematical modelling of static systems, for example a designer calculating the structural requirements of a new large open-span roof for an airport terminal.

Learning aim A – Examine how the forces acting in pin-jointed framed structures influence their structural integrity

- Using a formal presentation, you could describe different types of pin-jointed framed structures, the components within them, application of loads to the frames and support reactions. It might be useful to illustrate your presentation with images of well known structures, explaining to learners that, at Level 3, they are 'slicing' a structure so that it can be treated in a two dimensional (co-planar) way. The three dimensional analysis is something to keep for BTEC Levels 4 and 5.
- You could lead a whole class discussion about the conditions needed to achieve static equilibrium and how to resolve forces into component. This will build on what was covered in *Unit 1: Engineering Principles* (topic B1).
- You could then demonstrate the techniques for solving statically determinate frameworks (graphical method and analytical method).
- As a class discussion, review how the results of framework analysis should be presented (ie in tabular form using the correct conventions).
- Your learners should work through graded examples of frameworks, either individually or in small groups. This activity will also include practical work using

framed structure apparatus. Your learners can build the frameworks, apply loads and take measurements from load cells. There is scope here to also use simulation software. It is important that your learners develop their experimental technique so that they are properly prepared for the formal assessment activity.

- You could then lead a whole group discussion about the pros and cons of each method, (eg speed, accuracy, visualisation).
- In preparation for the assessment activity you could guide your learners through:
  - carrying out checks to establish if a framework is stable and statically determinate including the preparation of a space diagram of the framework (to a suitable scale and correctly annotated)
  - using the method of sections, graphical methods (including calculations) and analytical methods to determine support reactions and primary forces in a pin-jointed structure
  - justifying the most appropriate method for finding the forces in the central members of a pin-jointed framed structure that carries point loads and presenting their findings as a technical report.
- You should explain to your learners that assessment will be an individual, controlled activity.

Learning aim B – Explore safely the shear forces and bending moments in simply supported and cantilever beams

- Using a formal presentation you could describe simply supported and cantilever beams. There is plenty of scope here to illustrate your presentation with images of structures that have beam components.
- You could lead a whole class discussion about what happens when beams are subject to point and uniformly distributed loads; this was introduced in *Unit 1: Engineering Principles* (topic B1) and will now be developed.
- You could then demonstrate the techniques for finding the shear forces and bending moments in a range of beams.
- Your learners should work through graded examples of simply supported and cantilever beams either individually or in small groups. This activity will also include practical work. Your learners can set up beams, apply loads and take measurement from load cells. There is scope here to use simulation software. It is important that your learners develop their experimental technique so that they are properly prepared for the formal assessment activity.
- Having explored the production of shear force and bending moment diagrams, you should now make a formal presentation about how to establish where the maximum and minimum bending moments occur in a beam. This will require the application of differential calculus methods, which links with *Unit 7: Calculus to Solve Engineering Problems* (topic A4).
- In preparation for the assessment activity you could guide your learners through:
  - setting up beam apparatus by applying various loading configurations and gathering experimental results. The set-up configuration will be based on information taken from a drawing of the beam (reaction positions and loads), and the selection of the most appropriate measuring equipment. Your learners should design the experiment
  - processing results and presenting findings
  - evaluating the results of experimental testing against theoretical analysis (mathematical modelling), for example, analysing where the maximum bending moments occur and comparing with experimental position.

- You should explain to your learners that assessment will be an individual, controlled activity.

Learning aim C – Examine how axial, bending and shear loading affect the design of structural components

- Using a formal presentation, you could describe axial, bending and shear loading. There is plenty of scope here to illustrate your presentation with images of structures that carry combined loading. You should discuss the design implications of accurately determining the stresses and strains produced within components when subject to various forms of loading.
- You could lead a whole class discussion about the repercussions of a product suffering stress failure in-service; there are some well documented exemplars. If appropriate, indicate the links that this learning aim has to *Unit 1: Engineering Principles* (topic B2), *Unit 3: Engineering Product Design and Manufacture* (topic A4) and *Unit 25: Mechanical Behaviour of Metallic Materials* (topic C1).
- Your learners could work through graded examples of engineering components that carry different types of loading (ie calculation of stress, strain and evaluation against published reference data about the mechanical and physical properties of materials).
- In preparation for the assessment activity you should guide your learners through:
  - carrying out a stress analysis and optimising the physical parameters of structural components in order to establish if they are fit for purpose in terms of their load carrying capability
  - analysing complex structures with components carrying axial, bending and shear loads that have produced stress levels exceeding safe working values and suffered structural failure of components
  - redesigning a complex structure (for example a metal walkway between two levels in a shopping centre) to optimise its configuration (eg changing a solid beam component to a box section to reduce mass whilst maintaining strength).
- You should explain to your learners that assessment will be an individual, controlled activity.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 7: Calculus to Solve Engineering Problems*
- *Unit 8: Further Engineering Mathematics*
- *Unit 25: Mechanical Behaviour of Metallic Materials*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Delivery and assessment of this unit requires specialised science equipment including:

- two-dimensional pin-jointed framework apparatus
- load cells
- simply supported beam apparatus (shear force and bending moment measurement)
- solid and hollow section rectangular beams fitted with strain gauges
- strain gauge bridge.

Textbooks

Various A-level pure and applied mathematics books can be used to support the unit.

- Bird J and Ross C – *Mechanical Engineering Principles, 3rd Edition* (Routledge, 2014) ISBN 9781138781573.
  The chapters on statics and strength of materials match nicely to the unit content and all topics in the book have useful revision tests.
- Boyce A, Cooke E, Jones R, Mantovani B, Roberts D and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241.
  This book matches exactly the 2010 QCF specifications but has content that is very relevant to this unit. It contains learner support activities.
- Allen JH – *Statics for Dummies* (John Wiley & Sons Ltd, 2010) ISBN 9780470598948.
  This book provides a fairly light-hearted lead into static dynamic principles.
- Wearne P – *Collapse: When Buildings Fall Down* (Channel 4, 1999) ISBN 9780752218175.
  This accompanied a Channel 4 documentary that may be traceable. It

references design and construction errors leading to fatal collapse and provides interesting background reading for the tutor.

- Titherington D and Rimmer J – *Mechanical Engineering Science, SI Edition* (McGraw-Hill, 1969) ISBN 9780070942523.
  Out of print but relevant to the scientific principles underpinning the unit – useful worked examples for learners.
- Titherington D and Rimmer J, – *Applied Mechanics: Mechanical Science: Level 3, 2nd Edition* (McGraw-Hill, 1982) ISBN 9780070846593.
  Out of print but relevant to the scientific principles underpinning the unit – useful worked examples for learners.

Websites

- www.mathcentre.ac.uk/students/topics
  The mathcentre is a free and very robust resource. It provides easy access to topic review, revision work sheets, tests and animations. Learners can use this site for support when investigating vector representation of forces.
- www.tecquipment.com/structures.aspx
  Software-based virtual experiments to support delivery of the unit.

Unit 28: Dynamic Mechanical Principles in Practice

Delivery guidance

Approaching the unit

This unit builds on the scientific principles investigated in mandatory *Unit 1: Engineering Principles* and hence it is suggested that it is delivered after or at the same time as *Unit 1: Engineering Principles*. The unit content is structured so that learners are able to apply dynamic mechanical principles to the investigation of real-life situations such as lifts in tall buildings, motor vehicles and aircraft. To stimulate enquiry and investigation, your learners should combine theoretical studies with significant amounts of simulation and laboratory investigation. One of the key elements of this unit is to encourage your learners to mathematically model a situation, set up scientific equipment and then evaluate the results of experimentation.

Throughout the delivery, of this unit you should relate all teaching to actual engineering situations and make it clear to your learners that what they are learning is applied as opposed to pure science. Learning aim A investigates how applied force/torque produces acceleration or retardation in linear/angular systems; there is scope here to do a useful amount of laboratory investigation using fairly basic equipment, for example Fletcher's trolley. You could then move on to investigate (in learning aim B) centripetal acceleration and its application to engineering scenarios such as centrifugal clutches and motor vehicles travelling around flat and banked curved tracks. Learning aim C covers lifting machines, applications of linkage systems (for example a packaging machine) and simple harmonic motion.

To complete this unit, your learners will need access to a spreadsheet package.

You can use a range of delivery methods in this unit, such as:

- formal teaching
- individual and small group investigation
- structured worksheets
- laboratory investigation
- computer simulation
- case studies.

Learners will benefit from access to web-based mathematics support.

You should make your learners aware that your formal teaching will be supported by a significant amount of practical work involving the use of scientific equipment. During their investigations, your learners will mathematically model dynamic situations, for example a linked linear rotational system such as a lift car and its winding gear. As you work through the unit, you should show your learners how to set up experimental equipment, gather results and evaluate the success of practical work against theoretical analysis of dynamic systems. As you deliver the unit, you may wish to carry out virtual experiments using simulation software; this is a useful teaching resource but must not replace activities involving experimental apparatus.

A significant amount of unit content involves the understanding and application of mechanical principles that have remained unchanged for many years, for example the calculation of kinetic energy stored in a rotating flywheel. Your learners will be working with formulae that have been used by engineers for many years; what has changed is the way that the numbers are processed. Calculators and spreadsheets allow heavy-duty number crunching to be carried out efficiently, which will give your learners more time to investigate the application of what they have learnt to real engineering situations.

Learning aim C includes a topic about periodic motion; before starting teaching it is worth opening out the discussion with your learners by asking them to think about periodic motion in the wider sense. Having established that all around us there are examples of cyclic/periodic motion (eg phases of the moon), you can bring things back to engineering with a simple demonstration such as a bob weight pendulum or a mass attached to an elastic thread.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, you could introduce the topic by showing a short video clip of a rally car being driven at speed around a circuit. Ask your learners to identify the dynamic forces acting on it and to think about how they are produced; remind them about Newton's laws of motion, which they investigated in *Unit 1: Engineering Principles*. It is important to establish the difference between static and dynamic equilibrium; make the point that if the car were to be kept unused in a garage it would 'last forever' but, when subject to a dynamic environment (ie being driven), things will wear out and break. Reinforce the idea that, generally, it is the dynamic forces that cause the problem; you could contrast the operating envelopes of short-haul and long-haul flights of aircraft. On a short-haul flight, a plane goes up and down many more times than on a long-haul one and this is reflected by how hard the undercarriage has to work. Another example might be to contrast a car that is only driven short distances around town with one with a high mileage that is used mainly on motorways; which car wears out brake components and tyres more quickly?

Having set the scene, you can now move on to look at the linear and rotational motion of objects such as railway trucks moving along straight tracks and flywheels. This learning aim develops theories investigated in *Unit 1: Engineering Principles* so that your learners are able to consider complex systems from the aspects of energy and momentum interactions. There is a lot of scope here to support your formal teaching with relatively simple demonstrations, for example accelerating a mass along an air track and spinning up a flywheel using a hand drill or with a falling mass attached to a cord wound around the axle. Having taken your learners through the theory, they will be able to carry out their own experimentation and develop their techniques in preparation for assessment. As there is a lot of applied mathematics in this first learning aim, you will make it more accessible if you include plenty of demonstrations and case studies.

For learning aim B, you could introduce the topics by doing a very simple experiment that involves string and a plastic cup containing water; whirl the cup around a horizontal plane and then move it into a vertical plane. Demonstrate that the water does not fall out until you stop the rotation; then discuss the centrifuge, starting with the simplest example which is the spin action on a washing machine. You could ask your learners for the reasons why, sometimes, there is excessive vibration during the spin cycle.

This will then lead into the theoretical aspects of centripetal acceleration and centrifugal force. The aim here is to expand the straightforward task of substituting numbers into formulae into the application of theory to engineering situations such as centrifugal clutches and vehicles moving around banked tracks. Analysis involves the use of vector representation, something that will have been covered during the teaching of *Unit 1: Engineering Principles*. The final part of this learning aim covers dynamic balancing – there is scope here to link back to static balance (equilibrium). You could also give a practical demonstration using a balancing rig, but, as this is specialised laboratory equipment, a look at a wheel balancing machine in an auto workshop will suffice. Throughout your delivery, you should encourage your learners to make reference to the formulae sheet that you will give them. The purpose during delivery of the learning aim is application of scientific theory to engineering contexts – not preparation for a memory test.

You could start delivery of learning aim C by showing your learners exemplars of lifting machines and lever systems; hardware, simulation or video. Do remind your learners that they were introduced to lifting machines during the teaching of *Unit 1: Engineering Principles* and that now they will be investigating the operating parameters of these machines in greater detail. The simple lifting systems detailed in the topic content can be covered very quickly and you should be able to move into the more interesting aspects of complex systems, such as a compound gear train winch. If you have access to a vehicle or aircraft maintenance workshop, do take your learners to see this equipment. If you can get hold of the specification for a particular piece of equipment, you can go back to the classroom and model it using numbers.

The final topic for learning aim C is periodic motion. There are a number of simple demonstrations that you can carry out during your formal teaching; a good one is to use a long, slinky helical coil spring to which you attach different masses. Fix one end of the spring and allow the other end to hang vertically. Attach each mass, in turn, and set it into vibration by pulling down and releasing. Count the number of oscillations to determine the natural frequency of the system and see how this compares with the theoretical value. It is not in the topic content but will add interest if you develop the demonstration by undoing the fixed end of the spring and gently exciting it by hand with increasing frequency until you hit the natural frequency of the spring/mass. The system will bounce around in an uncontrolled manner – get your learners to think back to the washing machine (learning aim A – rotational systems).

Learning aim	Key content areas	Recommended assessment approach
A Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems	**A1** Dynamics of systems undergoing acceleration **A2** Linear systems **A3** Rotational systems **A4** Complex systems	A portfolio of results gathered by experimentation when investigating linear and angular motion and by theoretical calculation, supported by images, observation records and mathematical modelling.
B Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems	**B1** System parameters **B2** Rotating systems **B3** Dynamic balancing	A report containing research on a rotating system and mathematical modelling of the system.
C Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems	**C1** Parameters of lifting machines **C2** Lifting machines **C3** Relative velocity **C4** Periodic motion	A report containing mathematical modelling of lifting machines and linkage mechanisms, as well as experimental results gathered when investigating a simple pendulum and mass-spring system.

Assessment guidance

This unit is internally assessed and you should use three assignments with combinations of assessment criteria as listed in the unit specification. It is important to stick to these combinations because of the way that they are funnelled in order to achieve a thematic approach.

Your learners must independently generate hard-copy evidence presented as a portfolio. There is no requirement for them to word process their mathematical manipulations; for most learners, hand written/drawn evidence will be the most time efficient method of presentation. The use of still photos should be encouraged when carrying out experimental activities. For all three learning aims, learner evidence will be based on fixed tasks. Assessor signed observation records must contain comments about how each learner approached practical tasks, set up equipment, took measurements and processed them. Where experimentation is involved you will need to plan how each learner can access the laboratory equipment.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 28: Dynamic Mechanical Principles in Practice

Introduction

Begin by introducing the unit to your learners through a group discussion about the impact that dynamic systems have on everyday life, for example cars, planes, machinery or anything that moves. It is worth getting your learners to think about the difference between statics and dynamics in the context of engineering science. As it is possible that your learners will also be following *Unit 27: Static Mechanical Principles in Practice,* it will help their understanding if you discuss the conditions required to achieve both static and dynamic equilibrium.

Explain to your learners that there is a significant amount of mathematical content within the whole unit. However, it is important to emphasise that there is also a significant amount of practical investigation involving the use of scientific equipment. From their previous studies, your learners will have experience of carrying out science experiments, usually, with the aid of a laboratory task sheet. The intention in this unit is that, when your learners are carrying out experimental work, they should be given an overall objective that needs to be achieved but the way in which they approach the task(s) will be up to them; some will need guidance, others may not (differentiation within the group). For each learning aim, the thematic nature of the assessment criteria provides scope for your learners to show initiative and the experiments should become true investigative activities.

Where appropriate, use simulation packages to support your formal teaching and learner investigation but make sure that you do not deny learners proper hands-on experience with experimental apparatus. Most of what you will be teaching is applied mathematics but set in realistic engineering contexts. Emphasise to your learners that the principles they are being taught are used by people whose jobs involve carrying out mathematical modelling of dynamic systems, for example design engineers developing new aircraft and motor vehicles.

Learning aim A – Explore the dynamic characteristics of linear and rotational motion that are applied in mechanical systems

- Using a formal presentation, you could show a short video clip of a dynamic situation involving force and acceleration. A good example would be the launch of a rocket such as the space shuttle.
- You could lead a whole class discussion about displacement, velocity, acceleration and Newton's laws of motion as applied to both linear and angular (rotational) acceleration.
- You could then demonstrate acceleration and the associated accelerating force/torque using experimental equipment.
- Your learners could work through graded questions about linear and angular motion, either individually or in small groups.
- You could then lead a class discussion about energy transfers within dynamic systems.
- Having investigated the component parts of linear and rotational motion, you can bring it all together to mathematically model a dynamic system such as an elevator in a tall building.
- In preparation for the assessment, you could guide your learners through the following activities.

- Set up a simple linear dynamic experiment using a wheeled or air supported vehicle on a smooth horizontal track. Apply an accelerating force to the body and take distance and time measurements.
- Set up a simple rotational dynamic experiment using a flywheel with axle mounted horizontally and accelerated by cord and falling mass. Record the number of turns in the axle when the string is wound up, the diameter of the axle and dimensions of the flywheel. Take distance and time measurements.
- Using theoretical calculations, prepare a model of the simple linear and simple rotational systems and two further models (one for each system) using the experimental results. For example by plotting distance and velocity time graphs and calculating the uniform acceleration of the linear dynamic body.
- Using theoretical calculations, prepare a mathematical model of a complex system, for example a lift cage and its winding gear.

Learning aim B – Investigate the characteristics of uniform centripetal acceleration that is applied in mechanical systems

- Using a formal presentation, you could overview centripetal acceleration and centrifugal force.
- You could lead a whole class discussion about industrial uses for centrifuges and the impact of centripetal acceleration on wheeled vehicles as they are driven around curves and why aeroplanes make banked turns.
- You could then demonstrate how to calculate centripetal acceleration and centrifugal force.
- Your learners should now work through graded examples of application of centrifugal force – clutches, roller coaster, wheeled vehicles. For each vehicle, learners should investigate the sliding and rolling over modes – which scenario is worse? Most domestic vehicles are designed to slide (skid) at their limit rather than roll over without warning. Your learners should understand the significance of centre of gravity position and be able to draw vector diagrams to represent forces on vehicles; have a quick look at the Swedish Moose test (YouTube video clips are quite entertaining).
- Discuss dynamic balancing and its applications, for example vehicle wheels, aero engine rotating parts and electric motor armatures. Illustrate the destructive problems caused by out-of-balance forces – there are several YouTube clips about aero engine testing/failure to pick from.
- Demonstrate how to analyse the balancing of a two dimensional system of rotating point masses and follow up by asking learners to work through examples.
- In preparation for the assessment, you could guide your learners through the following activities.
  - Mathematically model the dynamic performance of simple rotating mechanical system comprising a single point mass as it rotates at constant angular velocity; calculate the centripetal acceleration and the corresponding forces.
  - Mathematically model a two dimensional system of unbalanced rotating masses and determine the magnitude and position of the balancing mass needed to achieve dynamic equilibrium.
  - Mathematically model complex rotating mechanical systems and analyse their performance, for example, the operation of a centrifugal clutch or the overturning and sliding properties of a vehicle moving at constant velocity around a curved banked track.

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Learning aim C – Explore the characteristics of lifting machines, relative velocity and periodic motion that are applied in mechanical systems

- Using a formal presentation, you could start by giving an overview of lifting machines and their uses in engineering situations. Expand this out into a whole class discussion.
- Demonstrate how to analyse a range of lifting devices and calculate their dynamic parameters.
- Learners should work independently or in small groups to investigate lifting machines.
- Give an overview of linkage mechanisms, for example a quick return mechanism in a packaging machine, and demonstrate how to determine relative velocities by constructing velocity diagrams (vector analysis).
- Your learners should then carry out graphical exercises to determine relative velocities.
- Make a formal presentation about periodic motion – illustrate this with engineering applications. Expand the presentation to include systems that have torsional properties, for example determining the natural frequency of a flywheel on a shaft.
- Learners should carry out investigations using spring/mass apparatus and bob weight pendulums. They should analyse the arrangements and compare calculated values with measured ones, for example natural frequency and periodic time.
- In preparation for the assessment, you could guide your learners through the following activities.
    - Determine the dynamic parameters of lifting and linkage systems.
    - Set up a simple pendulum (string and bob weight) experiment and time its swings for different lengths and attached masses. Compare experimental results with calculated values.
    - Set up a simple spring (with low stiffness) experiment and time its vertical oscillation for different initial displacements and mass. Compare experimental results with calculated values.
    - Evaluate, using mathematical modelling, the performance of a complex dynamic system.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 7: Calculus to Solve Engineering Problems*
- *Unit 8: Further Engineering Mathematics*
- *Unit 24: Maintenance of Mechanical Systems*
- *Unit 50: Aircraft Gas Turbine Engines*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Delivery and assessment of this unit requires specialised scientific equipment including:

- linear air-track kit/Fletcher's trolley with trucks and timing equipment
- flywheel apparatus
- centrifugal force apparatus
- lifting apparatus, eg screw jack, worm and wheel, differential pulley block
- simple pendulum and timing equipment.

Textbooks

Various A-level pure and applied mathematics books can be used to support the unit.

- Bird J and Ross C – *Mechanical Engineering Principles, 3rd Edition* (Routledge, 2014) ISBN 9781138781573.
  The chapters on dynamic principles match nicely to the unit content and all topics in the book have useful revision tests.
- Boyce A, Cooke E, Jones R, Mantovani B, Roberts D and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241.
  This book matches exactly the 2010 QCF specifications but has content that is very relevant to this unit. It also contains learner support activities.
- Titherington D and Rimmer J – *Mechanical Engineering Science, SI Edition* (McGraw-Hill, 1969) ISBN 9780070942523.
  Out of print but relevant to the scientific principles underpinning the unit – useful worked examples for learners.

- Titherington D and Rimmer J – *Applied Mechanics: Mechanical Science: Level 3, 2nd Edition* (McGraw-Hill, 1982) ISBN 9780070846593.
  Out of print but relevant to the scientific principles underpinning the unit – useful worked examples for learners.

Websites

- www.nuffieldfoundation.org/practical-physics/investigating-momentum-during-collisions
  The Nuffield Foundation, in association with the Institute of Physics, provides technical notes about experimental activities, for example the momentum of moving bodies:
- www.mathcentre.ac.uk/students/topics
  The mathcentre is a free and robust resource. It provides easy access to topic reviews, revision worksheets, tests and animations. Learners can use this site for general mathematics support.

Unit 29: Principles and Applications of Fluid Mechanics

Delivery guidance

Approaching the unit

This unit is designed to introduce the learners to, and develop their knowledge of, the fundamental principles of fluid statics and dynamics. It is expected that this subject will be novel to the vast majority of your learners and, as such, should be approached in this light. Wherever possible, students should be guided to draw on previously developed knowledge of physical principles. Stressing the direct links between momentum, conservation of energy, friction and potential and kinetic energy, as related to solid bodies and the principles of fluid mechanics, will aid learners to develop their understanding from a scaffold of familiar phenomena.

Developing confidence in the subject is a key target. Providing opportunities for the learners to develop their own knowledge through practical activities is strongly recommended. Given the opportunities for practical, laboratory activities, it is also recommended that you utilise group learning as a mechanism for knowledge development. Peer learning can be a potent tactic, under appropriate guidance, and it is recommended that you guide the learners in groups to conduct the experiments themselves, record data, and reduce the data to draw conclusions. Allow the learners to solve problems and manage their own learning wherever possible.

The aims of this unit indicate an emphasis on the practical application of fluid mechanics principles to real-world mechanisms. Where possible, you should highlight these connections by indicating the devices that utilise the principles being discussed. Observations of the use of such devices, following the development of theoretical knowledge, will help to embed this knowledge and engender a sense of practical application. All too often, learners fail to appreciate the significance of theory when they cannot comprehend the 'usefulness' of it. Emphasising the practical applications will not only contextualise the learning but also motivate the learners. Where access to such devices is not possible, it is recommended that you arrange for visits to industrial sites where these devices could be observed in action.

A survey of the assessment criteria will quickly show that the entire unit could be assessed through laboratory-based activities. It is also clear from the learning aims that all the theory development could be supported, if not indeed delivered, via laboratory activities. Clearly, however, there is likely to be a limit on available apparatus. From a planning perspective, the primary focus should be on those assessment criteria that stipulate the conduction of experiments. The entirety of the assessment criteria for learning aim B requires access to specific apparatus. Namely, you will require:

- apparatus for the evaluation of volume flow rates and pressure change through straight and tapered pipes
- at least two different flow measurement devices.

Beyond these mandatory requirements, it is recommended that, if possible, the following apparatus be resourced (note that each of the following devices, while generic in description, do exist as specific instructional devices and are readily available through purchase ready for immediate use):

- viscometer
- apparatus for the measurement of buoyancy of submerged and partially submerged bodies
- apparatus for the measurement of force on submerged and partially submerged surfaces
- apparatus for the demonstration of Charles's law, Boyle's law and the Pressure law
- apparatus for the demonstration of pneumatics
- wind tunnel (or other mechanism capable of delivering a controlled, variable speed of airflow)
- pitot tube
- U-tube manometer
- laboratory grade barometer
- apparatus for the measurement of force generated by a jet impinging on a surface
- fluid turbine (Pelton turbine).

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Begin learning aim A with an examination of the properties and characteristics of fluids. Before embarking on the development of theory you should first establish, and develop if necessary, the learners' understanding and ability to apply scientific mathematical notation and the conversion of measurements from one unit system to another. It should be stressed to the learners that accuracy is paramount and the use of appropriate units essential to the entirety of Unit 29. You should anticipate that these seemingly fundamental concepts are often misunderstood or unappreciated by learners and, as such, you should invest a reasonable amount of time ensuring that the learners develop competence in this regard. As part of their professional development, it would be sensible at this stage to stress to the learners the need for always reporting units in all submitted assessment material.

Properties such as viscosity can be difficult to conceive for learners, particularly since, in everyday English, this word is often applied in direct contradiction to its real meaning. A demonstration of viscosity and its variation with temperature is strongly recommended. Linking viscosity to shear stress could be illustrated through the discussion of lubricants in bearing applications. For example, why is it important that an engine be warm before rpm is increased?

Hydrostatic principles can also be developed through experiments and demonstrations. Whether experiments are possible or not, you should seek to link these principles to real applications. For example, buoyancy and Archimedes principle might be examined through the observation of ship operation. Why does the waterline on a ship entering the Panama canal change from its ocean position even though the cargo load has not changed? If you have access to a dry dock it would provide an excellent opportunity for learners to observe the hydrostatic force (on the dock door), as well as buoyancy (of the ship). The application of hydrostatic force and the effects of changing the parameters could be readily demonstrated with an automotive braking system. Perhaps your centre contains a motor vehicle department? This would be an ideal opportunity for the learners to gain experience of applying theoretical principles to an engineering product with which they are likely to be familiar.

Teaching of the gas laws is most typically achieved on a purely hypothetical basis. If you have access to demonstration apparatus, however, there is an opportunity to have the learners derive the relationships between pressure, volume and temperature for themselves through a series of planned experiments. In this way, the learners can gain confidence in developing their own knowledge as well as governing their own time. The derived relationships can then be reinforced with teaching. The combined gas law and the characteristic gas equation can then be introduced and applied using the same apparatus. Alternatively, these combined laws could be demonstrated with a thermometer and a barometer using the air in the classroom, where the derived values for, say, density, could be compared to values recorded for known conditions as reported in data sets such as the *International Standard Atmosphere*. Applications of pneumatics is best achieved through specific demonstration apparatus, but can be adequately explained through simple examples such as bicycle pumps.

For learning aim B, demonstration of laminar and turbulent flow regimes is best achieved via apparatus that closely mimics the original experiments of Reynolds. Where such equipment is not available, video footage, readily available on the internet, of such flow regimes, illuminated by one technique or another, will suffice. Both continuity of momentum and Bernoulli's equation can be demonstrated excellently with a wind tunnel. A simple contracting and diverging test section and a pitot probe could be used to demonstrate the relationship between total, static and dynamic pressure. Comparison of experimental results with continuity can be used to illuminate the shortcomings of Bernoulli's equation, namely, that it is an inviscid solution. You could ask the learners to conduct the experiment using Bernoulli's theorem and present the data. Then have them use continuity for the same ends and leave them to observe the different result. Ask the learners to investigate why the data diverges. During such experiments, you could ask the learners use a U-tube manometer to record the total and static pressures and hence reinforce the learning regarding hydrostatic pressure.

As stated previously, learners must perform experiments on the changes in parameters caused by contraction in a pipe system as well as different mechanisms for flow rate measurement. Most apparatus designs that satisfy this requirement will also include either a venturi meter or an orifice meter or both, in addition to the static pressure tappings throughout the length of the pipe system. The theoretical material could be delivered via demonstration on the apparatus for one set of conditions and the assessment then carried out for a different set of conditions. This would provide two opportunities for learning. Fundamentally, the learners must be able to see the wider ramifications of the theory that they have learned. What are the quantifiable losses in pumping power in a pipe network of given dimensions? What effect will the surface quality of these pipes have on the energy loss? You could require the learners utilise a Moody plot to calculate the potential differences due to surface roughness. If possible, arrange for a civil engineer from the local water utility provider to visit your learners, or arrange for them go to the plant, so that they can see, at first hand, the implications of pipe length, diameter etc. on available pressure at the consumer point compared with the power input to the system by pump and/or potential difference.

For learning aim C, fluid linear momentum principles are close enough to the solid mechanics counterparts to make guiding the learners from previous knowledge of Newton's laws to fluid laws relatively simple. You should stress that these laws are fundamentally derived from, and by, Newton. Determination of the forces generated by jets impinging on solid surfaces can be carried out with the correct apparatus, and changes in force due to surface shape, orientation, jet shape, jet size and mass flow rate can be readily measured. Note that the momentum principles and nozzle systems can both be demonstrated with the same apparatus, providing that the ancillary parts (different nozzles) are available. Linking nozzle systems to rocket systems is relatively simple since the changes in geometry of one has the same effect on the other. It can be difficult for learners to conceive of an engine that reacts against itself rather than some other medium and, as such, care must be taken to ensure that they understand the relationships between temperature, pressure and velocity of rocket gases within the exit nozzle. Connecting these theories to real rocket stages, such as were used in the *Apollo* missions (the data for these is in the public domain and easily resourced) is an excellent way of enthusing the learners: 'Today you are going to carry out the same calculations as performed by the NASA Apollo engineers.' Demonstration of fluid turbine principles can be difficult without access to appropriate demonstration equipment. It is highly recommended that, when resourcing either the apparatus for demonstrating pipe flow or the apparatus for demonstrating impinging jets, you include a Pelton wheel in the purchase. It is usual that manufacturers of such apparatus will supply Pelton wheels for both of these set-ups.

Learning aim	Key content areas	Recommended assessment approach
A Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems	**A1** Properties and characteristics of fluids **A2** Hydrostatic fluid principles and applications **A3** Pneumatic fluid principles and applications	A report covering the nature of fluids and the analysis of static fluid principles and their application in hydrostatic and pneumatic components and systems.
B Explore the application of dynamic fluid principles to internal fluid flows and measurement systems	**B1** Dynamic fluid principles **B2** Piped internal fluid flows and measurement systems	A portfolio of results gathered by experimentation when investigating fluid flows and internal fluid flow measuring instruments and associated piped systems, supported by images, observation records, graphs and mathematical analysis.
C Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation	**C1** Fluid linear momentum principles **C2** Nozzle systems and fluid turbines	A report covering the nature and analysis of fluid linear momentum principles and their application to the operation of rocket systems, nozzle systems and fluid turbines.

Assessment guidance

This unit will be internally assessed. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate hard-copy evidence that can be authenticated. The main sources of evidence are likely to be portfolios containing reports, graphs, mathematical analysis and observation records. There is no requirement for learners to word process their mathematical manipulations; for most learners hand-written/drawn evidence will be the most time efficient method of presentation. The use of still photos should be encouraged when carrying out experimental activities. BTEC assessors should complete observation records; note that observation records alone are not sufficient sources of learner evidence and that the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 29: Principles and Applications of Fluid Mechanics

Introduction

The key to motivating the learners through this significantly analytical unit will be through contextualisation and inspiring examples. Wherever possible, indicate that the theories being discussed and expounded have real-world applications. What are the applications? Which devices? Furthermore, what employment opportunities are there for an individual with skills in fluid mechanics?

It is strongly recommended that you made the widest possible use of practical learning through guided experiments. This will not only relieve the tedium of dry mathematics but also provide opportunity for self-guided learning and development of management and communication skills within a structured, active learning environment. Where possible, allow the learners to derive the relationships themselves from the observations they make. This learning can then be reinforced with the formal theory followed by application to engineering examples.

Learning aim A – Examine the application of static fluid principles that power hydrostatic and pneumatic components and systems

- Difference between properties of liquids and gases
  - Begin with a survey of the learners' understanding of units of measurement. Are they aware of the SI system? Do they understand its significance? Do they know what the specific SI units are for each of the quantities they will be using throughout the unit?
  - Scientific and engineering notation of magnitudes. Indicate to the learners that they will be encountering very large and very small numbers. Why is it important to adopt notation styles? What are the common practices in engineering?
  - Develop the learner awareness of the importance of accuracy. Why are there this many decimal places and no more or less?
  - Review their understanding of basic quantities. mass, weight, acceleration velocity, etc. Introduce pressure, density, compressibility and modulus.
  - Conduct basic exercises in calculating pressure from given areas and forces, and then in volumetric change.
- Viscosity
  - Introduce the concept of viscosity. Illustrate that this is a material property. A practical illustration with a spoon and a jar of honey can work well. Why does the honey drain out of the spoon and back into the jar?
  - Demonstrate the use of a viscometer. Follow this with a structured experiment designed to derive the viscosity of a range of fluids (eg honey, water and oil). Note that this, as a first experiment, is relatively simple and will present learners with an opportunity to develop scientific technique and discipline at an early stage before encountering the more demanding experiments in later stages of the unit. Stress the need for clear and concise recording. You may wish to arrange for the learners to work in groups, which will require task distribution and management.

- Perform a second experiment designed to illustrate the variation in viscosity with temperature. This can use the same fluids as in the previous experiment. You may wish to ask different groups to investigate different fluids and then present the data to the class. This will emphasise the need for learners to develop clear reporting and communication skills.
- Following on from the previous experiment, you should indicate the difference between dynamic and kinematic viscosity.
- Through the example of two plates separated by a film of oil, or by examination of a boundary layer, guide the learners to see that viscosity is a constant of proportionality that links force applied to the shear stress invoked.

- Surface tension, coefficient and capillary action
  - Surface tension of water can be simply, but brilliantly, demonstrated with the traditional experiment of a needle and a square of tissue floating on the surface of water. Remove the tissue and the needle floats despite its higher density. From here, indicate to the learners that this is due to the unbalanced intermolecular forces of attraction at the surface. Now add soap to the water and repeat. The needle will sink due to the destruction of the bonds.
  - Capillary action follows on directly from surface tension. This could be demonstrated with a glass tube of small diameter suspended in a volume of water. Indicate to the learners that the intermolecular forces of attraction between the water and the glass is higher than between the water molecules, and hence the water rises in the tube (adhesion versus cohesion).
- Characteristics of Newtonian fluids (including air, water, lubricating oils) and non-Newtonian fluids (including pseudo-plastics, Bingham plastics and dilatants)
  - It is recommended that, as an inspiring activity, you demonstrate the fascinating reactions of non-Newtonian fluids to time dependant loads with either starch or custard. The conclusions drawn from such experiments can be used to highlight the differences between Newtonian and non-Newtonian fluids.
- The use of air, water and oils as fluid power mediums
  - You could use examples of industrial mechanisms to discuss the uses of various fluids as power transmission media. This particular topic could be covered during the discussions of hydraulic and pneumatic components and systems in topics A2 and A3.
- Hydrostatic mass ($m = \rho Ah$), weight ($W = \rho Agh$) and gauge pressure (ρgh), absolute pressure, atmospheric pressure
  - Begin this topic by linking the principles of potential energy, as applied to solid mechanics, with those principles that govern fluid mechanics. You might want to introduce the concepts of molecular motion and energy as the driving phenomena behind pressure, in advance of those teaching sessions that will deal with the gas laws.
  - You should demonstrate the use of a U-tube manometer. This could be conducted as an experiment where the learners could use different fluids as the measuring medium (eg water or paraffin).
  - From experiment, link to the principle differences between differential and absolute pressure measurement.
- Pressure measurement, including mercury and aneroid barometers, U-tube manometer
  - This section should be delivered simultaneously with the previous section. The operation of manometers is best understood in the light of the theories involved. Where possible, allow the learners to observe the operation of the different manometer types.

- Buoyancy, forces acting on floating, sinking and rising bodies and Archimedes' principle
  - Begin with a treatment of relative density, and then proceed to considerations of the volume of displaced fluid.
  - Exercises that involve the same body but at differing forced water levels will allow the learners to link upthrust with displaced equivalent weight.
- Partially- and fully-immersed vertical surfaces
  - Thrust force ($F_T = \rho A g h_a$) where h_a = distance to centroid (centre of area). Begin by linking back to hydrostatic pressure fundamentals (depth of fluid being the prime mover when density and gravitational acceleration are constant). Show that the equivalent force can be modelled as a single vector placed at the centroid. Ensure that the learners understand the link between the magnitude of this vector and the summed pressure distribution over the area.

    Distance to centre of pressure (h_c) and the one third from base rule. Begin by indicating that the pressure distribution is triangular in form. Link this to the centroid of a triangle (one third rule). Show that this represents the position of equivalent force.
  - Principle of moments, line of action of net thrust. Revision of fundamentals of moments should be all that is required prior to applying the concept of equivalent line of action.
  - Theory can now be reinforced with experimentation where the relevant equipment is available. The learners should be directed to compare experimentally recorded values with theoretical values. An exercise like this will provide an opportunity for the learners to develop skills in interpretation and problem solving. Prompt the learners to identify why there are differences between the theoretical and experimental values and report their arguments. Link the findings to accuracy and discipline in experimental procedure.
  - Learners should investigate forces and pressures acting on vertical retaining walls of tanks and reservoirs.
- Hydrostatic components and systems, including immersed surfaces, hydraulic actuators, Bramah press, hydraulic braking system
  - The objective here should be to link the theoretical knowledge developed thus far to actual practical application. This would be an ideal opportunity to expose the learners to real devices (such as the car braking system) so that they can link the theory to the operation. A suitable task could require learners to explain how theoretical principles are used in the operation of the devices that they were given to investigate.
- Hydrostatic system parameters, eg cylinder dimensions, input and output forces, internal pressure, input and output motions
  - Following from the suggested task detailed above, you might provide notional dimensions for the device, stipulate the fluids, and ask the learners to carry out the relevant calculations. This will ensure continuity of the tasks as well as contextualisation of the calculations.
- Expansion and compression of perfect gases, including Charles's Law, Boyle's Law and the combined gas laws and their parameters, isothermal expansion and compression
  - Begin by outlining molecular kinematics. Discuss motion and energy states as a function of temperature. Ensure that learners fully comprehend the difference between heat and temperature.

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- Continue by expanding the molecular argument to explain how changes in volume do not change the energy state but do increase the mean rate of molecular collision and hence increase pressure.
- Where equipment is available, a series of experiments that involve holding one of the three variables constant (temperature, volume, pressure) while altering a second and observing the effect on the third will allow the learners to derive the fundamental relationships that constitute the three basic laws. This will also allow the learners to develop their skills in analysis and interpretation.

- Characteristic gas equation, including units, parameters and use of the equation $pV = mRT$ or $p = \rho RT$
  - Prompt the learners to consider the likelihood of one variable remaining constant. On identifying the practical limitations, therefore, of the three laws, introduce the combined law.
  - Derive the characteristic gas equation (CGE) from the combined law and demonstrate its practical use. You might perform a simple experiment involving recording the temperature and pressure outside and using the CGE to determine the density. This value could then be compared to the Met office value reported for the day locally.
- Specific heat of gas, including relationships between characteristic gas constant and specific heats $R = c_p - c_v$ and ratio of specific heats $c_p/c_v=\gamma$
  - Establish the first law of thermodynamics for the learners. Ask them to consider what happens to the internal energy of the gas under conditions of constant volume and then under constant pressure. Show that this is modelled in the specific heat equations.
- Adiabatic expansion and compression of a perfect gas (no heat lost during the process), including formulae pV^γ = constant, $p_1V_1^\gamma = p_2V_2^\gamma$ and $T_1 = T_2(V_2/V_1)^{\gamma-1}$, their parameters and units
  - Introduce the ideal gas law for a system where no energy is lost, only converted, and the process is completely reversible. You may wish to introduce the use of *PV* diagrams at this stage to assist in the interpretation of data. You might also wish to have the learners construct a *PV* diagram for a given scenario as part of the assessment. This could also be contextualised as a real mechanism.
- Buoyancy and applications to balloons and airships
- Application of gas laws and isothermal and adiabatic expansion and compression to pneumatic components and systems, including cylinders, receivers, braking system
- Pneumatic system parameters, eg cylinder dimensions, internal pressures and temperatures, input and output motions
  - With access to a pneumatic demonstration unit, this part of the unit could be delivered through another structured experiment. This would require a range of cylinder dimensions, variable supply pressure and a means of measuring piston displacement. Ideally, the output load provided by the piston should also be measurable. Connecting to real-world devices is again important – you could provide the necessary variables.

Learning aim B – Explore the application of dynamic fluid principles to internal fluid flows and measurement systems

- Laminar and turbulent fluid flow and relationship to Reynolds number $R_N = ud/v_k$, where u = mean velocity, v_k = kinematic viscosity, d = hydraulic diameter of pipe
  - If possible, the qualitative nature of laminar, transitional, and turbulent flow should be demonstrated with a Reynolds number apparatus. Introduce the

concept of the streamline and streamtube to the learners. Link the kinetic characteristics of the flow types to the motions observed in the demonstration.

- Illustrate that the transition of the flow is being driven by velocity, pipe diameter and viscosity. Introduce the Reynolds number. Describe the importance of similarity parameters, like Reynolds, and how they are used. Have the learners consider the question of how to relate observations and recordings made at an experimental scale to real-world cases where all three parameters may be different.

- Continuity equations, including parameters, units and use for steady mass flow $= \rho_1 A_1 v_1 = \rho_2 A_2 v_2$ and for constant density volume flow rate $Q = A_1 v_1 = A_2 v_2$
  - Having already introduced the concept of the streamtube, have the learners consider the effect of changing the CSA of such a tube if it were a closed system. This will also require an assumption of incompressibility.
- Bernoulli's equation, including parameters, units and use of Bernoulli's steady flow energy equation (SF*EE) for incompressible fluid flow*
  SFEE $= mgh_1 + 1/2mv_1^2 + p_1V_1 = mgh_2 + 1/2mv_2^2 + p_2V_2$, and general form of Bernoulli's SFEE $= \rho gh + 1/2\rho v^2 + p = C$ where C = constant
  - Introduce Bernoulli's equation. Focus on the fact that this is also a continuity equation and stress that it is an inviscid solution. Show that if the total pressure remains constant, the static and dynamic pressures must vary in direct inverse proportion to one another. Have the learners explore the idea that if one of these quantities is known the other must be discernible.
  - Introduce dynamic pressure and how this can be manipulated mathematically to arrive at velocity. Again, show that assuming the total and static pressures are known, the dynamic can be computed. Hence, velocity can be calculated. This might be demonstrated via a pitot tube and a U-tube manometer. If you have access to a converging diverging section on a wind tunnel, have the learners survey the total pressure through the section and report the observation that the total pressure does not vary (confirmation of Bernoulli's principle).
  - A further experiment using the same apparatus might be conducted to survey variation in velocity with changing CSA using Bernoulli; however, since the assessment criteria requires an experiment utilising pipe flow, you may prefer to proceed to that experiment. In this case the learners will use the variation in static pressure to establish the dynamic pressure and hence velocity. If this method is utilised, you could have the learners compare their pressure loss results to the Blasius solution, or alternatively, the theoretical solution derived from a Darcy Weisbach (Moody) plot. Velocity distribution could be compared to the data of Nikuradse. This will provide an opportunity for evaluation as well as analysis.
- Internal fluid flow system, including flow through pipe lengths, tapered pipes, inclined and tapered pipes
  - The variation in flow parameters according to CSA change and relative slope would best be communicated via demonstration as detailed above. Here, you would require the ability to alter the inclination of the pipe in question. Introduce the concepts of flow energy, potential energy and kinetic energy. Illustrate the balance of the three as a function of changes in parameter. Link this to the altered version of Bernoulli's equation before proceeding to wall friction and hence energy loss.
- Piped system parameters, eg pressure energy losses, fluid velocities, laminar or turbulent flow determination
  - Return to the demonstration and direct the learners to record pressure loss and velocity distribution for different parameters and link the results to the flow

state (laminar or turbulent). Direct the learners back to previous learning regarding Reynolds number. Evaluation should be conducted in regards the learners connecting the energy loss to the flow state.

- Measuring instruments and systems, eg Venturi meter, orifice meter, manometer, pitot-static tube, velocity meter, turbine meter
  - Dependant on the available apparatus, flow measurement systems should be demonstrated prior to any assessment.
  - Adequate sectioned diagrams should be provided to aid comprehension of operational principles.
- Measuring instrument and system parameters, eg mass and volume flow rates, entry and exit velocities, pressure losses, efficiencies and efficiency coefficients, instrument working section dimensions
  - This could take the form of an experiment where the learners operate the available flow measurement device for changes in the parameters of flow rate and entry velocities.
  - Learners should investigate the shortfalls of these devices such as pressure losses and efficiency. Analysis might take the form of comparing devices and their performance in relation to given conditions. Which instrument would best suit this scenario and why?

Learning aim C – Examine the application of fluid linear momentum principles to nozzle systems and fluid turbine operation

- Newton's laws
  - Work through calculations involving Newton's second law and change in momentum $F = ma = \dot{m}(v - u)$, where $\dot{m}$ is the fluid mass flow rate kg/s and $(\dot{m})$ = momentum force of fluid. Begin by linking these principles to the continuity laws explored in previous sections. As before, link the fluid laws to the solid mechanics laws to emphasise the derivation.
  - Explain Newton's third law in the context of reaction of vane to force of a fluid jet. Introduce the concept of free jets of fluid interacting with solid surfaces. Ask learners to examine the nature of momentum transfer from fluid to solid. Link this principle to the operation of a turbine through simple examples such as paddle mill wheels.
- Force of jet of fluid on surface normal to jet, including $F = mv = \rho A v_2 = \rho Q v$, where $m = \rho A v$ and Q = volume flow rate in m^3/s.
  - Following the broader concepts of momentum transfer, direct learners to consider the analytical methods. Go through worked examples set in real-world scenarios. If possible, carry out the first water jet experiment where the target plate is kept flat but the jet velocity varied.
- Force of jet on inclined flat surface, including use of $F = \rho A v_2 \sin\theta$.
  - Continuing from the previous experiment, direct students to conduct an experiment to directly measure the force exerted on an inclined plate by a water jet. Vary the parameters, such as velocity and angle of plate, such that the learners can observe the impact on delivered force.
- Fluid force acting on walls of a reducer, including use of $F = p_1 A_1 - p_2 A_2 - \dot{m}(v_2 - v_1)$
  - This could be demonstrated and explored through a third experiment with the same apparatus as usedpreviously. This will require the relevant ancillary parts.

- Nozzle systems
  - Learners need to understand the principles of converging and diverging ducts and nozzles, including the relationship with the Venturi principle and resulting changes in pressure and velocity of fluid. Direct the learners to connect the previous learning regarding converging section in pipe networks with the convergence in a nozzle. Follow with the analytical treatment of the case.
  - You should explain nozzle forces, including net force exerted on the fluid of a converging nozzle using $F_N = \dot{m}(v_2 - v_1)$ or from the continuity equation $F_N = (\dot{m}^2/\rho)[1/A_2 - 1/A_1]$ where A_1 = nozzle entry area and A_2 = nozzle exit area at throat. Again, begin by linking to earlier learning. Connect the continuity equation to the converging nozzle and show how the geometric parameter changes drive the output force of the jet.
  - Explain the rocket as a nozzle system, including basic operation, use of convergent/divergent duct rocket control volume for gas flow velocity and pressure changes. Begin by linking the water nozzle activities to a rocket expansion nozzle. Show how the theory might be applied to the design of an exit nozzle and refer to real cases such as the Apollo mission rockets.
  - Work through calculations of rocket thrust, including total thrust force = gas mass flow force plus force due to pressure differential at exhaust nozzle or $F_T = mv_j + (p_j - p_{amb})A_j$, where v_j, p_j = exhaust gas jet velocity/pressure, p_{amb} = ambient pressure and A_j = gas jet exhaust exit area. This might be delivered as pure theory. Alternatively, you might consider the published educational video lectures from the NASA rocket propulsion laboratory. These involve actual rocket engineers expounding the central concepts and analytical methods stipulated in this learning aim.
- Fluid turbines
  - You should explain the operation of the Pelton impulse hydraulic turbine, including function and principles of operation. If possible, this can be demonstrated through experiment. If not possible, focus on the geometry of the Pelton wheel cups. Link back to the learning regarding fluid jets interacting with surfaces. Show that the basic principles of the free jet on the fixed surface can be extended to a mobile cup/plate as would be found on a turbine.
  - Discuss the gas turbine engine, including basic operation, changes in pressure and temperature of the gas passing through the engine and industrial applications.
  - Consider the use of *PV* and *TS* diagrams as a means of elaborating the operation of a gas turbine engine. Indicate the similarity with piston IC engines but stress the fundamental difference of continuous operation and what advantages this can provide.
  - Where the operation of a gas turbine is not possible, consider an industrial visit to the closest airport and the ground crew/maintenance teams. Direct access to the real devices and some explanation from operators would constitute a strongly contextualised experience.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 12: Pneumatic and Hydraulic Systems*
- *Unit 31: Thermodynamic Principles and Practice*
- *Unit 50: Aircraft Gas Turbine Engines*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Widden M – *Foundations of Engineering Series – Fluid Mechanics* (Macmillan, 1996) ISBN 9780333517994.
  This textbook particularly useful as it is pitched at an appropriate level for this unit. Every learning aim of this unit is thoroughly covered, with the exception of rockets, and all theory is supported by multiple worked examples. The author has gone to considerable effort to clearly explain and describe each theory, making it an excellent resource for the students.
- Kinsky R – *Applied Fluid Mechanics* (McGraw-Hill,1983)
  ISBN 9780070729964.
  This textbook covers a large proportion of the learning aims of the unit and, again, carries multiple worked examples for each analytical theory. Furthermore, each theory and worked example is thoroughly contextualised by making reference to real-world devices.

Unit 30: Mechanical Measurement and Inspection Technology

Delivery guidance

Approaching the unit

This is a practical unit, which allows your learners to investigate a range of mechanical measurement and inspection methods. The focus should be on the learners developing practical and research skills to be able to understand the principles and technology applied to a range of mechanical measurement equipment and inspection methods. Your learners will also need to develop and use statistical process control charts to inspect components and determine if the process is in control. They will also undertake a process capability study on a precision manufacturing process to increase productivity and establish whether the process is capable.

You will need to have skills development sessions for applying measuring and inspection methods and your learners should be able to research these methods and apply the knowledge gained. During the practical sessions you will need to ensure that your learners know how to use a range of equipment such as comparators and gauging systems, as well as the more traditional mechanical measuring equipment.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

It would be worthwhile starting learning aim A with a class discussion that introduces your learners to the principles of mechanical measurement and inspection methods used in industry. You could then ask individuals in the group to research separately different principles found under topic A, for example limits and fits, tolerances and gauge types. You need to ensure that they cover clearance, transition and interference types of fit (including maximum and minimum material condition and the use of British Standards and limits and fits tables). The research into gauges should include types and materials of limit gauges (including slip gauges) and the application of Taylor's principle. Once individuals have collected their research information, each could be asked to give a simple PowerPoint presentation to the rest of the group along with a set of handouts that should be given out as supporting 'class notes'.

At this stage, where possible, it would be appropriate if you could arrange a visit to a local company where mechanical measurement and inspection methods are being used. Alternatively, or as well as, you should hold formal practical sessions to develop skills in gauge design. A visit to an engineering workshop in your centre would be useful to identify a range of components that have appropriate features such as holes or shafts, or other external features that could be inspected through gauging.

Learning aim B builds upon some of the areas covered in learning aim A by looking in a more practical sense at carrying out mechanical measurement and inspection methods. Before any practical work, you will need to develop knowledge about the principles applied to measuring practice. The rest of this learning aim could be delivered in a workshop (inspection area) over several sessions in which learners work through a carousel of activities that involve using different types of mechanical measuring equipment, comparators and gauging systems. You may need to supply 'usage sheets' that inform the learners how to use the equipment correctly. The assessment requirements of learning aim B can be used to help you to decide on the range of mechanical measuring equipment, comparators and gauging systems each of your learners need to be exposed to. It will also help you decide what skills they need to develop when using them. According to the staffing levels in your workshops and the equipment available, you will need to develop a strategy that allows your learners to gather skills in at least three types of mechanical measuring equipment and at least two types of comparator. It will be better to have a smaller range of equipment that require high-level skills, rather than providing a wider range of lower-level skills across more equipment. To ensure that you maintain a safe environment while skills development is taking place, some of the group could be given desk-type activities in which they are asked to find out and report to the whole group about different comparators and gauging systems. You should provide many opportunities to cover the theory required to discuss typical manufacturing high-precision processes that are used to produce component features that are likely to need the use of comparators and gauging systems. During these practical skills development sessions, you must ensure that learners work in a safe manner, so consider carefully your staffing levels and learner to staff ratio and the equipment you have available.

Learning aim C requires learners to explore the use of statistical process control (SPC) and, again, has a mix of theoretical, knowledge-based requirements and practical activity. You may wish to hold formal sessions to develop the principles applied to SPC, including statistical methods as outlined in topic C1. Following this, you will need to explain to learners how to design an SPC procedure to control the mean and range to enable process conditions to be monitored. This should include the use of variable and attribute charts.

Learning aim D allows your learners to reflect, in a detailed way, on how the skills they have developed in learning aim C are applicable when checking the capability of a process and carrying out a process capability study. You will need to hold formal sessions in which you explain to learners the procedures involved in designing a process capability study. You will need to give a step-by-step approach to developing specification limits and control chart limits as part of a capability study for a given machine. You will need a range of exercises and data for individual learners to use. You should allow the learners to practise the use of graphical techniques when displaying process capability outcomes and develop their skills of analysis of information relative to process performance. You will also need to show your learners examples of completed process capability reports, which could be sourced from local engineering employers. To develop the skills required in this learning aim, learners should be given opportunities to practise with case study materials, information and data.

<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 (SPC) 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>

Assessment guidance

This unit is internally assessed using instruments that allow your learners access to all of the assessment criteria. The learning aims are the 'building blocks' for assessment. Each assessment instrument should cover a whole learning aim; learning aims must not be split over two or more assignments.

Learning aim A will be assessed thorough a written report which will need to include the design of limit gauges to inspect four different product features including a hole diameter, a shaft diameter, one other external dimension/size and a tapered hole. Analysis should also be included on how the use of slip gauges and different limit gauges rely on the principles of limits and fits and tolerances. For learning aims C and D, each learner will need to produce two separate reports consisting of notes and sketches supported by a developmental log book. The first report will need to show how basic statistics have been applied to the control procedures used during inspection. It should include the design and use of variable and attribute control charts along with the analysis of the process they are controlling. The second report should include a process capability study and analysis of the accuracy of the process used in this study.

The assessment for learning aim B requires learners to demonstrate practical skills. You will need to supply a set of drawings of at least three components and a range of measuring equipment for learners to establish the accuracy of a range of features. There should be at least two different types of comparators and appropriate limit gauges to inspect round and linear machined features on the different engineering components. You should also pay due regard to the texture and geometric features of these components. You should ensure that learners record their evidence in an appropriate manner. This evidence could be gathered in a variety of ways and should include a developmental log book, witness statements/observation records, annotated drawings and photographs and a measurement and inspection report.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 30: Mechanical Measurement and Inspection Technology

Introduction

Many of the products we use daily rely on components being manufactured accurately. The manufacturing process that will be used is governed by the level of accuracy required of the component but, sometimes, speed of manufacture or the ability to shape materials is used to make the choice.

The ultimate aim of this unit is for your learners to explore the selection of and the variation in these processes by which engineers control the manufacturing process and avoid faulty products and/or components being manufactured.

Learning aim A – Explore the principles applied to mechanical measurement and inspection methods as used in industry

- This first learning aim is about gaining a realisation associated with the principles applied to mechanical measurement and inspection methods used in industry. You could begin by having a group or class discussion on the concepts of limits and fits: for example, a brief debate on the different types of fit and the part that tables (ISO, ANSI etc.) play when designing limit gauges.
- This learning aim sets the scene for the practical learning aims in this unit.
- Your learners will require your initial input so that they have an awareness of the different principles applied to the mechanical measurement and inspection methods covered by this unit. You could use a range of slides to show how limit gauges are designed. It is appropriate that you provide this input as this is an important aspect of this unit.
- Once your learners are familiar with the need to design and use limit gauges, you could split the learning by giving responsibility to different learners for different parts of the content. All learners will need to know about all the principles applied to mechanical measurement and inspection methods. A good way to do this could be to ask different learners to research different principles and report back to the whole group through the use of handouts and PowerPoint presentations. You should ensure that the relevant principles found under topics A1 and A2 in each case are covered. Should some of your learners struggle, it would be appropriate to utilise paired work for this activity, which would gradually give confidence to those needing to gain more self-belief.
- Further, your learners will need to consolidate their understanding of the types of fit and concepts of limits and fits. You could use a range of videos to show the different types of fit. You will need to include a formal input on Taylor's Principle when applied to go/no-go limit gauges.
- Before you move on to the gauge types in topic A3, your learners will need to gain an appreciation of the size/level of tolerances achievable by the four different machining processes listed in the content of the unit. You will need to give formal input about these precision manufacturing processes.
- As an alternative or additional approach, which would be different and therefore more engaging for your learners, you could arrange a visit to a local engineering company who could demonstrate a range of processes, explain the tolerances possible with each and make clear the importance to product manufacture.

- Although this learning aim is predominantly a knowledge-based one it is appropriate that you expose your learners to the workshop or metrology laboratory. You will need to demonstrate and explain the use of slip gauges and the care needed during use, maintenance and storage.
- Finally you should involve your learners in either laboratory or classroom activities to design a range of limit gauges, covering component features such as hole and shaft diameter, another external dimension (such as a length) and a tapered hole.
- Delivering this learning aim in the manner suggested will give your learners an opportunity to practise skills in designing, analysing and evaluating the use of gauges following the principles of limits and fits and tolerances, which are part of the assessment requirement for this learning aim.

Learning aim B – Carry out mechanical measurement and inspection methods to determine if components are fit for purpose

- This learning aim builds upon some of the areas covered in learning aim A but in a practical sense. Learners will need to measure a range of component features using different types of mechanical measuring equipment and different types of comparators and gauges.
- You could take an holistic approach and deliver this practical work in association with learning aim A. However, even if you choose to teach learning aims A and B concurrently, in this delivery guide, they have been kept separate.
- Your learners will require your initial input so that they have an awareness of the different principles applied to measuring practice: precision, accuracy, uncertainty and resolution.
- The rest of the delivery for this learning aim could take place in the workshop or metrology laboratory. Each of your learners will need to practise a range of skills in using mechanical measuring and inspection methods.
- You will need to ensure that there is a safe practical environment in which each learner has access to all of the methods covered in the unit content: topics B2, B3 and B4. Alternatively, or additionally, this is something that you could do by demonstrating the use of these methods.
- Learners should gain experience of using several types of mechanical measuring equipment (linear, surface texture, straightness, squareness and flatness, and angular measurement equipment), so you will need to produce a set of instructions for using each piece of equipment in the workshop. These instructions will need to inform your learners how to use the equipment correctly and safely.
- You should implement a 'carousel' of equipment use and it would be appropriate to have technician support throughout these practical sessions.
- You will need to supply other documentation to support the workshop application such as calibration charts, surface texture charts (symbols etc.) and recording documentation.
- To ensure that you maintain a safe environment while skills development is taking place, depending on the size of the group, some of the learners could be given desk-type activities in which they need to find out about different comparators and gauging systems. They could report their findings to the whole group.
- You should allow sufficient time to cover the theory behind the typical manufacturing high-precision processes that are used to produce component features (such as those found under topic B5), which are likely to need the use of comparators and gauging systems to measure or inspect them for accuracy.

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- During this practical work you need to carry out formative assessment of your learners to ensure that they can use at least three types of mechanical measuring equipment and at least two types of comparator.

Learning aim C – Explore statistical process control to inspect components and increase productivity

- It is appropriate that you explain to your learners that not every single component or feature of a manufactured component can be measured or inspected. This will allow you to introduce the reasons for process control and its application through the use of statistics.
- The more theoretical parts of learning aim C could be delivered as formal lectures. It is important to cover all the concepts of data processing concerned with precision manufacturing: eg characteristics of population, sample, sample size, frequency, mean, mode, median, range, variance and standard deviation.
- Further, you could ask different learners to explore different topics from the list of requirements of topic C1 and then report their finding back to the group through PowerPoint presentations accompanied by handouts. Topics for investigation should include the characteristics of the normal distribution, non-normal distribution curves, graphical methods and causes of variation in manufacturing processes.
- You could deliver the rest of the content under topic C1 by engaging your learners in case study activities.
- You could provide the learners with exercises that require them to use graphical tools and analysis, for example bar charts, Pareto diagrams etc. in relation to the variations found in manufacturing processes. These exercises would need to use data that shows a range of causes of variation. Causes such as tool breakage could be highlighted by graphical analysis (which would show a sudden or special event) and variations through tool wear, for example, could be shown by moving trends in a time series chart. This would complete the knowledge-based aspect to this learning aim, but be delivered in a practical manner.
- It is appropriate to develop learners' practical skills concurrently with concentrating on SPC procedures. As each learner will be working at a different rate, you may need to provide a range of different exercises and activities.
- For learning aim C, your learners will be expected to design and use SPC charts which would include and be for both variable control and attribute charts. To accomplish this skills development, you should supply data from processes such as turning or grinding. You will need to supply initial data to enable the control limits to be established and then production data so that your learners can track the machine performance and comment about the outcomes. It would be highly advantageous to gain data such as this from local engineering companies.
- Your learners should be given the opportunity to develop these skills at their own pace, so, once you have demonstrated the procedures and approach to designing SPC charts, you will need to let your learners work through and use the data to design their own SPC charts.
- Presenting data and case study material to your learners in this manner would mean that you will need PowerPoint slides to back up the outcomes that your learners should be maintaining.

Learning aim D – Carry out a process capability study to establish machine suitability for a given application

This learning aim is about reflecting on what has been learnt throughout the unit, especially in learning aim C, with particular reference to the way in which the accuracy of manufacturing processes follows statistical patterns.

- Your learners will require your initial input through formal sessions so that they have an understanding of the procedures involved in designing a process capability study. You could do this as formal lectures which should include:
  - a step-by-step approach to developing specification limits and control chart limits as part of a capability study for a given machine
  - using data to carry out a pre-process capability study, and to produce a modified control chart
  - practising the use of graphical techniques when displaying process capability outcomes
  - developing learners' skills of analysis of information relative to process performance
  - showing your learners examples of completed process capability reports.
- Similarly to learning aim C, a good way to do this would be by using case study materials, information and data, some of which could be from local engineering employers.
- Further, you could ask your learners to research the use of relative precision indexes and the equations used during process capability studies and then share their findings, perhaps by producing a poster to display this information. To give an opportunity for peer assessment, you could allow other learners in the group to make a judgement about the usefulness of these posters and even issue a prize to the one that is judged to be the best. This activity may work well as either paired or group work.
- You will need to provide formal input about the use of modified control charts and discuss changes that could be made to the processes to improve their capability.
- Your learners will require a demonstration on how to prepare a process capability report, so you will need to have examples of good process capability reports to show them.
- Presenting data and case study material to your learners in this manner would mean that you need PowerPoint slides to back up the outcomes that your learners should be maintaining.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- National Physical Laboratory – *Good Practice Guide No. 131 Beginner's Guide to Measurement in Mechanical Engineering* (Institution of Mechanical Engineers) ISSN 13686550.
  This is an excellent resource in the form of a pdf file. It does exactly as it says. A beginner's guide; by far the best resource for the knowledge.
- Bicheno J – *Quality 50: A Guide to Gurus, Tools, Wastes, Techniques and Systems, 2nd Edition* (PICSIE Books, 1994) ISBN 9780951382967.
  This is a good paperback book with a simple-to-read section about SPC. It may be old but it is still relevant.
- Muhlemann A, Oakland J, and Lockyer K – *Production and Operations Management, 6th Edition* (Pearson, 1992) ISBN 9780273032359.
  Although this is a large book, it has a whole chapter on SPC and capability studies and includes a range of illustrations and detailed instructions on how to set up control charts. A 'Lecturer's Guide' (ISBN 9780273037910) is available and has a case study about controlling a lathe.
- Relyea D – *The Practical Application of the Process Capability Study: Evolving From Product Control to Process Control* (Productivity Press, 2011) ISBN 9781439847787.
  This is a good resource for the tutor.

Websites

- www.stemnet.org.uk/ambassadors
  The STEMNET website, providing information and details about STEM Ambassadors for support.

Unit 31: Thermodynamic Principles and Practice

Delivery guidance

Approaching the unit

In this unit, you will introduce learners to the principles of thermodynamics, relating these to practical engineering applications such as the systems found in aircraft, internal combustion engines or coal fired power stations. You will encourage learners to develop their knowledge and understanding of thermal energy production and how thermal energy can be transferred into more useful forms.

You will explore thermodynamic systems with learners, considering the effects of process parameters on these systems. You should introduce learners to both open and closed-loop thermodynamic systems, allowing learners to explore the applications of both types of system, for example, as found in aircraft.

In this unit, you will also demonstrate practical methods which can be used to determine the calorific values of different types of fuel. You should allow learners the opportunity to research the combustion processes for solid and liquid fuel types prior to them conducting their own tests to determine calorific values.

Finally, you will give learners the opportunity to investigate the sustainability of the main types of fuels. Learners should consider the environmental impacts of conventional fuels such as coal, oil and gas and compare these to a range of alternative fuels including LPG, hydrogen and biodiesels.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you could introduce learners to the fundamental thermodynamic parameters which will form the foundations on which theory of thermodynamics is based. You should introduce learners to the key concepts of sensible and latent heat, along with the concepts of thermal energy and thermal power. You should discuss with learners the different temperature scales that they are familiar with, introducing them to absolute temperature. You should provide learners with the skills required to be able to convert between the temperature scales, which they will encounter during practical engineering activities.

Once learners have a good understanding of the fundamental parameters of thermodynamics, you could introduce them to the process parameters associated with thermodynamics, for example the concepts associated with reversible and irreversible transformations and the ideal gas laws.

Finally, you should introduce learners to polytropic processes and explain how these link with thermodynamic process parameters. You should cover a range of the theoretical aspects of thermodynamics, which learners can then apply to mechanical systems.

For learning aim B you should introduce learners to both closed- and open-loop thermodynamic systems. You could discuss with learners the first law of thermodynamics with respect to closed systems such as piston cylinders or bomb calorimeters. You could develop this by considering thermal energy transfer, and the energy within the system. You should explain fully the relationship between the various parameters and system constants which relate to closed-loop thermodynamic systems. You should consider practical applications of the closed-loop thermodynamic systems that learners may encounter as mechanical engineers, such as the practical four-stroke cycle for a piston engine, or a more modern application, such as a Stirling engine used as a cooling device. Once learners are secure in their understanding of closed-loop systems, you could move on to consider open systems and discuss the differences in the application of the first law of thermodynamics when compared to a closed system. As with closed systems, you could use real-world engineering applications of open systems to illustrate the theory, including heat exchangers or gas turbine engines.

You should also make sure that learners have an understanding of the thermodynamic systems used in aircraft in addition to those in steam plants. You could provide learners with some self-directed research activities to allow them to explore the conditions affecting the operation of a steam plant. If possible, you could arrange a visit to a steam plant, or invite a guest speaker from such a facility into your centre.

For learning aim C, you will introduce learners to the combustion processes associated with different fuel types. Learners should develop the skills they need to be able to carry out experiments safely. You must emphasise to learners the importance of safe working procedures associated with carrying out experiments and the procedure that they should follow in the event of an emergency. You should make sure that this is customised to your centre, and that learners are confident with these procedures prior to beginning any practical tasks.

When developing learners' understanding of the combustion process, you should consider a range of fuel types, including examples of gaseous, solid and liquid fuels. This would give learners the opportunity to gain experience of the fuels that they may encounter in their role as an engineering apprentice. There is an opportunity, when carrying out these practical activities, to develop links with local engineering organisations that use calorimeters, such as those in the chemical or mechanical engineering sectors. You could learners' theoretical knowledge of the combustion process to underpin practical experiments using both a bomb calorimeter and a Boys' gas type calorimeter to determine the calorific values of fuels. To prepare learners for this activity, you should demonstrate safe working practices during a tutor-led experiment.

Finally, having considered the calorific values of fuels with learners, you could discuss the sustainability issues associated with fuels. You should consider the same range of fuel types, allowing learners the opportunity to investigate conventional fuels such as petrol and more modern alternatives such as LPG.

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Learning aim	Key content areas	Recommended assessment approach
A Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems	**A1** Thermodynamic parameters **A2** Polytropic processes	A report will focus on the thermodynamic principles related to both the expansion and compression of gases and an analysis of investigations into the outcomes of polytropic processes.
B Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems	**B1** Closed thermodynamic systems **B2** Open thermodynamic system **B3** Applications of thermodynamic systems in engineering	A report will focus on the energy transfer principles for both open- and closed-loop thermodynamic systems in given engineering applications.
C Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems	**C1** Safe working practices for thermodynamic systems **C2** Combustion processes **C3** Calorific values. **C4** Sustainability of fuels	A report will focus on safe practical activities using calorimeters in the form of observation records, witness statements and annotated photographs and drawings, along with notes which discuss the results of experiments and considerations of sustainability.

Assessment guidance

The assessment of this unit is most likely to be in the form of three assignments, one for each of the individual learning aims. Evidence for each of the assignments is likely to be in the form of a written report, although some aspects of both learning aims A and B could be addressed through the use of a presentation, along with appropriate speaker notes. Reports are likely to include both written aspects, along with calculations where these are appropriate to support the theories investigated.

In their evidence for learning aim C, learners will need to demonstrate that they have been able to carry out experimental investigations safely; the evidence for this will be in the form of detailed observation records, witness statements and annotated photographs of learners carrying out experiments. Diagrams may also be an appropriate form of evidence to support learner evidence.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 31: Thermodynamic principles and practice

Introduction

This unit offers the opportunity for learners to investigate a range of thermodynamic principles that they are likely to encounter in a future role in the mechanical engineering sector.

You should provide learners with the background knowledge that they will need to understand the links between the theory of thermodynamics and its application, both experimentally and in engineering systems.

Finally, you will demonstrate to learners the safe working practices which they will need to follow when carrying out practical investigations prior to learners embarking on their own experiments using calorimeters to investigate the combustion of a range of different fuels.

Learning aim A – Investigate thermodynamic principles related to the expansion and compression of gases that are applied in mechanical systems

- You could approach learning aim A by providing learners with a number of opportunities to work in small groups to develop their intrapersonal skills by researching and investigating thermodynamic parameters such as sensible and latent heat. There is also the opportunity for independent study to investigate thermodynamic temperature along with the range of temperature scales that are commonly used in engineering, both within the UK and internationally.
- You could then consider in fuller detail the specifics of concepts such as thermal heat and power along with factors such as the ratio of specific heat and methods to determine thermal expansion. This would provide you with the basis from which learners could develop their understanding of thermodynamic process parameters. This could be approached by encouraging learners to carry out some independent study to consider these parameters, and then present their findings to the rest of the class. You could then clarify the finer details with learners and address any misconceptions or misunderstandings that they may hold.
- You should also demonstrate to learners how they can illustrate whether a process is reversible or not through the use of calculations, explaining how they could use the Gas Laws to support their theories.
- Once you have considered the fundamental parameters of thermodynamics, you could introduce learners to the theory of polytropic processes within an engineering context. You could use a more formal delivery method to introduce learners to the constants and equations that relate to polytropic processes. You should also give learners the opportunity to apply these equations in a range of contexts in order to prepare them for assignment one.
- Once learners have a thorough understanding of the principles related to thermodynamics, you could give learners their first assignment. In this assignment they should produce a written report on the thermodynamic principles of related gases and the analysis of polytropic processes, which should include their own independent research into thermodynamic parameters and their effects on thermodynamic systems within an engineering context. It should also contain an evaluation of polytropic processes, including expansion and compression of gases.

They should explain the need for different temperature scales, and be able to convert between each scale in a given engineering context. Finally they should include evidence of carrying out calculations of the masses of gases and related thermodynamic parameters for a range of polytropic processes which you have provided them.
Learning aim B – Investigate energy transfer in thermodynamic systems and applications of open- and closed-loop systems
• When delivering learning aim B, you could use a range of engineering applications to illustrate the theories involved with energy transfer in engineering systems. As with learning aim A, there is opportunity to provide research activities for learners to complete either in small groups or as individuals. This could focus on investigating examples of closed-loop thermodynamic systems and, in particular, learners could consider how the first law of thermodynamics is applied to the system. You could then follow this by considering energy transfer, work done and the relationships between the system constants within the closed system. It may be appropriate at this stage to consider examples of closed-loop systems, so that learners can begin to apply their gained knowledge to engineering applications. You could set learners an investigation into the operation of piston engines and then they could prepare a presentation to describe the practical four-stroke cycle for piston engines. • This could be followed by a consideration of open-loop thermodynamic systems. As with before, learners could investigate the application of the first law of thermodynamics, but in an open system. You should encourage learners to investigate the work done within the system. This could then be followed with a tutor-led activity which focuses on the application of the open system energy equation. • Learners could carry out independent study to examine examples of open systems. There is potential for further group activities to develop a presentation to describe the operation of open systems, including gas turbine engines. • This could be followed by further tutor-led activities to investigate the thermodynamic systems that are found in aircraft and steam plants. There is the opportunity for learners to complete further investigations into the aforementioned systems to gain a thorough understanding of their operations. If possible, you should arrange for learners to visit a steam plant so that they can gain first-hand experience of the processes that occur there, or you could invite a guest speaker to the centre who could explain how the systems operate. • For both closed- and open-loop systems you should enable learners to develop the skills they need for determining the power input and output for systems and therefore also the efficiency of systems. • You should ensure that learners are comfortable with the use of thermodynamic property tables, and know how the data contained in them is to determine enthalpy values. • Once learners have a secure understanding of both closed- and open-loop thermodynamic systems, they should complete their second assignment for learning aim B. In their evidence for this assignment you should make sure that learners use the Laws of Thermodynamics to investigate energy transfer principles within the open and closed thermodynamic systems which you have given to them. You should emphasise to learners that their report will need to be professionally presented and contain appropriate calculations to support their findings. • Learners must provide evidence of research into given applications of thermodynamic systems which then evaluate how the First and Second Law of Thermodynamics are applied to these open and closed thermodynamic systems. It is important that their reports include an evaluation which considers the interrelationships of the principles

and parameters, and the advantages and disadvantages of the systems in general. You should ensure that learners are given the opportunity to calculate the work done, thermal energy transfer and the overall system efficiency for the application of the systems, for example in aircraft or in the generation of electricity.

Learning aim C – Explore the combustion and sustainability of fuels that are used to produce work in mechanical systems

- As it is based around carrying out practical activities, you could introduce learning aim C by providing learners with a range of scenarios where emergency procedures need to be followed. You could encourage learners to work collaboratively to develop a suitable strategy that could be followed in each circumstance. Ask each group of learners to present their findings to the wider group and discuss the merits of each group's plan. Compare the procedures that the learners develop with those already followed in your centre. You should make sure that learners are fully aware of these procedures prior to starting any practical tasks.
- You should demonstrate to learners the correct methods for carrying out practical experiments using calorimeters; this should emphasise the safety practices which are specific to the use of the equipment (eg the procedure for filling vessels and the correct methods to connect pipes and hoses within the apparatus). If possible, invite staff from local engineering organisations into the centre to explain how they use calorimeters in their role, and to demonstrate the safe use of the equipment.
- You could allow learners to investigate a range of different fuels along with the phases of combustion, through independent study, prior to the learners completing their own practical tasks. You should also ensure that learners have a good understanding of how to apply stoichiometric equations for combustion processes; you could give them suitable data from which they could extrapolate values. Learners should also investigate the various products of combustion, along with the theoretical oxygen and air requirements for complete combustion.
- Divide learners into pairs to carry out experiments using calorimeters; both a bomb calorimeter and a Boys' gas type calorimeter should be used, if possible, in order to determine calorific values of fuels. You may wish to give learners a range of fuels of each type, for example several different fossil fuels; this may be an appropriate approach to adopt if there is a relatively large group in order for there to be some variation in the results obtained.
- Finally, there is further opportunity for you to provide learners with independent study activities to investigate the relative efficiencies of different types of fuel. You could discuss with learners the environmental impacts of combustion. This should be done prior to learners working in pairs to develop a presentation which considers the sustainability of fuels, including the environmental impact of combustion and the relative cleanliness of each fuel. They should also consider a range of alternative fuels, such as LPG or biodiesel, which they are likely to encounter in their future roles as mechanical engineers.
- Once fully prepared, learners should complete their assessment for learning aim C. Ensure that learners are able to conduct experiments safely to determine the calorific values, and the combustion requirements, of fuels. Make sure that they record the process they have followed using a range of methods, which could include annotated photographs or sketches. As with the delivery of this part of the content, you may wish to provide a range of fuels for learners.
- Learners should compare their experimental findings with their calculated values for the fuel types investigated. The report should also consider the sustainability implications of different fuel types to evaluate the implications for mechanical systems.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 18: Electrical Power Distribution and Transmission*
- *Unit 50: Aircraft Gas Turbine Engines*
- *Unit 51: Aircraft Propulsion Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Nag P K – *Engineering Thermodynamics (*McGraw-Hill, 2008) ISBN 9780070260627.
  This book provides theory for many of the topics covered in the unit content.
- Rayner J – *Basic Engineering Thermodynamics* (Pearson Education, 1996) ISBN 9780582256293.
  This book provides an introduction to the subject at an accessible level for learners.
- Sivasankar B – *Engineering Chemistry* (McGraw-Hill, 2008) ISBN 9780070669321.
  This book covers combustion and the use of calorimeters.

Videos

- www.youtube.com/watch?v=ohyA9amFfsc
  A video of a bomb calorimeter experiment.
- www.youtube.com/watch?v=xiu9fIgydx4
  A video explaining the operation of gas turbine engine.
- www.youtube.com/watch?v=ChvI2v85fsU
  A video showing the workings of a steam plant.

Websites

- www.grc.nasa.gov/www/k-12/airplane/thermo.html
  The NASA website which covers a significant amount of the unit content, in varying levels of detail.

- www.livescience.com/50776-thermodynamics.html
  A science website which covers thermodynamic parameters and the laws of thermodynamics.
- www.innovateus.net/science/what-fuel-combustion
  An innovative US website which covers fuel combustion processes and fuel types, including alternative fuels.

Unit 32: Computer System Principles and Practice

Delivery guidance

Approaching the unit

In today's technology driven market, computer systems have become essential to any engineering organisation. The need for reliable, scalable and efficient systems drives organisations to ensure their systems are the most up to date and specific to their needs allowing them to achieve within their sector. The focus of this unit is to give the learner the essential knowledge and skills to design, develop and analyse computer software systems.

Learners would benefit from exposure to applications used in manufacturing, automotive and process industries, as well as those closer to home with commercial and domestic systems.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Firstly, in learning aim A, learners could examine different types of applications used in engineering. Through collaborative work they could investigate the typical hardware and software features in applications across a range of engineering sectors. For example, each group could examine and compare an application from the manufacturing, aerospace, automotive, process and commercial and domestic sectors.

Learners should become familiar with the procedures and measures in place in engineering applications to prevent and protect against threats such as hacking, malicious software and data loss. They should look at the common features of hardware and software that are present in a range of engineering applications, suggesting where improvements could be made.

In learning aim B, learners could use role-play or group work to examine how data is represented and manipulated in computer systems. Learners should be able to distinguish between the different units of digital data. Exercises converting between the different types of data that are performed by computer systems would be beneficial to the learner. Perhaps ASCII and UNICODE charts can be used to enable the learner to understand how the data is manipulated in the processor of a computer system.

In learning aim C, learners could use group work to devise a set of process and flow diagrams to examine the flow of data through a microprocessor. Learners should know the different instruction cycles within a processor and the factors that affect execution speeds. Group work and discussions could be used to solidify the learning of the more technical aspects of the function and operations of micro-architecture, such as multiprocessing, multithreading and registers.

In learning aim D, learners will design a solution to an engineering problem onscreen. They should be given a problem definition statement, and asked to develop a list of steps or pseudo code to describe the possible solution. They should also identify areas within the code that can be refactored and modularised, for example moving repeating patterns and blocks of commonly used code to a global file or module.

Learners should also produce and identify test scenarios for their solution during development to aid testers during the test stage. Although the learner is likely to be the tester of this application, developing test scenarios is a common role for a developer in many engineering organisations. Learners should also understand the need for and use of basic computer program constructs. The learner may not wish to use all of the constructs but should be able to explain and discuss why they have or have not chosen each one. The use of constructs should complement the efficiency of the application, which should be analysed. For example, the learner should not initialise a large sized array without the necessary resources to contain it. Development of the solution should be carried out within an appropriate development environment for their chosen language. Code should be commented where appropriate, for example learners should comment method and function headers, but not necessarily comment every single line of code.

Learning aim	Key content areas	Recommended assessment approach
A Examine the technology and security protection measures used in computer systems for different applications	**A1** Applications of computer systems **A2** Typical hardware components in computer systems **A3** Software in computer based systems **A4** Security of computer systems	A report that examines two computer systems from a chosen engineering specialist area that demonstrates why the hardware components, software and security are suitable for the application and where improvements could be made.
B Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function	**B1** Numeric and alphanumeric data representation and manipulation	A report, including calculations, that analyses how data is represented and manipulated in a microprocessor, including worked examples. It should also include how a microprocessor operates, using diagrams, examples of handling data (such as an addition or a comparison), an example of how the microprocessor handles data using tracing methods and a commentary.
C Examine the architecture and operation of microprocessors to appreciate how computer systems function	**C1** Operation of key components of the microprocessor **C2** Function and operation micro-architecture **C3** Registers and register handling	
D Develop a computer program to solve an engineering related problem onscreen	**D1** Design a computer program **D2** Computer program constructs **D3** Computer program development	Solve a screen-based engineering problem using a computer program. Evidence will include design documentation, annotated program code and test results.

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Assessment guidance

The assessment for this unit is typically documentation, source code and test results. However, it would be beneficial for the learner to be assessed in the form of observation reports, videos and work logs. The evidence should be clear and concise, containing the information stated in the specification. Learners should produce evidence showing a solid technical understanding of computer system principles and programming.

Changing the requirements of the computer program would require the learners to adapt their solution and be flexible with their design and development procedures. This would give them experience of real life system development in engineering. Using a realistic scenario to serve as the engineering problem will allow you to alter the requirements without changing the direction of the development project, but still enough that designs and methods would have to be evaluated and engineered.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 32: Computer Systems Principles and Practice

Introduction

Introduce the unit to the learners, covering the aims and objectives. Produce an overview of the assessment for the unit and give them an outline of the importance of the principles and practice involved in computer systems within engineering, and how they are key to any engineering organisation's IT offering.

Discuss the practical skills (such as analysing engineering problems, designing algorithms using core programming constructs and developing computer software solutions) that this unit will develop in learners, and how they will ensure their solutions meet requirements.

Learning aim A – Examine the technology and security protection measures used in computer systems for different applications

- Ask learners to work in groups to prepare a presentation to an audience of engineering learners that compares two engineering computer systems – a Computer Numerical Control machine and a typical office computer. Learners should cover the following concepts found on each system:
    - comparisons in the hardware and software
    - security protection methods.
- They should also evaluate the two contrasting systems detailing why they are appropriate for their primary use. They should highlight, where possible, improvements that could be made to each system.
- Ideally, part of the assessment evidence for this unit could be an observation report for each learner in the group. You may use different engineering computer systems as examples to compare and require the learner to submit presentation slides and group roles or notes to support each learner's assessment evidence.

Learning aims B & C – Examine how data is represented and manipulated in microprocessors to appreciate how computer systems function; and Examine the architecture and operation of microprocessors to appreciate how computer systems function

- Learners should examine how data is represented, manipulated and processed within a microprocessor. You could facilitate this using group work that reflects tutor delivered information. Learners are to analyse microprocessor architecture and compare the standard Von Neumann microprocessor architecture with another typically used in engineering applications. Example chips or devices that contain these architectures would be beneficial as visual learning aids, although simulators would suffice. Learners should be able to demonstrate how data is stored and manipulated using a set of instructions that have been given to them. This could be evidenced using diagrams and process charts rather than a written report.
- Learners should be able to discuss the limitations of data manipulation within a microprocessor, evaluating the measures that are used to ensure accuracy. They should also explain ways in which microprocessor performance can be improved. Evidence for this could be in the form of a presentation, but to guarantee detailed understanding a report would be more beneficial to the learner and for assessment.

Learning aim D – Develop a computer program to solve an engineering related problem onscreen
• Learners should design and develop a programming solution to a problem using a range of programming constructs resulting in a working and tested solution. It is essential that you deliver techniques required to produce programming solutions. This could be in the form of lecture style presentations, or through a series of workshops and labs delivering programming constructs and concepts allowing the learner to apply and practise the knowledge and skills before being assessed. • Learners should analyse an engineering problem that can be solved using a computer problem. An example of a typical engineering problem is to carry out Ohm's Law calculations for electrical engineers, or Newton's Second Law for mechanical engineers. • They should produce designs for their solution based on their analysis of the problem. Their designs could be in the form of typical software design documentation. Flowcharts, pseudo code and test scenarios that are clearly annotated will suffice. • Learners should develop a working computer program using appropriate programming constructs. The source code should be annotated to show how it works and how it has been optimised for efficiency and performance. • The development of test scenarios during the design stage will facilitate the production of a test plan, which must be used during and post development to ensure the solution actually solves the engineering problem. Assessment of this solution should be in the form of observation records and technical documentation, including prints of source code. However, where resources are limited, assessment may take the form of videos, documentation and snippets of essential code blocks.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 33: Computer Systems Security*
- *Unit 35: Computer Programming*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are access to:

- computer hardware components including CPU, motherboards, power supply units, hard drives, random access memory (RAM), expansion cards, video cards, sound cards, network cards
- input and output devices, eg keyboards, mice, specialist input devices, printers, speakers, screens, LEDs, robot arms
- storage devices, including hard drives, detachable drives, CDs, DVDs
- software applications, eg office applications, CAD and software relevant to engineering, programming language software, integrated development environments
- access to security software, eg virus protection, anti-malware, anti-spyware and anti-adware.

Textbooks

Albahari B and Albahari J – *C# 5.0 in a Nutshell: The Definitive Reference*, *5th Edition* (O'Reilly, 2012) ISBN 9781449320102.
Reference guide for C# 5.0.

- Lomax P, Petrusha R and Roman S – *VB.NET Language in a Nutshell*: *A Desktop Quick Reference* 2nd Edition (O'Reilly, 2002) ISBN 9780596003081.
  A key part of every .NET developer's bookshelf.
- Sims C and Johnson HL – *Scrum: a Breathtakingly Brief and Agile Introduction* (Dymaxicon, 2012) ISBN 9781937965044.
  A brief insight into Agile development.

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Journals

- IEEE Computer Society
  Publications and journals of IEEE related computing topics.

Websites

- www.khanacademy.org
  Khan Academy online courses.
- http://stackoverflow.com
  Stack Overflow – answers to common programming questions.
- www.codecademy.com
  Codecademy – online programming learning opportunities.
- https://msdn.microsoft.com/en-GB
  MSDN – Microsoft Developer Network online information and resources.

Unit 33: Computer Systems Security

Delivery guidance

Approaching the unit

Computer security is a significant issue for engineering professionals, so this unit is relevant to all engineering learners. Computer security is a dynamic area, as there are constant technological developments and newly discovered security threats. In many ways, computer security is a struggle between terrorist, cyber criminals and others and computing professionals trying to protect personal, technological and business computing systems. While this is an exciting and fascinating topic of study for learners to engage with, it may also prove challenging for you to keep up to date with the latest developments and you will need to carry out regular research.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, you could start with a class discussion about security issues. Many learners will have some experience of this topic and are likely to have heard of some well-known security breaches. However, much of their knowledge is likely to relate to their personal IT use, and you should make it clear that this issue is also of vital importance to engineering users. You may find it useful to set learners a variety of research tasks, asking learners look into the most recent examples of data breaches, virus attacks and politically-motivated hacking.

Topic A2 concerns legal requirements, so to engage your learners you might ask them to research people, companies or organisations who have fallen foul of these laws, covering not only what they did but also the laws that they broke and the eventual outcome.

Learning aim B concerns the techniques used to protect IT systems, and so is linked with the threats covered in learning aim A. You could link the two learning aims together, covering the threat and then the associated protection methods. Another possible approach would be to build on the research task of looking at recent examples of data breaches, virus attacks etc, and ask learners to consider what protection methods might have been effective in preventing the problems they have researched.

Topic B4, covering policies and procedures, could be enlivened by looking at several different IT, internet or network usage policies, perhaps taking your own policies from school or college and comparing them with policies from different types of organisations. You could focus on the purpose of each part of the policies and discuss their appropriateness.

You could also consider delivering topic B3 in conjunction with the associated practical tasks in learning aims C and D. This will help to ensure that learners can see clearly that the theoretical content relating to software-based protection links to the practical applications.

For learning aim C learners will need to be given a suitable engineering related scenario so they can assess risks and plan protection. It may be possible to use a scenario from another unit where computers are used.

For learning aim D, learners will need access to systems on which they can practise their skills and implement what they have planned in learning aim C. It is highly unlikely that they will be allowed to adjust the security settings on the live computing systems within your school or college, so you have two options. You could:

- have separate, dedicated, unrestricted computer systems which are not directly connected to the main college/school system
- use virtual PCs, there are a number of software products that allow you to install a software-emulated virtual PC, such as VirtualBox.

It will also be beneficial to have a Wi-Fi access point for learners to set up and configure. These can be obtained from a range of IT equipment suppliers.

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Investigate the threats to computer systems in engineering organisations and the organisation's legal responsibilities</td><td>A1 Computer system security threats
A2 Legal responsibilities</td><td rowspan="2">A report or presentation investigating contrasting computer systems in at least one engineering organisation. The report should cover a range of security threats, the legal requirements placed on organisations, system vulnerabilities and a range of possible security measures.</td></tr>
<tr><td>B Investigate computer system vulnerabilities and protection measures used in engineering organisations</td><td>B1 Computer system vulnerabilities
B2 Physical security measures
B3 Software and hardware security measures
B4 Policy security measures</td></tr>
<tr><td>C Plan security measures to protect an engineering computer system from threats</td><td>C1 Assessment of computers system vulnerabilities
C2 Assessment of the risk severity for each threat
C3 A security plan for a computer system</td><td rowspan="2">A plan to provide security protection for an engineering computer system.
The installation and configuration of the security measures to protect a computer system. Testing and optimisation of the system.
A portfolio of evidence including a report, screen shots, test results, witness testimony and observation records, analysis and interpretation.</td></tr>
<tr><td>D Implement security measures to protect an engineering computer system from threats</td><td>D1 Installation and configuration of security measures for a computer system
D2 Testing a computer security measures</td></tr>
</table>

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Assessment guidance

This is an internally assessed unit, meaning that learners need to complete assignments that are devised and marked internally and that cover the learning aims. Learning aims A and B are theoretical in nature and the assignment should be based on a case study for a real or fictitious organisation. Evidence can be in the form of a written report or a presentation (with slides and notes) to be given to the company's managers. Alternatively, you could film learners giving their presentations.

Learning aims C and D require learners to assess the risks, plan and apply security protection to an IT system. Give them a scenario with sufficient detail for them to meet the assessment criteria. For example, they need requirements for different levels of access control (read, modify etc) to various folders for different users or groups, and the system should require connection to the internet and a Wi-Fi network. The scenario should also give sufficient details of the applications and user access required to allow the learners to justify their choice of protection strategies.

The system can be a physical computer system or a virtualised environment. Learners need to have a portfolio of evidence showing that they planned the protection strategies and can justify their choices. They need to collect evidence of applying the security measures, such as screen shots, photos, videos, witness testimony etc, and evidence that they have refined and optimised the protection. They also need to include the test plan that they used to test the protected system and a written or audio-/video-recorded evaluation of their plan and its implementation. Learners may find it helpful to maintain a diary of their progress in setting up the system, as this may help them evaluate the protected system.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 33: Computer Systems Security

Introduction

Security is a key issue in engineering computer systems. The aim of this unit is to give learners a clear understanding of the threats faced by every computer system and to give them the skills to apply the basic protection techniques required to keep a system secure.

Learning aim A – Investigate the threats to computer systems in engineering organisations and the organisations' legal responsibilities

- You could begin by having a class discussion about learners' own experience of security issues and cyber-attacks that have recently been in the news.
- Learners could work in small groups researching well-known or recent security issues and then present back to the whole class, giving details of the attack. Facilitate further discussion about how the attacks could have been prevented. You could further extend the discussion by asking learners to consider the impact of these breaches, relating their responses to those listed in the content.
- Because computer security is such a fast-moving field, it would be beneficial to ask learners to research the most recently identified threats and breaches. Learners could work in small groups to prepare a brief presentation on threats or security breaches that have occurred in the last six months. Give each group a different recent threat or type of threat to look at. Encourage them not just to look at the mechanism of the threat itself and the details of the security breach, but also to consider the impact and possible methods of prevention. The technology section of the BBC News website could prove a useful starting point for learners' research.
- Learners need to understand that requirements to protect home personal computers from security threats are different to those required for organisations' systems, and that the consequences of security breaches are different for individuals and organisations. It may be difficult to get industry speakers to talk about specific issues or protection methods, but it would be beneficial to find someone willing to talk to learners about the general security issues and consequences faced by engineering companies.
- Learners could examine legal requirements using case studies. They could investigate individuals or companies prosecuted under these laws. They can report back on what actually happened, how the legislation was applied and what the consequences were. Learners can find facts on the website of the Information Commissioner's Office (ICO), which gives details of cases where they have taken action under the Data Protection Act.

Learning aim B – Investigate computer system vulnerabilities and protection measures used in engineering organisations

- You could start by looking at some of the threats that learners identified in learning aim A, followed by a discussion of the ways in which IT systems can be protected against specific threats.
- Use case studies to allow learners to investigate the physical security measures that could be applied to a specified engineering IT system. Encourage learners to bear in mind the need to balance the level of threat, the usability of systems and

the cost of protection. For example, ask them to consider a number of different scenarios, ranging from top-secret military data to simple business data such as price lists, and consider what sort of protection would be appropriate in each scenario. • You may be able to arrange a class visit from a computing manager employed by a local engineering organisation. Ask them to talk to your learners about the backup and disaster recovery procedures that they use and their organisation's general approach to security. However, remind learners that it is unlikely that the visiting speaker will be willing to talk about specific security measures that their organisation takes. • To cover the topic of policies and procedures, learners could work in small groups looking at some given examples of internet usage policies. You could use the policies of your college or school and local employers where possible and an internet search will produce many global examples. Ask learners to identify the reasons for the 'dos' and 'don'ts' given in these policies, and see if they can spot any omissions without prompting. • This learning aim gives opportunities for learners to investigate user authentication, which is an area that learners will have experienced (eg by signing into school or college systems, social media sites, banking websites or email services). In groups or as individuals, learners could research password-related issues, such as how to deal with the large number of passwords users require for accounts on different websites (and how those websites hold these authentication details securely), password good practice, non-text-based passwords and other alternative authentication methods. Learners could also research and debate the issue of security versus usability, which they will have to consider for learning aims C and D.
Learning aim C – Plan security measures to protect an engineering computer system from threats
• When covering topic C1, it is unlikely that learner will be able to use these tools on the college or school networked computer systems. However, they may be able to use them on dedicated unrestricted systems if these are available, or alternatively they could assess the vulnerabilities of their own home computer systems. • To investigate topic C2, learners will need to consider a variety of different scenarios as the risk severity will vary to some extent depending on the application. For example, in mission critical applications such as transport control, the severity of the risk could be very high indeed. • If learners are doing suitable optional units that involve the use of computer systems, it may be beneficial for them to assess the security risks associated with the unit of computers in those specific areas and develop a suitable security plan, which they can implement in real life. • Learners may find it effective to review each other's risk assessments and plans and suggest improvements as they are often better at being critical of other people's work than their own. Developing critical skills is important to allow learners to achieve develop an appropriate security plan.
Learning aim D – Implement security measures to protect an engineering computer system from threats
• This learning aim is primarily practical, with learners practising how to implement the various protection methods that they have planned in learning aim C. They could do this on a physical IT system that is separate from the school or college's live systems or alternatively, if this is not possible, they could do it on a virtualised environment.

- Give learners a case study that explains the system that they are helping to set up and the levels of access to give to different users. Working in pairs, learners could then set up the required folder access controls and test that their set-up works correctly and gives the correct level of access.
- When it comes to setting up anti-malware software, firewalls and wireless network security, the results are likely to be predictable if all the learners follow the same procedures. It could be more interesting to have learners work in groups and configure these items differently, and then compare the results as a whole class discussion. If network restrictions make it difficult to try out different settings to see how they affect different applications, you could set this as a homework task for learners to try out on their home computers and ask them to report back to the rest of the class on their findings. However, you will need to remind learners not to switch off these features or configure them in a way that would compromise the security of their home systems.
- Learners often struggle to test and review their own work effectively, so it may be beneficial to have learners work in pairs. Each learner could set up a protected system and then create a test plan for that system. Learners should then test and review each other's protected system following the given test plan. This may help them to be more objective and critical of the degree to which the system is protected and the usability of the protected system. Learners could also use this experience to help them when considering how they could enhance their protected systems.
- Learners should maintain a diary of the various practical activities that they complete in their lessons. They can then use this information when they start work on their assignment and can no longer receive detailed guidance from you.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 35: Computer Programming*
- *Unit 37: Computer Networks*
- *Unit 38: Website Production to Control Devices.*

Pearson BTEC Level 3 Nationals in Computing (NQF):

- *Unit 6: IT System Security.*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Websites

- www.bbc.co.uk/news/technology
  BBC News Technology section – technology news, including cases of significant cyber-attacks.
- www.ico.org.uk/
  The Information Commissioner's Office website – gives case studies of action taken under the Data Protection Act.
- http://home.mcafee.com/advicecenter
  McAfee's security advice centre – useful and up-to-date information on security, virus attacks and viruses, written in a reasonably accessible manner.
- www.microsoft.com/security
  Microsoft's security advice centre – features a regularly updated blog and FAQ on security issues.
- http://uk.norton.com/security-center
  Norton's security centre – articles on security, spam email, software piracy etc.
- www.virtualbox.org
  VirtualBox – a free open source product that allows you to install a software-emulated virtual PC.

Unit 34: Computer Systems Support and Performance

Delivery guidance

Approaching the unit

Computer systems are a crucial component in engineering organisations. They are essential for providing customer satisfaction, productivity and financial profitability. Professionals within these organisations rely on computer systems: for example, a designer using a Computer Aided Design software package or a machine setter operator using a Computer Numerical Controlled machine. In this unit, learners will investigate and explore the use of computer systems in industrial settings, examining where support and maintenance is essential and critical to the organisation's performance. Learners will delve into the legislation and policies in place to protect organisations and employees alike.

The technological focus of this unit is on the support, routine maintenance and performance improvement of computer systems used within engineering organisations. It specifically covers the systems used at the core of the business, such as stock-level management or computer aided manufacturing systems, rather than the typical office system. By providing learners with the opportunity to use these systems, you will allow them to experience a wide range of hardware and software such as sensors, robotics and specialist tools.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Firstly, in learning aim A, learners could consider their own use of computer systems and what support the systems they use could need. They could explore selected examples of the purposes outlined in the specification, and through collaborative work, investigate third party services for support and maintenance of computer systems, as well as the contracts and policies in place at your centre.

Learners should be familiar with the typical policies at any engineering organisation, such as data protection, environmental and waste management, procurement and sustainability. You could introduce these policies along with the health and safety regulations that drive them. You could also introduce those that are motivated by the organisation's need to protect the continuity of business and welfare of its infrastructure and resources.

For learning aim B, learners should be familiar with the standard operating procedures of computer systems maintenance professionals and be able to identify areas of risk and faults that you will have created for an example system. You would ideally choose or design a system that encompasses a variety of engineering features, such as specialist software tools and hardware, as suggested in the specification.

Work shadowing, support logs and contact with technical professionals working in this field would provide superb technical knowledge and support for broadening learners' experience of problem solving and identification of faults.

Discussions with industry experts should enable you to create a typical computer system for learners to practise and use in the assessments.

For learning aim C, learners would ideally carry out routine maintenance on a real computer system, preferably in a workshop using appropriate tools and taking account of health and safety procedures. Should you not have access to physical systems to repair and maintain, then a number of simulators, remote access and system diagnostic tools are available on the Internet. Ideally, learners should have access to specialist equipment used in an engineering organisation, such as CNC, CAD, robotics and measurement devices.

Learners should also suggest improvements and carry these out on the computer system. They should justify these improvements with respect to cost, usability, environmental factors and durability. Learners should be aware that improvements to a system in one area might increase risk and fault occurrences in other areas. For example, the upgrading of a graphics card in a CAD workstation may cause issues with power supplies, RAM or CPU within the overall system, and incur costly improvements and replacements.

For learning aim D, learners would reflect on their own work in the unit, perhaps through peer feedback and collaboration. They should use the skills and knowledge developed in the other learning aims to research and produce an application for one of the ISO standards documented in the specification. Although they will not go through the full application process to ISO, they will provide an insight into their chosen engineering organisation and the benefits that certification can provide.

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Issue 1 – May © Pearson 2016

Learning aim	Key content areas	Recommended assessment approach
A Examine the computer support needs for different engineering organisations that are essential to their operation	**A1** Purpose and policy of computer system support **A2** Safe working practice **A3** Contingency planning for computer systems **A4** Infrastructure security for computer systems	A research study supported by case studies. The study should cover four computer support characteristics: purpose of the system, policies and safe working practices, contingency planning and infrastructure security.
B Develop a support plan for a new computer system, as undertaken in industry	**B1** Graphical representation of systems **B2** Contingency planning **B3** Levels of support and standard operating procedures	A collection of plans supported by at least one of each of the following: route map, upgrade path, schedule, Gantt chart and standard operating procedure.
C Carry out routine support of a computer system and improve its performance	**C1** Support for computer systems **C2** Software, hardware and firmware management **C3** Unit testing	A developmental log supported by observational witness statements. The log should contain task logs, documentation regarding problems encountered, applied software, hardware and firmware upgrades, test scripts and results, appropriate data sheets and where hardware components have been replaced or upgraded.
D Review the support provided for a computer system and reflect on own performance	**D1** Lessons learnt from the support of a computer system. **D2** Personal performance while supporting a computer system	The evidence will focus on what went well and what did not go so well when supporting engineering computer systems, reviewing the processes and reflecting on own performance. The portfolio of evidence generated while supporting engineering computer systems and reviewing the processes and reflecting on own performance.

Assessment guidance

This unit could be assessed by means of reports and documentation. However, it would be beneficial for the learners if it also took the form of observation reports, videos and work logs. The evidence should be clear and concise, containing the information stated in the specification. Learners should use appropriate language to produce evidence showing a solid technical understanding of computer systems support and how to effect performance.

Learners would benefit from having a fully functioning example computer system for practice and assessment purposes. This could be a computer system used by engineers within the centre, or one designed on a system used in a local or an example engineering organisation. Should this equipment not be available, various diagnostic and hardware simulators are available on the Internet.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 34: Computer Systems Support and Performance
Introduction Introduce the unit to learners, covering the aims and objectives. Provide an overview of the assessment for the unit, and give them an outline of the importance of the support of computer systems and how their performance affects engineering organisations. Discuss the practical skills (such as installing and repairing hardware, following of safe working practices, portable application testing and diagnosing of faults within a hardware system) that this unit will develop in learners. Briefly describe how they will investigate faults and risks that occur in engineering computer systems and learn how to remedy them in their role as a computer support professional.
Learning aim A – Examine the computer support needs for different engineering organisations that are essential to their operation
• Begin by introducing the needs of a typical engineering organisation with respect to their computer systems. You could choose at least two local engineering companies as an example, and suggest a typical computer system critical to their businesses. This would be a great opportunity to connect with industry by inviting a guest speaker or carrying out case studies in a suitable workplace. You could use a formal presentation to provide learners with an overview of two systems, and provide case studies if available. • In groups, learners should identify the faults and risks that could occur in the two computer systems. Allow learners to present their findings to the rest of the class so that all end up with a comprehensive list of possible faults and risks. • In pairs, learners should prepare a presentation on the differences between the two computer systems. They should identify the key support characteristics such as policies, safe working practices, contingency planning and infrastructure security, and suggest improvements that could be made to each system. • Lead a class discussion on the support required for engineering computer systems, and the policies and legislation required by law and by the organisation. Learners should produce a case study to contrast the two systems and provide justification for improvements that could be made to each.
Learning aims B and C – Develop a support plan for a new computer system, as undertaken in industry; and Carry out routine support of a computer system and improve its performance
• These learning aims offer a great opportunity to involve a local engineering organisation in the redevelopment of one of their existing computer systems. It would be beneficial for learners to perform the maintenance on an actual computer system. Links to industry would be useful here. However, a simulated computer system for assessment and delivery would be required within the centre for learners to practise on and for assessement. Ideally, the computer system would contain a wide range of hardware and software features, identified in the specification. • Begin by asking learners what they think the stages of a maintenance procedure on an industry specific computer system are. Learners could work in groups to identify the key areas for routine housekeeping and maintenance.

- Deliver key information on the legislation and policies required in organisations regarding health and safety, and standard operating procedures. Learners should be respectful of these documents during the development of their maintenance plan. Learners should produce a range of graphical documentations such as upgrade paths, Gantt charts and schedules to plan their maintenance routine.
- Learners should produce their own checklist for the steps they would take to carry out the routine maintenance and support of the computer system. They should identify and upgrade at least two features of hardware or software.
- Learners should carry out the routine maintenance on the computer system. They should complete the checklist that they have created and identify areas where the performance could be improved. They should also consider whether their own performance led to the success or failure of upgrades.

Learning aim D – Review the support provided for a computer system and reflect on own performance

- This learning aim allows learners to reflect on their own performance throughout the unit, while planning key documentation for the continuation of the computer system support programme.
- Begin by giving learners an overview of the International Standards Organisation, and its benefits to engineering organisations. Learners should work in pairs to research and present the typical ISO standards that engineering organisations could obtain. Suggest that learners focus on the two ISO standards depicted in the specification.
- Discuss how an engineering organisation goes about applying for ISO certification, and ask learners to report on the key topics required in the application process. Learners do not have to complete the application process as outlined by ISO, but can cover the information required to show a solid understanding of the computer system they are supporting and maintaining, and the organisation that uses it. Within this application, they should identify and analyse procedures and policies that help support the application.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 5: A Specialist Engineering Project*
- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 10: Computer Aided Design in Engineering*

This unit is beneficial for learners who wish to go on to employment in the roles of IT Support Technician or Computer Systems Technician, or those wishing to undertake an apprenticeship in IT Systems and Networking. This unit might benefit those considering further studies and certification in CompTIA qualifications.

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Limoncelli T, Hogan C J and Chalup S R – *The Practice of System and Network Administration*, *2nd edition* (Addison Wesley, 2007) ISBN 9780321492661.
- McRae K – *Computer* Manual: The Step-by-step guide to upgrading, repairing and maintaining a PC, 5th edition (Haynes & Co. Ltd, 2010) ISBN 9781844259281.

Journals

- www.webuser.co.uk
  This is an online journal that gives tips to help you improve your PC.
- PCPro magazine
  An online magazine with pages of news, reviews and advice.
- IEEE Computer Society
  The IEEE Computer Society produces magazines and journals of IEEE related computing topics.

Websites

- www.iso.org/
  International Standards Organisation.
- www.spiceworks.com/
  Spiceworks - tips and problem-solving techniques for IT professionals.

- www.pcguide.com
  The PC Guide and detailed technical reference.
- www.teach-sim.com
  Teach-sim – a range of computer simulators for learning about operating system, CPU and compiler configurations.
- www.americanitsolutions.com/hard-drive-simulator
  Hard Disk Drive Simulator – simulator showing potential pitfalls when repairing hard drives.

Unit 35: Computer Programming

Delivery guidance

Approaching the unit

Controlling computer systems is a key part of processes and routines carried out in engineering organisations. Advancements in technology and computing have driven the need for more complex and higher functioning software solutions. This unit focuses on core programming concepts, allowing the learner to develop a strong knowledge and skill set for designing and developing software products using a range of tools and techniques, and ensuring good quality production code.

This unit will allow you to deliver industry standard programming concepts to the learner, including methodologies used to design and develop, through to the testing and analysis of software products. The development of this knowledge should ease the transfer of skills throughout the careers of the learners in engineering.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Firstly, in learning aim A, learners could investigate the key features of starting a software design project. Through collaborative work, they could investigate a set of user requirements for a software project. Using group work and role-play, the learners could demonstrate their understanding of the different roles played in a development team within an engineering organisation.

Learners should become familiar with the development methodologies used in organisations, such as Agile, Waterfall and Rapid Application Development. They should give the benefits and limitations of the three methodologies. You could introduce these methodologies along with examples of when and where they may be used. Typically, RAD would be used when a product is required in a very short time span, and where the specification is clear and simple and not likely to change. Agile would be used in a project where user requirements are ever-changing and the development team and business are required to be flexible enough to react to these changes.

In learning aim B, you could provide learners with example documentation for the design of a software product. The learners' experiences would be enhanced if these documents were provided by a local software development company. Alternatively, a visiting professional from a local software company could provide an insight into how a typical software engineer creates software design documents.

Learners should become familiar with project planning for time and resources (eg the use of Gantt charts), and the consideration of target platforms with system requirements. All this information should be encompassed in a set of terms of reference documents, including user interface mock-ups and structure designs. Work experience would be highly beneficial for the learners. Experience of a software design house where user requirements and system design are present would be invaluable to the learners.

In learning aim C, the learners should have the opportunity to experience programming constructs and the tools and techniques used in the development of any software product. It would be beneficial to choose a programming language that encompasses a range of programming paradigms. There are many choices for that language, but Microsoft .NET languages such as VB.NET and C# would be strong choices, due to the rapid development and learning curve. These would allow the learner to progress to careers in programming and software development. Languages such as Python or Java would also suffice.

Learners should familiarise themselves with the core programming concepts required to develop code that is usable, scalable and maintainable. Learners could pair program during these sessions, but they should be monitored closely and regularly to ensure good quality code and retain high standards. Through this learning, they should investigate different integrated development environments (IDEs), including methods of storing and securing source code and software development kits (SDKs) and application programming interfaces (APIs). Third party kits could be provided to interest learners. For example, common APIs could be provided to the learners. Many social networks offer APIs to develop with. Learners should develop a software product following the user requirements set in learning aim B. This could be performed in groups, as is done in many engineering organisations and higher level engineering qualifications. The learners should test and report on their software product, and this could be done in the form of peer to peer feedback.

In learning aim D, learners should reflect on their own work in the unit, perhaps through peer feedback and collaboration. The results of their testing from learning aim C should be discussed, focusing on where achievements were made and how barriers were overcome.

<table>
<tr><th>Learning aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine the project structures and methods used in the development of software programs</td><td>A1 User requirements and typical project job roles
A2 Software development methodologies
A3 Development stages</td><td>A case study into the initial development plan of a software project to cover a typical software development lifecycle, discussing the stages of development and the key roles of a development team. It should include a comparison of software development methodologies, identifying which areas may benefit a project and where pitfalls may occur.</td></tr>
<tr><td>B Design a software program based on user requirements to solve a problem</td><td>B1 Design documentation and system design diagrams</td><td rowspan="2">Design documentation and diagrams of user requirements, user interface mock-ups, other structured tools, like 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.</td></tr>
<tr><td>C Develop a software program to solve a problem</td><td>C1 Programming standards and constructs
C2 Development tools
C3 Testing and reporting</td></tr>
<tr><td>D Review and reflect on own performance for the development of a software program</td><td>D1 Lessons learned from developing a software program
D2 Personal performance while developing a software program</td><td>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.</td></tr>
</table>

Assessment guidance

The assessment for this unit involves documentation and source code. However, it would be beneficial for the learners if assessments were to take the form of observation reports, videos and work logs. The evidence should be clear and concise, containing the information stated in the specification. Learners should produce evidence showing a solid technical understanding of computer programming.

Changing the user requirements of the software project would require the learners to be flexible with their design and development procedures. This would give them experience of real life software development. Using a realistic scenario to serve as the function of the software product will allow you to alter the requirements without changing the direction of the development completely, but still change it enough so that designs and methods would need to be re-evaluated and re-engineered.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 35: Computer Programming

Introduction

Introduce the unit to learners, covering the aims and objectives. Provide an overview of the assessment for the unit, and give them an outline of the importance of computer programming and how the professionals that work in the field are key to any engineering organisation's IT offering.

Discuss the practical skills (such as analysing software problems, designing algorithms using core programming constructs and developing programming solutions to solve problems) that this unit will develop in learners and how they will investigate requirements, barriers and risks during the development of a software product.

Learning aim A – Examine the project structures and methods used in the development of software programs

- Examine the different roles of individuals, stages and methodologies involved in a software development project. You could allow learners to work in groups to research and present what they think are the key roles and stages within the project. You could ask learners to reflect on what roles they think they would play within different sized organisations.
- In small organisations, software engineers and developers play a wider role compared with programmers, typically taking on business analysis, testing and support roles. In large and established organisations, a project team would have clear defined roles for individuals and have standard operating procedures in place to structure the projects. You could give learners the following two tasks and ask them to present their findings to provide an overview of different sized organisations.
    - Examine two different software development methodologies, describing the roles and stages.
    - Evaluate each methodology by comparing the key features, and describe how each has benefits and limitations in the development of a software product.

Learning aim B – Design a software program based on user requirements to solve a problem

- Learners could redesign an existing computer program, providing documented user requirements following the Agile methodology. You could do this by providing the learners with a set of user requirements and allowing them to produce their own documentation detailing the features and functionality of the new program.
- Ideally, you would provide an example 'terms of reference' document for learners to base theirs on. A 'terms of reference' document typically contains an overview of user requirements, an analysis of the existing system in the form of process maps, and UML documents (such as class, use-case and state diagrams). Learners should produce this as a report.
- They should accompany this report with a set of user stories and developer subtasks. You could provide cards and marker pens for learners to create these, and create a mock agile scrum board. These stories should form the basis of the test script to be used post development. You could create sample stories for the

learners to use as examples, but providing them with a framework to write their stories will be more beneficial. An example of a user story is 'As a user of the software, I want to search for customers by first name and last name'. They could line up their stories in order of complexity or their vision of difficulty, and assign numerical values (story points from 1 to 10) from least complex being the lowest number to most complex being the highest number. They should also produce one or more developer tasks for each story, such as 'Create a database', 'Create the user interface', or 'Add logic to save button'. Each task should be assigned an estimated time in hours for how long they think the task would take. You should ensure that their estimates are not over the allocated time for the development learning aim.

- You could ask learners to work in teams to design a prototype (non-functioning system) as part of their designs. This could be what learners take up on their own to produce their fully functioning system in the next learning aim.

Learning aim C – Develop a software program to solve a problem

- Learners could implement a programming solution based on development subtasks, and test against user stories. Paired work could be used here, to allow learners to support each other in the learning of the programming techniques required to develop their systems. They should follow the stories they designed in the previous design stage. Although there will be a risk of similar code solutions with pair programming, learners would be expected to evidence their own programs. You would need to ensure that each learner developed their own solutions, perhaps by swapping the pairs between each development session. It would be advisable for learners to complete the majority of development during private, independent study, and use guided hours to deliver the theory and content of the tools and techniques used in programming.
- Following the implementation of their software programs, learners could work in small teams to test each program. They should 'QA' the program (check the program meets the requirements of the user story), but also test the program for functionality and identify errors that require further development. This could be delivered as part of a presentation into quality assurance, unit testing and regression testing within software development projects.

Learning aim D – Review and reflect on own performance for the development of a software program.

- Learners should then examine their performance during the design and development of a programming solution. It would be a good idea for learners to work in pairs or small groups for this learning aim. You could ask the groups to review the approaches they took in the development of the program. They could compare the estimated times with how long they actually took on the tasks and, as a class, discuss the factors that would affect the development of the program for better or for worse.
- Introduce learners to the concept of blockers within a development project. Ask them to report on the blockers that they encountered during their development and how they overcame them.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Albahari B and Albahari J – C# 5.0 in a Nutshell: The Definitive Reference (O'Reilly, 2012) ISBN 9781491927069, ASIN: B008E6I1K8 (For VB.NET 0596003080).
  A key part of every .NET developer's bookshelf.
- Sims C – Scrum: a Breathtakingly Brief and Agile Introduction (Dymaxicon, 2012) ISBN 9781937965044.
  A brief insight into Agile development.

Journals

- IEEE Computer Society
  The IEEE Computer Society produces magazines and journals of IEEE related computing topics.

Websites

- www.khanacademy.org
  Khan Academy.
- http://stackoverflow.com
  Stack Overflow has answers to common programming questions.
- www.codecademy.com
  Codecademy.
- https://msdn.microsoft.com/en-GB
  MSDN.
- www.agilealliance.org/
  Agile.

Unit 36: Programmable Logic Controllers

Delivery guidance

Approaching the unit

The emphasis in this unit is very much on the development of practical skills that can be transferred to the modern workplace. Learners need to develop knowledge and understanding of the hardware and software requirements of contrasting applications of programmable logic controllers (PLCs) since PLCs form the basis of many industrial control solutions.

Learners should take a systematic approach to software development. Many engineering problems lend themselves to a procedural approach. Learners should use a variety of tools such as pseudocode and flowcharts to plan and document their work. These skills are transferrable to other scenarios such as problem solving.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A provides the underpinning knowledge of the features and functions of PLCs and their associated hardware. It is important for you to indicate the range of devices and applications available and it would be worth considering a visit to a local employer to see them in action in the early stages of delivery. Learning aim A provides opportunities for learners to gather formative evidence, interpreting manufacturers' data to select appropriate PLC types for given applications.

Learning aim B allows learners to develop the knowledge and skills to program a chosen type of PLC to interact with inputs and outputs in order to carry out typical functions. Learners can progress through a series of exercises to become confident in the use of an appropriate integrated development environment (IDE) and programming structures. They could be exercises provided by equipment suppliers, or you could develop ones to meet local need. It is important that these exercises perform actual functions, for example switching devices on/off using timers and counters and integrating with hardware rather than be simulations only. You need to encourage learners to collate their evidence as they go along.

Learning aim C provides an opportunity for learners to apply their skills and knowledge to design and develop a PLC solution to an engineering problem as a mini-project. It is summative in nature and concentrates on how well the learners can apply their knowledge and skills to analyse an engineering problem, then develop and test a solution. The scenarios should be realistic, either from the learners' own workplaces or from suggestions from local employers of problems that they may not have the time or resources to address themselves. It is important, however, that you carefully vet proposed investigations to ensure that they provide sufficient challenge but that learners can expect to complete them in the allowable timeframe. You need to provide sufficient resources to allow learners to meet all the requirements of the assessment criteria. You should encourage learners to collect evidence such as sketches, photographs, text, calculations and detailed observation records as they progress. You may need to help learners organise their evidence.

Learning aim D is a reflective exercise based on the outcomes from learning aim C. Reflection is an important feature for professional engineers. It is an opportunity for learners to develop interpersonal skills (self-management, adaptability and resilience, self-monitoring and development). It is also an opportunity for learners to develop skills in précising information into a summary of what went well, what improvements could be made and what would be done differently next time. When considering learning aim D, it is important to guide learners to reflect not only on the technological aspects of the development work carried out for learning aim C but also on their personal development (eg improved knowledge and transferrable skills).

Learning aim	Key content areas	Recommended assessment approach
A Investigate the technology used in industrial programmable logic controller systems (PLCs)	**A1** Features and functions of PLCs **A2** PLC system hardware **A3** Internal operation of Programmable Logic Controllers	A report comparing two contrasting industrial PLC control systems.
B Explore programming structures and methods to control programmable logic controllers (PLCs)	**B1** Integrated development environment (IDE) **B2** Programming skills for PLCs **B3** Test and debug PLC Programs	Collated reports and programs demonstrating the use of PLC instructions in increasingly complex situations.
C Develop an industrial programmable logic controller system to solve an engineering problem	**C1** Problem definition and identification of hardware requirements **C2** Physical system design and assembly **C3** Software design tools **C4** Program development **C5** Testing a PLC system	A portfolio of evidence covering the design and development of a PLC system to solve an engineering problem. This should be accompanied by one or more observational witness statements, photographic evidence and formal testing of the final system. The reflective evidence will focus on what went well and what did not go so well when developing an industrial PLC control system, and reflect on own performance, suggesting possible improvements.
D Review the development of an industrial control system and reflect on own performance	**D1** Lessons learnt from developing an industrial PLC system **D2** Personal performance while developing an industrial PLC system	

Assessment guidance

This is a practical unit with opportunities to develop a smooth flow from identifying the types and applications of PLCs and understanding how to program them to using the skills and knowledge developed to design, build and test an industrial application. It would be helpful if learners could use their own workplaces or placements to identify suitable engineering problems, but you could use suggestions from local industry, who may have issues that they do not have time or resources to address.

You could encourage learners to supplement a report on PLC types and hardware for learning aim A with manufacturers' data and catalogues; however, if they do these should be annotated and referred to in the report.

For learning aim B, learners should include evidence of working programs, for example screen shots, brief explanations of each purpose of the program, program listings, evidence of testing and brief explanations of how the instructions work. You could provide detailed observation records confirming the practical activities carried out.

Learners should demonstrate the skills and knowledge developed in the unit by designing, implementing and testing a solution to an engineering problem. It is important that you vet the proposed problems to ensure that they provide sufficient stretch but are achievable in the time available. Learners need to provide evidence of planning, implementation and testing of their designed systems.

Learning aims C and D are closely connected, providing a vehicle for learners to reflect on technical lessons learnt in terms of how to select and use a PLC and associated hardware and software, as well as on their own performance and personal development in prioritising, planning and working to deadlines. Learners should identify areas of strength and those requiring further development. They should include suggestions for what they would do differently in future.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 36: Programmable Logic Controllers
You could introduce the unit by demonstrating examples of PLCs in operation. It would be an advantage if the examples used different types of PLC; the more noise and movement the better. A pneumatic system such as a stamp and clamp would give a good introduction. A test rig using a mixture of sensors and actuators would give learners an idea of the adaptability of PLCs. Learners need to get their hands on the hardware early in the unit to grab their interest. They can quickly develop from switching a lamp on and off to a latch with a reset. This could introduce the idea of the IDE as an important element in the process before going into too much programming detail. It is important that learners understand the variety and uses of PLCs and the interdependence of their functional behaviour with associated hardware and software. You could encourage learners to understand the flexibility of PLCs by observing them in use in local industry. A visit to local industrial premises to observe PLCs in use in different applications could be helpful for learners with no previous experience.
Learning aim A – Investigate the technology used in industrial Programmable Logic Controller systems

• As a result of an industrial visit (or ideas from learners' own workplaces/placements or using the demonstration rigs) you could ask learners to:
  ○ research two industrial systems based on different types of PLC
  ○ evaluate the two contrasting systems detailing their appropriateness for the industrial application.
• It would be an advantage for learners to research applications from their workplace or a work placement as this could form the basis of the activity for learning aim C.
• You may choose to require learners to present their findings for one of the systems investigated to the group, as part of their preparation of a report for a group of apprentices about the features and functions of the systems they have identified. This would offer an opportunity for peer feedback. Learners could identify the:
  ○ application
  ○ characteristics of the PLC that make it suitable for the application
  ○ input and output devices used.
• You could summarise the information by leading a plenary session to collate the outcomes from the learner investigations and identify any areas not sufficiently covered for learners to complete their report on their investigation.
• You should guide learners to organise their portfolios/logbooks so that they can add material as they progress through the unit.

Learning aim B – Explore programming structures and methods to control Programmable Logic Controllers
• Learners need to be able to use the features of an appropriate IDE. You may decide that this is best approached through a series of exercises that build up skills in

using program instructions by mean of short programs of increasing complexity using input and output devices. For example, the tasks could include:

  - switching an actuator on and off
  - latching an output (concentrating now on the instructions and how they are used)
  - introducing a reset and an emergency stop
  - using a counter and a timer
  - creating a sequence to open the doors of an air-lock.

- You could also build testing and debugging into each exercise to develop learners' skills and appreciation of different techniques embedded in the software and other monitoring techniques.
- You need to encourage learners to collate evidence of the working programs (eg the purpose of the program, program listings, evidence of testing and explanations of how the instructions work). This could provide an invaluable resource when planning potential solutions for the application investigated for learning aim C.

Learning aim C – Develop an industrial Programmable Logic Controller system to solve an engineering problem

- You could prime learners to prepare for the requirements of learning aim C by looking at potential areas of investigation within their own workplace, or based on a work placement before the start of the unit.
- You could begin by requiring learners to complete a 'Project Proposal Form' as the basis of discussion about the suitability of the proposed investigation and to set the operational parameters. It is important that investigations are sufficiently rigorous to allow learners access to the full range of assessment criteria, but not so complex as to be unfeasible in the time allowed.
- You should set the parameters for each investigation so that learners are set unique targets to minimise the potential for plagiarism. There is potential to use business contacts to provide realistic scenarios for any learners having difficulty finding one for themselves. You should ensure that learners carry out the planning stages before commencing any construction. Learners need to work safely.
- The evidence that learners provide for learning aim C should contain:
  - a safely constructed PLC installation
  - a log detailing construction, testing, calculations, physical layout and construction plans, photographs and observational/witness statements.

Learning aim D – Review the development of an industrial control system and reflect on own performance

- Learners need to review and reflect on the development of their PLC system by preparing a 'lessons learnt' report. The report should explain how health and safety, electronic and general engineering skills were used to design, construct and test the system. An explanation of the importance and use of behaviours (eg time management) should be integrated into the report.
- You could help the learners structure their reflections so that they:
  - review and reflect on the activities that have been completed and make notes about what went well, what improvements could be made and what would be done differently next time
  - analyse the notes they have made and differentiate between facts and opinions
  - produce a professional report.

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- In reflecting on their activity, learners should consider the transferable skills they have used, for example the ability to:
    - learn independently
    - research actively and methodically
    - plan and manage their time to complete all the different activities in an appropriate time and in an appropriate order
    - use communication and literacy skills to follow and implement instructions appropriately, interpret documentation and communicate effectively with others in writing and orally
    - problem solve issues as they occur, eg logical and syntax program errors and hardware assembly faults.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 33: Computer System Security*
- *Unit 35: Computer Programming*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Bolton W – Programmable Logic Controllers, 6th edition (Newnes, 2015) ISBN 9780128029299.
  This book gives a good overview of PLCs without being specific about any one system.

Unit 37: Computer Networks

Delivery guidance

Approaching the unit

This internally assessed unit is intended to give learners the skills that they will need as computer network engineers to develop network systems that meet a client’s brief.

In order to become a successful computer network engineer, your learners will benefit from recognising how networking plays a large part in the way in which they interact with their devices and systems. In order to develop their understanding, and subsequently be able to apply this to real-life networking briefs and problems, they will learn best through practical exploration.

There is plenty of scope for delivering this unit through small group discussion and problem-solving, learning from mistakes and comparing outcomes with each other. You will need to allow many opportunities to use pervasive technologies.

To engage learners, you can use a range of activities that replicate real-life situations, such as working in teams while varying the team members and individual roles, so all learners have the chance to experience different levels of responsibility.

As computing comprises numerous technical terms, it is helpful to make no assumptions about your learners' previous knowledge of these terms, as this may reinforce misinterpretations. Learners can compile their own glossary of terms that can be ongoing throughout their study of this unit and their course.

Delivery of this unit is likely to use a range of different methods, including tutor input, as well as individual, paired and group work, which emulate problem-solving scenarios. The more occasions learners have to explore resolutions as case studies, the more able they will be to relate theory to practice, and any industrial links should be exploited in full.

This unit is structured in the same way as the stages for implementing a computer network so it would be sensible to introduce the notion of testing a system early on in your delivery. Subsequently, learners can better prepare and plan for the impact of testing and develop processes along the way that they can use and evaluate when they get to the end of the unit.

There is also scope to involve guest speakers, preferably from industry. The earlier you investigate, the sooner you can reveal their involvement to learners. This should hopefully foster their enthusiasm. Guest speakers might be sourced through your local Chamber of Commerce, Employer Business Partnership, or local authority. Alternatively, you could try organisations such as JISC and STEM. Such opportunities may also open up chances for visits and possibly even work experience or future employment. The armed forces are often willing to help and progression opportunities exist for learners to gain employment with sponsored apprenticeships and access to HE. The army also gives excellent training for teamwork.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the topics

Learning aim A is the opportunity to introduce learners to different types of computer networks and a range of technical terms to include in their personal glossaries. Giving learners handouts is likely to be less successful. Expecting learners to produce their own glossary helps them recognise their responsibilities and is likely to ensure the terms are memorable.

Initially, you could ask learners to share their current knowledge and understanding of networks that they will then match to examples you give in the lessons. The more chances learners have to touch, feel and examine any aspect of a network, no matter how small, the more questions they will raise and the more engaged they will be. Any opportunity that entices learners to question, answer and think hard will develop their communication skills and confidence. These skills are fundamental to finding employment.

As learners start to develop their understanding and increase their knowledge, you can assist them by supplying case studies that they can read and see if they comprehend. You will expand their understanding more quickly by putting learners in small groups to problem-solve and then share their processes, progress and outcomes with the rest of the class. If you start as you mean to go on, learners will expect to be involved and central to their own learning process. Encourage and expect them to critique their own work and the work of others. They will become more adept as the weeks go on although they may find it awkward at first. However, by setting high expectations of every single learner, you will prepare them for their assignments where they will have to think critically. They will have practised their analytical skills and developed the process of evaluation, all of which they will require to achieve the higher grades.

When you prepare for teaching learners about networking protocols, standards and security, be aware that they may find these topics hard to grasp. The more approaches you can use that involve learners, the more likely they are to understand. For example, ask learners to imagine how they would feel if they found out someone had used their password to access their phone or emails. Each learner could imagine something different, perhaps picking out a scenario from a 'lucky dip' and discuss with a peer. Then get learners to research real-life examples of network security issues such as cyber threats, personal security and malware.

A powerful way of getting learners to understand is to have them actually feel the experience. For example, to help learners understand confidentiality, ask learners to write a secret about themselves on a piece of paper. They place this in an envelope, write their name on it, seal it and hand it to you. You wait for a minute or two and then shuffle the envelopes as if to hand them out randomly around the room. Ask them how they feel right now and what they think is going to happen next, then without distributing, hand the envelopes back or shred them.

Before embarking on learning aim B, learners can begin to write procedures and policies for each of the aspects of computer network protection, in small groups. These could be posted electronically onto a dedicated group discussion board for comparison and you could invite online feedback and comments.

Learning aim B is about the planning stage. Before learners can plan a networking project, they need to understand the client's brief. One activity to help them appreciate that the client's brief and expectations might not match the outcome is to introduce the topic with a quick Chinese Whispers type activity. Learners can write their own brief requirements, bring them to the lesson and pass them on to other learners who have to interpret them. This could be in small groups to save time. It can be highly effective if they are required to hold a debrief in their groups to identify what went wrong (and right) and how to improve (and maintain the standard) next time. Learners will again benefit from your input when they apply it to case studies or small scenarios, but they will require guidance on how to plan for any type of project. Giving learners examples of real-life plans will help them, and learners could create procedures for the stages they have to undergo.

It is possible that learners might never have seen a site plan, therefore examples would also be useful especially where contextualised to their scenarios. Your learners might be studying 2D and 3D technical drawing and if not, might be encouraged to take this as an additional subject. Giving them examples of a range of site plans, including rough sketches and photographs, will encourage learners to think widely about how they prepare for client meetings. Learners could create their own from a given scenario or perhaps generate a site plan based on the surroundings in their place of study and then work with each other to compare interpretations. They could be given a likely plan or a generic plan and asked to identify the key areas to consider in their plan, such as where the router or server will be situated, whether any walls will interrupt the signal and how to connect to the network etc.

As you move forward with learning aim B you could again rearrange teams (rather than getting learners to decide on who they want to work with), to reflect real business practice, but this time identify which learners in each team will take the role of the client. In each case, learners should be given time to prepare for their roles and consider what they need to do to enhance the experience. As they need to demonstrate their appreciation of the support clients might need or demand, a simulation or role play would help within the boundaries of professional behaviour.

Learning aim C is the development stage of the computer network and its infrastructure. Learners will need to be exposed to many practical opportunities and you will need to plan early for access to any workshops or resources you might need. Learners can apply their learning to small, scaled down mock-ups or components, which will give them hands-on experience even if they have to pass examples around. Use of simulators, remote labs and equipment would be beneficial to your teaching, especially the harder to learn aspects. Learners could be encouraged to use their own mobile technologies in sync with other networking resources, although you may need to seek permissions in accordance with your organisation's safeguarding policies.

Ensure that where you set up small groups every single learner has a role to fulfil and that they are assessed on their contribution. Involve learners in assessing their performance and that of their peers for a rounded and meaningful approach to formative assessment.

Although learning aim C ends with testing the network, learners will need to know what they are testing and how to plan ahead for the outcomes. Encourage them to keep a log and photographs of every stage of the process and emphasise the importance of planning for the outcomes, just as they do when planning their own study progress and action plans. If you invite your learners to keep a folder or portfolio at every stage, including their errors and records of what and how they changed the way they worked etc, they will find it invaluable to look back at and recognise their learning and progress. Promote this type of activity from the beginning as something to be proud of and even use it to show future employers or higher education establishments as proof of their abilities.

Summary of unit

Learning aim	Key content areas	Recommended assessment approach
A Examine the types, applications, technologies, and security of computer networks used in engineering	**A1** Types and applications of computer networks in engineering **A2** Computer networking technologies – hardware, software and services **A3** Computer networking protocols and standards **A4** Network security	A report, examining current types and engineering applications of computer networks along with the enabling technologies, including the hardware, software, services, protocols and standards and network security.
B Plan the implementation of a secure computer network infrastructure to meet a client brief	**B1** Services planning **B2** Infrastructure planning **B3** Planning client support **B4** Security planning	Design documentation and planning for the development of a computer network.
C Develop a secure computer network infrastructure to meet a client brief	**C1** Construction of a computer network **C2** Security features and resources **C3** Systems testing	Completion of a practical activity to construct and test a networked computer system. Evidence should include test results, observation reports and witness statements, annotated screenshots and/or photographs of the network in operation.

Assessment guidance

As this unit is internally assessed, you can prepare learners for their main assignments throughout the delivery by incorporating mini projects, involving them in analysing and evaluating their progress and achievements and identifying ways to improve. As problem-solving is a key skill to operate as a network engineer, the more opportunities they have to hone this skill the more adept they will become.

One of the ways learners will become more familiar with assessment language, develop their comprehension and become more disciplined is by being encouraged to undertake the activities and explore the case studies in the student book. A debrief of their experiences and questions raised could form part of lesson plenaries.

There are a maximum number of three summative assignments for this unit and whilst you could issue less than three, you and your learners will benefit from having formal measures of progress at interim stages throughout the planned delivery and assessment period.

You and your learners will also benefit from collaborative planning with your colleagues' delivery on related units as shown later in this delivery guide.

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Together you can coordinate the order for delivering new topics and avoid duplication of delivery or assignment overload.

In this unit, the learners are expected to produce examples to achieve a pass, which gives plenty of scope for including hardware, software and physical or virtual devices. As engineers, they are likely to have access to CAD and CAM applications and possibly an Additive Manufacturing Machine.

Your learners might prefer to present their outputs in the way they choose, supported by a selection of, for example video recordings, logs, diaries, discussion boards, blogs, testimonials, verbal and written accounts etc.

Your learners will benefit greatly from your expectation of their ability to reach merit and distinction levels. Therefore setting the bar high at the beginning will boost their confidence. They will need to demonstrate their ability to problem-solve, analyse and evaluate the issues and make recommendations which they can justify. By keeping a log or portfolio of their activities that shows their achievements and especially how they overcame their challenges, they will become independent and responsible learners.

Getting started

This gives you a starting place for one way of delivering the unit.
Activities are suggested in preparation for the summative assessments.

Unit 37: Computer Networks

Introduction

As networking requires a systematic and methodical approach, the way you deliver this unit can emulate this process. In other words, the lesson structure could involve learners in the discipline of identifying what is required, planning, designing, implementing and reviewing the outcomes.

In delivering this unit your learners will remain motivated if they are surprised, challenged and stimulated by creative tasks. Therefore, even if workshops are not always available the activities and resources should be accessible in classrooms to avoid extended periods of tutor input where learners become quickly bored and disinterested.

Use your learners as a resource and get them to think hard by asking them to examine and identify components, and research and propose ideas that will enable you and them to question, evaluate and turn knowledge into understanding.

Involving guest speakers and arranging visits to industry will contextualise their learning and are greatly enhanced when learners have to plan for such occasions and evaluate the outcomes. Time set aside for learners to discuss and share ideas is an investment and will pay dividends when well structured.

Most of the underpinning knowledge is delivered throughout learning aim A then assessed, followed by learning aims B and C where knowledge is developed and understanding deepens through scenarios. Learning aims B and C could be assessed as a larger project rather than individually, giving other methods of formal assessment to gauge progress.

Learning aim A – Examine the types, applications, technologies and security of computer networks used in engineering

- Learning aim A gives learners the ideal opportunity to discover what they already know about networks and relate their prior knowledge to industry practices. To expose misconceptions and correct misunderstandings, for example in terminology, learners can start to create their own glossary immediately on starting this unit. To integrate opportunities for learners to develop their English and mathematical (functional) skills, you can involve learners in discussions, which are best varied by you deciding the grouping or pairing to avoid learners only working in friendship groups. Explain to them, or get them to explain, the reasons why they are placed in groups with others and how this practice will ultimately make them more employable.
- Encourage every learner to participate in group feedback by taking turns during plenaries to explain their findings, justify their outcomes and describe their processes and thinking. As learners become more articulate, their use of language and application of terminology will also improve and prepare them to aim for higher grades in their assignments. During plenaries, or at the beginning or end of topics, learners could raise questions and share experiences gained through undertaking case studies and practice assignments from the student book. By allocating regular time to do this, learners will know they are being monitored and recognised for spending additional time on these. Any learners who have not engaged in these may well be encouraged to do so when hearing accounts from their peers.

- When you deliver computer network models, you could take learners to see the central servers in your organisation, possibly in small groups. You could set them a quick activity at the start of the lesson to distinguish the different models and get them to explore decentralised computer systems by using their own devices. When you introduce applications of engineering networks, learners might have examples they could give from part-time jobs or perhaps relatives' experiences. You might want to arrange a visit to a local engineering factory. It is possible that you have apprentices working locally so links with employers are already developed. If your organisation has a work-based learning manager or business development manager, these people might be very useful in finding some contacts.
- As you progress through this learning aim your learners will value being able to examine and become familiar with different networking components, instruction booklets, case studies and research sources. Ideally, these should be made available before you introduce these concepts. Encourage learners to undertake preparation and research prior to introducing each new topic, through homework. Lessons could begin with an opener, a short activity such as sharing in a small group what they have found, understood and not understood, which relates to the rest of the lesson. This method involves them in meaningful research and replicates how they might undertake a workplace task.
- The recommended assessment approaches include a report for this learning aim. This might be the first time learners have been asked to produce a report or they may possibly have a fixed idea about what a report looks like and contains. As a report can appear in many different formats, learners should be given choices about the approach they take so long as their product contains the key ingredients. This is worth spending time on and is beneficial when incorporated into small group activities and not given as a handout or list. If learners are expected to give presentations as part of their assessment, discourage immediate rushing to use PowerPoint as too often attention and time is heavily devoted to the aesthetics of a slide show with little consideration given to planning and quality of content.
- When you introduce the notion of protocols, learners can experience setting and understanding the purpose of rules by setting their own rules for behaviour in the class and in their groups. This can be a swift opener, in small groups, where they discuss briefly, identify how they should behave or refer to work and generate a list. They share these quickly with the whole class and the entire group vote on the five most important ones. Many will be duplicated or mean the same thing but it is highly likely they will agree on a list that represents the way you would want them to work. They will take responsibility for working in this manner during every lesson and correct any unacceptable behaviour. This invaluable activity quickly contextualises the purpose of protocols in computing and policies in business, relieving any future need to reinforce its importance as it is often portrayed as a dry topic or an order.
- Learners need to plan and prepare for how they will test their system and this topic should be introduced early on in the programme rather than as a surprise towards the end. Learners will not understand how to plan for testing, the time element, cost and other considerations that will involve the client. This topic should be reinforced throughout learning aim B nd expanded upon before being put into practice in learning aim C.
- The issuing of assignments should be in line with the topics being delivered and issuing to learners early on in the programme is very often welcomed. Learners can apply their planning skills so they become habitual routines and your expectations will be that assignments are worked on outside of lessons and not used to fill gaps in lesson time where new learning and experiences should be maximised.

Learning aim B – Plan the implementation of a secure computer network infrastructure to meet a client brief

- Learning aim B lends itself to a mini project with small group work dominating the majority of every lesson. Each designated group might take on a role play with one group member taking the client's position. Give each group a scenario that presents a problem to solve in a business context. There are numerous case studies on the internet and reputable sites such as government projects, JISC, STEM and others listed at the end of this guide might give some useful starting points. Involve learners in finding their own projects (as homework) and then agree upon as a lesson opener. Alternatively, you may be able to involve a local employer who has undergone a recent networking project. In this example, each group could undertake the same project but tackle it in a different way and the results be compared between groups. By using several different projects the results can be analysed and compared, better preparing learners for a networking engineer role in the future.
- You will find another valuable investment is to structure an activity where learners decide upon their team roles in their project groups. As effective teamwork is a major skill and continually criticised by employers as lacking in many, you will need to introduce learners to different types of roles, their titles and what duties are associated with them. One way to do this is to invite a guest speaker or perhaps involve someone from your technical department. Another is to give learners a selection of titles and get them to match with some job descriptions. These can be sourced from the internet or possibly an employer. Learners will also learn from evaluating their own strengths and weaknesses to assess what they bring to the team. They can do this by undertaking a SWOT analysis or by using another theoretical model such as Belbin's team roles.
- There is a considerable emphasis on the client in this topic and learners may naturally want to incorporate their own devices into this project so ensure that organisational policies are not being compromised. You might need to make a case for changing the current policy that may be out of date or too generic. Perhaps your learners could make a case for change as they would in employment. As you want to encourage your learners to put additional time into their learning outside of planned lessons, set up a dedicated networking area of their course so learners can communicate with each other, post messages, ask questions and upload examples or evidence of their progress. These types of activities give invaluable opportunities for debriefings and learning from oversights or errors and so reinforce the importance of capturing such events.
- When delivering security planning, once again learners will understand and appreciate security better if they have actually experienced a breach of security. The example given at the beginning of this guide where learners are exposed to the threat of private information being shared could be used as an opener to this topic. Once again, the terminology needs to be clearly defined and learners should be keeping their ever-increasing glossary that could culminate in a useful booklet at the end of this unit. Examples of firewalls, traffic filters etc in whatever form available are more likely to remain memorable than just telling learners what they are or what they do. An opener for this topic could be to give learners terms and for learners to give explanations of their purposes. Each group could share their conclusions and the most relevant could become a class definition. Activities such as these could be captured as posters and displayed but would carry more gravitas and longevity if captured electronically for the group by learners themselves, using their own ideas and methods. By continually placing the responsibility on learners to think, solve problems and be creative, you will motivate and demonstrate how you value their input.

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Learning aim C – Develop a secure computer network infrastructure to meet a client brief
• Learning aim C brings the project to fruition and is the final part to this unit. Learners will need to have access to sufficient resources to undertake this part and the final two parts of this topic will require considerable time early on to prepare them for the process of testing. • It would be extremely beneficial if some employer involvement could be integrated into each stage of the project or even during debriefs. If any employers were initially involved, then the situation is probably better. Otherwise asking learners if they have a mentor they could invite or involving someone from your organisation's technical department will be beneficial. This arrangement will need to be planned well in advance so learners and the employers can plan and prepare for a useful event. Ensure any visitors have copies of the assessment criteria and the brief issued to learners. They might need to have an interpretation of the criteria to avoid any misunderstanding. • As learning aim C ends with testing the network, learners will benefit from being introduced to testing and feel better prepared by planning ahead for the outcomes. Encouraging them to keep a log and photographs of every stage of the process will enhance their learning experience. • These lessons will be mainly practical and learners should be encouraged to continue their thinking and problem-solving outside of lessons by continuing to engage in discussion threads, blogs, videos and any other forms of media to capture their experiences and learning. It is possible that every lesson should conclude with a debrief where each team critiques their own progress and performance and possibly shares key findings with the whole class. Learners should also capture these findings whilst you can give witness statements or feed back your observations and constructive, developmental feedback to each team.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 32: Computer System Principles and Practice*
- *Unit 33: Computer Systems Security*
- *Unit 34: Computer Systems Support and Performance*
- *Unit 36: Programmable Logic Controllers*
- *Unit 38: Website Production to Control Devices*

Pearson BTEC Level 3 Nationals in Computing (NQF):

- *Unit 30: Communication Technologies*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Videos

- www.bing.com/videos/search?q=videos+of+computer+networks&view=detail&mid=487F210125C9814BBEA5487F210125C9814BBEA5&FORM=VIRE1
  Introduction to basic computer networking.
- www.youtube.com/playlist?list=PLmPWlwoQjRFV6-ku8DefA_Qtn5mM2E6KC
  Cisco networking.

Websites

- www.belbin.com
  Belbin's team roles.
- www.cisco.com/c/en/us/products/security/customer-case-study.html
  Case studies and research.
- www.educatornetwork.com
  Microsoft's tutor forum for advice, sharing resources and learning from others globally. Very useful for learning teaching techniques from other cultures.
- http://ethics.iit.edu/eelibrary/case-study-collection
  Database of ethical case studies relating to computing.
- www.excellencegateway.org.uk/node/16631
  Invaluable free resource for teaching and learning materials based on

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activities, blended learning and incorporating development of 'soft' and employability skills.

- www.gov.uk/government/case-studies/clever-engineering-macrete-bridges-the-technology-gap
  Case studies relating to government technology project.
- www.jisc.ac.uk/content
  Direct link to the JISC library containing multiple digital resources on a wide range of technological topics. The JISC community gives tutors with opportunities to network and share ideas.
- www.legislation.gov.uk/ukpga/1965/4
  Government website links for technology legislation – Science and Technology Act 1965.
- http://www.legislation.gov.uk/all?title=information%20technology
  Government website links for technology legislation.
- www.local.gov.uk/documents/10180/11553/Transforming+public+services+using+technology+and+digital+approaches/ab9af2bd-9b68-4473-ac17-bbddf2adec05
  Authenticated local government public services case studies - PDF.
- www.mindtools.com/pages/article/newTMC_05.htm
  How to use a SWOT analysis in business to evaluate strengths and weaknesses.
- www.network-box.com/casestudies
  Technology project case studies.
- www.stemnet.org.uk
  Networking site where tutors and employers are brought together to share ideas and create relationships to support learners.
- www.stem.org.uk/audience/secondary-computing
  Specialist advice, ideas and practical solutions for teaching computing and technology to secondary and FE learners. Multiple free resources and bespoke training events.
- www.technologyreview.com/view/526401/laws-and-ethics-cant-keep-pace-with-technology
  Technology review of issues keeping up with laws and ethical considerations in a fast moving industry.

Unit 38: Website Production to Control Devices

Delivery guidance

Approaching the unit

The purpose of this unit is for learners to investigate web controlled devices, web applications and server-side scripting that enable the remote control of physical devices. Learners will design and develop a web application that could be used to remotely control a physical device.

Learners should have access to adequate web development environments and servers (such as those stated in the unit specification) in order to complete the assessments for this unit. Preferably, learners will have access to a selection of servers and development environments as this will enable greater opportunity for comparison between the development options.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

You could begin learning aim A with a discussion of website-controlled devices and web applications that enable them and the difference between client-side and server-side scripting. Learners could discuss the web applications that they are familiar with and you could reference where applications and principles are used in their examples. You should cover several server-scripting options, including the benefits and drawbacks of their use, and demonstrate where they would be used most effectively.

Learners should investigate several server-side web applications and be able to examine the use of server-side scripting within them to discover how user interaction is achieved and what processing takes place to provide function.

You should introduce learning aim B with by discussing the application of security principles, using examples and case studies as appropriate. You could spend time discussing the types of threats that websites and users could face. This should be expanded to cover vulnerabilities, with further discussion on how threats and security holes could be exploited.

Further to a discussion on threats and vulnerabilities, you should discuss protection measures. This could follow from the points raised in the context of measures taken to avoid vulnerabilities and counter threats. This could be a good time to invite a guest speaker from a web development environment to discuss how to build and maintain secure websites.

In learning aims C and D, learners will need to design and develop their own web application using selected programming languages and environments. Learners must understand what options are available and it is recommended that you introduce learners to programming and development environments as early as possible to allow plenty of time for them to practise their skills.

When designing their web applications for learning aim C, learners should be aware that, as with any software design, they should be familiar with the scope of the design. You should guide learners in the process of choosing appropriate methods to use in their designs. Learners should be familiar with techniques used in web application design and confident in the use of those techniques in their own designs.

Throughout this learning aim and learning aim D, you should impress upon the learners the stages of software development, including analysis, design (in learning aim C) and development and testing (in learning aim D). You should ensure that learners know what is required in the analysis and design of a mobile app and the management of a software development project.

You should allow time for the learners to review their designs with their peers; this could be by means of presentations or seminars, where learners could ask questions and make suggestions directly to one another.

In learning aim D, learners will complete their development projects and you should ensure that they are proficient with the development and testing stages of software development.

You should provide learners with as much practical experience as possible, introducing the use of development environments early so that learners have time to experiment with the use of the tools available.

You should instruct learners on the use of the chosen environment, ensuring that they are familiar with all of the techniques listed in the unit specification.

You should allow time for learners to review their web applications and the web applications of their peers. This should be done late enough that the learners have a functional website, but early enough that they will have time to make refinements based on the feedback they receive.

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Issue 1 – May © Pearson 2016

Learning aim	Key content areas	Recommended assessment approach
A Investigate the technology used in website applications for controlling physical devices across the internet	**A1** Website controlled devices **A2** Web Server-Side scripting languages **A3** Applications of web server scripting	A report providing an introduction to scripting principles, covering security issues, and an introduction to scripting principles.
B Investigate security measures used to protect website applications from malicious attacks	**B1** Website security threats and vulnerabilities **B2** Security protection measures for website applications	
C Design a website application to remotely control a physical device across the internet	**C1** Website design **C2** Common tools and techniques used to produce websites **C3** Client-side scripting languages	Design documentation showing the planning, preparation and design for a website application. Presentation of a functional website application with supporting development and test documentation.
D Develop a website application to remotely control a physical device across the internet	**D1** Website development **D2** Common tools and techniques used in server-side scripting	

Assessment guidance

It is suggested that the assessment for this unit should be covered in two assignments.

Assignment 1 will cover learning aims A and B. This should be a report providing an investigation of existing web applications that examines the scripting that has been used and which discusses the security threats and measures within web applications.

Assignment 2 will cover learning aims C and D. This should be project based: learners will need to design and develop their own web application to meet a client's requirements. Learners should consider hosting options, database integration and features to be included in their websites. The project should be presented for assessment as a functional web application, which could be demonstrated in a classroom or lab environment, along with an associated development report.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 38: Website Production to Control Devices
Introduction From cameras to interplanetary spacecraft, there is a multitude of devices that can be controlled remotely. A common way to control remote devices is to use server-side scripting embedded in websites. You should introduce this unit to learners with an investigation of the web applications and server scripting that can be used to enable remote devices. You should explain to learners that they will be asked to design a functional website and implement server-side capabilities using server-scripting languages to control a remote device.
Learning aim A – Investigate the technology used in website applications for controlling physical devices across the internet
• In learning aim A, learners will investigate web applications for controlling devices, along with their function and the scripting applied. • As learners will need knowledge of several implementation options, you should provide them with examples of web applications with different functionality and implementations. • You should provide demonstrations and examples of server-side programming options and functions. It would be beneficial for learners to have access to a server and demonstrations of the options and functions that you discuss. • You should provide learners with programmed examples and the opportunity to investigate and experiment with server-scripting code to highlight how interaction and a website's functions are achieved. • You should introduce learners to programming and programming environments for web development and allow time for learners to work regularly with development tools. This is particularly important if they have not yet had exposure to programming in other units.
Learning aim B – Investigate security measures used to protect website applications from malicious attack
• In learning aim B, learners could investigate the same web applications they investigated in learning aim A and focus on the security measures employed. • Learners should be familiar with types of threats to web applications, the potential issues they could cause, and the severity of a breach in security. To ensure they understand this, you could lead discussions of threats posed to the websites investigated in learning aim A and how they could affect the website or the user. During discussions, it would be useful to highlight areas of vulnerability and include an investigation into the ways in which websites can be exploited. • Here you could expand on the earlier discussions by including ways to prevent vulnerabilities and reduce threats. As learners will need knowledge of several security options, this could be a good opportunity to invite a guest speaker to discuss the security measures that they use in industry and to explain how they maintain secure websites. It would be beneficial to provide learners with examples of web security with different applications and effectiveness. • It is necessary that learners understand that security measures must be taken and know how to apply them. You should provide learners with worked examples of

securing web applications and give them time to practise securing web applications themselves.
Learning aim C – Design a website application to remotely control a physical device across the internet
• When delivering this aim you could refer to the web applications identified in learning aim A. • Learners must understand the process of designing a web application. Learners should be provided with examples of good practice and example case studies for development of web applications. • You should guide learners in the process of choosing appropriate methods to use in their designs. Learners should be familiar with techniques used in website design and be confident in the application of those that they will use in their own designs. • Learners must be familiar with software development and the design documentation that is expected of them. Learners must be able to design the purpose, interface, scripting and hosting options for their website. To this end, they should be confident in the use of diagramming techniques and pseudocode. • Learners should review their designs with their peers and refine as necessary. They could present the concepts of their web application designs to the class and invite their colleagues to comment, making a note of any refinements required.
Learning aim D – Develop a website application to remotely control a physical device across the internet
• When delivering this learning aim, learners will develop their web application from their own designs created in learning aim C. • Learners must know how to develop software from a design schematic. They should be able to produce a prototype of their website using appropriate tools and techniques. Learners should have the use of several web development environments so that they can build their skills. • Learners should understand the use of database systems and know how to integrate them into their websites effectively. • Learners should be able to test their web applications for compatibility, stability and acceptance. These tests should be performed using a variety of methods, including white box and black box methodologies, and any issues that are identified should be rectified. • Learners should demonstrate their website to an audience and gather feedback from sample users to identify improvements and the overall level of acceptance.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 5: A Specialist Engineering Project*
- *Unit 6: Microcontroller Systems for Engineers*
- *Unit 19: Electronic Devices and Circuits*
- *Unit 32: Computer System Principles and Practice*
- *Unit 33: Computer System Security*
- *Unit 36: Programmable Logic Controllers*
- *Unit 37: Computer Networks*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Dalziel H – *How to Attack and Defend Your Website* (Syngress, 2014) ISBN 9780128027325.
  This book explains how to find vulnerabilities and defend against them.

Websites

- www.lucidchart.com
  Lucid Chart – an online diagramming tool.
- www.w3schools.com
  W3Schools – this site has web development tutorials.

Unit 39: Modern Manufacturing Systems

Delivery guidance

Approaching the unit

In this unit, your learners will investigate the functional areas of a manufacturing organisation that include activities encompassed by manufacturing operations, how manufacturing facilities are physically arranged, and how their activities are controlled and coordinated. In addition, they will study the importance of responding to economic, social and technological change in order to stay competitive and enable on-going commercial success.

Manufacturing operations must perform efficiently with low waste and high productivity. The use of manufacturing simulation exercises in the classroom will help to illustrate and embed the potential benefits of some of the Lean concepts covered in the unit in an enjoyable and engaging way.

There is scope within the unit to develop relationships with industrial partners from a diverse range of sectors as dictated by centre location, specialism or area of interest/expertise (eg white goods, consumer electronics, automotive or food). The involvement of an industrial partner will ensure that the case study materials required to deliver the unit (eg shop floor documentation or factory layouts) are realistic, relevant and reflect current industrial practice. Studying the manufacture of a particular product(s) in a real-life manufacturing operation will help to bring the unit content to life and encourage learner engagement. To support this approach, classroom teaching and independent research should be blended with visiting speakers, industrial site visits and perhaps even relevant work experience placements, to show how industrial manufacturing works in practice.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, you could begin by introducing the various functions that make up manufacturing operations. This might initially be tutor led but would be enhanced greatly by the involvement of an industrial partner. A factory tour or guest speaker early in the delivery of the unit will encourage learner engagement and provide a good starting point for additional independent research.

It is important that learners establish a firm understanding of the activities encompassed by manufacturing operations. You might then work with learners to develop the necessary analytical skills to formulate well-researched and reasoned links between the performance objectives of a manufacturing operation and their overall success. An important aspect of learning aim A is to encourage learners to develop the evaluative skills to form valid opinions as to the relative importance of contrasting performance objectives in specific circumstances. To allow this, they should choose or be assigned individual case studies to work with. Allocating individual case studies will help you to validate the authenticity of learner work.

In order for a manufacturing operation to acquire or maintain a competitive advantage, it must effectively exploit or mitigate against technological, social and environmental trends. It is important that your learners, as engineers of the future, develop an appreciation of the potential impact on the performance of manufacturing operations that emerging technologies, or other factors such as climate change, may have. You could achieve this through an initial tutor-led overview followed by detailed independent research into a range of specific trends that are likely to have most impact on the case studies that individual learners will use. This detailed research can then form the basis of an analysis and evaluation of the relative potential impact and importance of the trends on particular performance objectives.

For learning aim B, you must ensure that learners can clearly distinguish between process types and typically associated process layouts and link these to the requirements of contrasting products with different volume/variety characteristics. You should also introduce examples of the documentation used to coordinate the manufacture of a quantity of a component or product from when a production order reaches the shop floor through to its completion. This will require a range of appropriate resources, which would ideally be developed in conjunction with one or more industrial partners.

Learning aim C brings together many of the process improvement techniques used by manufacturing organisations to reduce waste and minimise costs that are collectively referred to as Lean. Your learners will require an understanding of the Lean philosophy and its general characteristics as well as the purpose and effectiveness of a selection of lean tools and methods. Due to the practical difficulties of applying these techniques in a real life industrial setting, learners will develop their knowledge and skills by applying a range of Lean tools and methods to simple manufacturing simulations. These can be conducted in the classroom using relatively basic resources and allow the effects of the techniques applied to be easily observed and measured. Kits of components to enable you to simulate the manufacturing environment are commercially available but you could develop your own.

Learning aim	Key content areas	Recommended assessment approach
A Understand the functions of manufacturing operations and factors influencing their success	**A1** Manufacturing operations **A2** Performance objectives in manufacturing operations **A3** Future trends influencing manufacturing operations	A written report on the functions contained in a manufacturing operation and factors affecting the performance of a manufacturing organisation. Learners must also investigate likely future trends affecting manufacturing organisations.
B Examine process systems that are commonly used in manufacturing industry	**B1** Process types and typical industrial applications **B2** Manufacturing layout types **B3** Characteristics of effective system layout **B4** Manufacturing documentation	A written report justifying the type of manufacturing system used to manufacture contrasting products, which should include an explanation of all relevant documentation. Evidence should include diagrams and/or photographs to support an evaluation of the layout used. This would best be achieved in collaboration with an industrial partner or it could be based on case study materials.
C Investigate the principles of Lean manufacturing and how these influence productivity	**C1** The Lean philosophy **C2** Key elements of Lean **C3** Lean tools and methods	A presentation outlining the principles of Lean and its application to transform a traditional manufacturing operation. Part of the presentation will include the delivery of an activity devised by the learners that illustrates a range of the principles of Lean effectively by simulating how part of a manufacturing system might be improved.

Assessment guidance

The assessment of this unit is most likely to be in the form of written reports for learning aim A and learning aim B and a presentation for learning aim C, as suggested in the specification. There is, however, flexibility in the forms of evidence that are acceptable as long as the learners' work fulfils the necessary requirements of the assessment criteria and is individual to each learner.

Evidence for learning aim A is most likely to be in the form of a written report, but it could be delivered as a presentation with detailed presenter notes or perhaps a video narrated by the learner.

Evidence for learning aim B is most likely to be an illustrated written report that should include appropriately referenced images, diagrams and/or photographs to support the text. Copies of manufacturing documentation should also be included and their usage explained. These could be included in an annex to the report and should be cited appropriately in the text.

Evidence for learning aim C will include examples of Lean manufacturing simulations and will most likely be in the form of a presentation. This may include embedded video evidence of the learner carrying out the simulation exercises. Copies of any presentations, including presenter notes, should be submitted by each learner after their presentation. You should provide an observation record detailing the content and effectiveness of their presentation, to accompany this evidence. This will greatly assist you when formally assessing the evidence and during any subsequent internal verification.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 39: Modern Manufacturing Systems

Introduction

The manufacturing systems used by engineering organisations vary greatly from company to company and vary in their scale and complexity. Individual organisations often have highly customised systems that have been developed empirically over time to suit their specific needs. In general, there is no one solution that fits all. This unit aims to give your learners an introduction to the general principles that underpin many of these systems. It will equip them with the skills to assess why real organisations have chosen to organise themselves in particular ways. Your delivery of the unit will be greatly enhanced with the involvement of industrial partners, who might help develop case study materials or provide site visits and visiting speakers to help contextualise the unit content.

As part of your teaching, you should encourage learners to develop the analytical skills necessary to form links between the different elements within each learning aim and across the unit as a whole. Under your guidance, they should develop effective research skills from a range of sources. For example, they may develop research skills not only by using web-based information but also by using appropriate reference books and by raising questions with industry experts during industrial visits, work experience or during conversations with visiting speakers. This will enable your learners to evaluate the importance of achieving performance objectives and the potential impact of future trends likely to affect manufacturing by the time they, themselves, might be employed in the sector.

You will also find that the use of simplified manufacturing simulations in the classroom will make the effects of Lean tools and methods on manufacturing operations accessible and understandable, as individual ideas can be tested in isolation and their impact analysed.

Learning aim A – Understand the functions of manufacturing operations and factors influencing their success

- Learning aim A provides learners with an introduction to manufacturing operations, the factors that affect their performance and how these might change in response to future trends.
- You should make clear that manufacturing operations are the part of an engineering organisation that deals only with the manufacture and delivery of products and/or services. The relationship between manufacturing operations and other elements of an engineering organisation such as sales or finance are, of course, of great importance but are outside the scope of this unit and are dealt with in *Unit 4 Applied Commercial and Quality Principles in Engineering*.
- You might start this learning aim in the classroom by asking learners to work in small groups to identify the important functions necessary in the manufacture and delivery of products or services. This will you give you the opportunity to gauge their existing knowledge and then, once their ideas have been shared, make clear the areas dealt with in operations that will be considered in this unit. Working collaboratively in groups is a useful way to develop intrapersonal and communication skills during teaching and learning. Once the main functions have been identified, with additional input from you if necessary, learners could then be asked to work in pairs to methodically research a selection of them and report back their findings. Throughout any research activity, you should ensure that each

learner records detailed notes, perhaps in a logbook, which can then be used to support subsequent activities. Notes should include all information considered important. Web addresses, sources of images, book titles and page numbers should also be noted, so that their use in any subsequent work can be properly referenced.

- You should ensure that all learners understand the functions encompassed by manufacturing operations before you proceed.
- It is important that your learners gain an understanding of the performance objectives driving manufacturing operations. They must develop an understanding of how these help to support the underlying aims common to all manufacturing companies, such as making the most efficient use of time, equipment and materials, in order to minimise costs whilst at the same time meeting the expectations of their customers.
- You should give learners the opportunity to develop the analytical skills necessary to establish links between the performance objectives in manufacturing operations and the operations functions themselves. Many performance objectives will affect more than one function. For example, high dependability can only be achieved if health and safety is managed effectively to prevent delays caused by accidents, or if maintenance activities are organised to prevent unscheduled breakdowns, etc. You should also encourage learners, perhaps in tutor-led discussions, to start to evaluate which performance objective will have the greatest impact on a manufacturing operation. This could be achieved by using an analysis of the consequences of poor performance in a range of areas as a starting point.
- At this stage, it might be useful, if possible, for you to arrange an industrial visit or factory tour to introduce learners to a real manufacturing operation. Early involvement with local industry will also firmly establish the vocational nature and relevance of the topics being studied. A good way to identify a suitable industrial partner is to look at those companies recruiting engineers or engineering apprentices in your area. Many will be willing to provide support as they often appreciate the opportunity to market themselves to your learners as potential future employers or apprenticeship providers.
- A factory tour would allow your learners to see at first hand manufacturing in action and provide an opportunity for them to ask questions about the how performance of the operation is managed. It will also allow them to talk with professional engineers about current and future trends that are driving change in their organisation, providing a starting point for research into the final part of the learning aim.
- As future engineers, your learners will need an understanding of how manufacturing operations continually develop, evolve and adapt to technological, social and environmental trends. This part of the learning aim will give them the opportunity to develop the skills required to undertake independent and methodical research. It will help increase learner engagement if you encourage individuals to research developing or future trends that catch their imagination or those in which they have a particular interest. Once your learners have considered a range of trends and their possible consequences, they should be asked to research two of them in depth. The results of this research should then be related back to the performance objectives for manufacturing operations, in order to analyse their potential impact.
- As their knowledge and understanding deepens, it is important that your learners are able to develop well-reasoned opinions as to the influence of these trends and their relative impact. You could ask them to present their findings back to the group and facilitate feedback through peer assessment of their research and subsequent conclusions.
- Following a period of reflection and revision you should establish your learners' readiness to complete the first assignment which covers learning aim A. This will most likely be in the form of a written report.

Learning aim B – Examine process systems that are commonly used in the manufacturing industry

- Learning aim B looks at the different process systems applied in the manufacture of products with differing volume/variety characteristics, physical arrangement of machinery, equipment and materials. It also considers the documentation that triggers and coordinates manufacturing activities.
- Before beginning this learning aim, you will need to ensure that you have adequate product examples and related case study material to deliver the content to your learners effectively. Ideally, case study material should be developed in conjunction with an industrial partner(s) using real-life examples of products or components that they manufacture. Case studies should include a description of the product being manufactured, typical batch sizes, detailed plans and/or photographs of the facility layout, the route taken through the facility during manufacture and examples of the documentation used to control the process. If you have sufficient recent industrial experience, you could devise your own resources without the involvement of an industrial partner organisation. However, learners engage much better when dealing with real-life scenarios, especially if these can be linked to an industrial visit to see some of the products used in teaching actually being manufactured. Those learners studying part-time as part of an engineering apprenticeship or undertaking work experience in a manufacturing environment should be encouraged to compile their own case study materials for use in this learning aim.
- In your introduction to this learning aim, you should discuss a wide range of contrasting products from a range of engineering sectors using physical examples where possible. Learners should quickly become comfortable in determining an appropriate process type given the volume/variety characteristics for a product or component. You should encourage learners to develop their analytical skills by establishing links between process types and their defining characteristics when manufacturing a range of contrasting products.
- You can use case study materials detailing factory layouts to illustrate the characteristics and typical applications of contrasting layout types. Again, you can help develop analytical skills by asking learners to evaluate the effectiveness of example layouts in different manufacturing scenarios. This might involve studying factory layout plans, photographs or video footage of factory layouts provided, or using information gathered by the learners themselves during an industrial visit or work placement. This might involve work in small groups to discuss the advantages and disadvantages of the approach to system layout taken in a range of examples. You should encourage learners to look for potential improvements that could be made in each case and to evaluate the potential impact these might have on the overall effectiveness of the layout.
- Those working in manufacturing industry appreciate the importance of using appropriate documentation to trigger and subsequently control the manufacture of a product. Learners, however, tend to find it hard to engage with this area of study. Purely as a teaching aid and to stimulate learner interest, you might find it useful to set up a basic manufacturing process in the classroom. It need not be complicated, with three or four assembly operations involving a limited number of components (this may share the resources required for the Lean manufacturing simulations in learning aim C). You could then ask learners to work in groups to develop their own systems for coordinating the manufacture of this simple product. If learners have limited success, you could introduce some of the documents detailed in the unit content but without detailing the exact information they need to contain. Determining this could be the focus of further practical investigation. When a viable system has been devised, the results should be compared with your reference documentation and discussed with the group.

- Complication tends to increase with increasing volume, variety and product complexity and so, with this simple example, the basic requirements of the documentation can be established before more complex products are considered in case study material or during independent research.
- When you consider that learners are sufficiently familiar with process types, layouts and manufacturing documentation, you should issue the second assignment, which covers learning aim B. This will most likely be in the form of a written report.

Learning aim C – Investigate the principles of Lean manufacturing and how these influence productivity

- The Lean philosophy born out of the post-war reconstruction of Japanese industry is one of the defining aspects of modern manufacturing processes. The scope of this learning aim is sufficient to give learners an introduction and overview of basic Lean principles, their application and beneficial effects.
- You might start this unit by first demonstrating the problems with traditional forecast based manufacturing. You can achieve this by using a simplified manufacturing simulation similar to that used in the delivery of learning aim B. Instead of manufacturing a single product, introduce a second or third, establish a forecast for each product and start production in large batches to match the forecast. If you then introduce an urgent customer requirement for a small number of each of the products, learners will find that they are unable to fulfil all the requirements on time. Investigating potential solutions to this problem in small groups will help develop the analytical skills required in this unit. The obvious solution is to hold more stock so that customer orders can be fulfilled immediately, but this is a costly strategy in terms of the capital tied up in inventory and storage facilities, etc. Learners may decide to make smaller batches of individual products as and when customer orders are received. This might be the solution and is the basis of Lean just in time (JIT) methodology. This, however, will bring its own problems that must be overcome in terms of production flexibility. This is a suitable starting point for you to introduce the wider Lean philosophy and its characteristics emphasizing that JIT is only one of a range of tools used to support the key elements of Lean.
- Learners are far more likely to engage with this learning aim if you use practical exercises such as these to demonstrate the problems that Lean tools and methodologies were developed to address in addition to theoretical discussion and individual research into the subject.
- Using the same manufacturing simulation, you should guide and encourage learners to experiment with a range of Lean tools and methods that support different key elements of Lean throughout the delivery of this learning aim.
- You should guide learners to develop a firm understanding of the Lean philosophy and its key elements through taught input and independent research reviewed in tutor-led group discussions and/or tutorials. Learners must also relate each Lean tool or method discussed or investigated to the key elements of Lean. The relative ease with which the tools and methods can be applied and an assessment of their impact on manufacturing efficiency and lead-time performance should be analysed by learners as they go. Detailed notes, photographs and/or videos of the simulations carried out should also be made.
- Many large commercial organisations have trained specialists in the application of Lean (often in combination with the statistical process control methodologies of Six Sigma), who may be willing to support the delivery of this unit. A large number of training companies specialise in supporting manufacturing organisations implementing Lean. These could provide expertise and training materials, including manufacturing simulations, although, usually, there would be costs associated with this approach.

- When you are satisfied that learners have sufficient insight into the Lean philosophy, its key elements and how these are supported by Lean tools and methods, you should issue the third assignment which covers learning aim C. This will most likely take the form of a presentation.
- Learners should be encouraged to deliver presentations to you or the rest of the group in order to develop their communication skills and confidence. These are important aspects of overall learner development, but learners will not need to be directly assessed on these skills here.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 4: Applied Commercial and Quality Principles in Engineering*
- *Unit 11: Engineering Maintenance and Condition Monitoring Techniques*
- *Unit 40: Computer Aided Manufacturing and Planning*
- *Unit 45: Additive Manufacturing Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Slack N – *Operations Management, Seventh Edition* (Pearson, 2013) ISBN 9780273776208.
  This book provides information on many aspects of manufacturing systems relevant to this unit and includes useful examples and case studies that can be used in teaching.
- Liker J – *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer* (McGraw-Hill, 2004) ISBN 9780071392310.
  This book details the Lean philosophy and processes developed in the automotive sector by Toyota who were pioneers in the application of Lean.
- Pascal, D, *Lean Production Simplified, Second Edition: A Plain-Language Guide to the World's Most Powerful Production System* (Productivity Press, 2007) ISBN 9781563273568.
  This book covers examples of each of the components of Lean within a Lean production system. It is a common sense and accessible introduction to Lean principles and processes.

Websites

- www.toyotaglobal.com/company/vision_philosophy/toyota_production_system
  This is a useful overview of the Lean production system developed by Toyota who were pioneers in the implementation of Lean manufacturing.
- www.leansimulations.org/p/huge-list-of-free-lean-games.html
  This is a free online resource detailing a range of games and simulations that can be used to demonstrate the principals of Lean.

- www.leansimulations.org/2011/01/seven-benefits-of-teaching-lean-with.html
  This gives an insight into why teaching using Lean games and simulations are effective.
- www.leangames.co.uk
  This website can provide ready-to-use manufacturing simulations and training games. This site may also provide ideas for developing your own resources in house.

Unit 40: Computer Aided Manufacturing and Planning

Delivery guidance

Approaching the unit

This unit may be new learning for some learners or a subject where they have seen the manufacturing process in operation, for example with robotics and flexible manufacturing cells working in tandem, but never had to plan, or practically use this type of manufacturing process. This unit could follow on from, or be taught concurrently with, units such as *Unit 10: Computer Aided Design in Engineering*, *Unit 43: Manufacturing Computer Numerical Control Machining Processes* or *Unit 45: Additive Manufacturing Processes*. Learners may also bring their knowledge of CAM technology via employment or previous experience to bear in this unit. It may be useful to promote discussion to explore these areas.

You should encourage learners to develop their theoretical knowledge of the various processes and how they interact, and relate these to the practical skills required. This unit contains a practical activity and encourages learners to develop their rationale for completing Computer-aided Manufacturing and Planning in a specific way, so that the final component could be successfully simulated to show how it would be machined.

To complete this unit your learners will need access to a virtual reality or simulated CAM process and the associated resources, consumables and materials.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions on Computer-aided Manufacturing
- individual or group presentations – covering the practical manufacturing skills required
- demonstrations of the set up and safety issues associated with CAM processes
- case studies illustrating components and products created by CAM processes
- internet sources, such as the information and videos available
- an industrial visit to a manufacturing company could support the learners' skill base
- a visit to a technological exhibition could also support the learners' skill base
- a guest speaker would support the delivery of the theoretical aspect of this unit.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with Computer-aided Manufacturing and the benefits of planning. Pose the question 'Can it be integrated with Additive Machining or can Additive Machining compete with multi axis machines within CAM systems?' Learners need to consider how Computer-aided Manufacturing spans many areas of engineering and other industries, from small jobbing companies to the aerospace and automotive sectors. The dental industry has adopted CAD/CAM for the production of crowns and inlays. Examine the philosophy by discussing the major points of the introduction of CAM into different industries. Give initial input for your learners on the different types of CAM systems and how these relate to remote programming, Direct Numerical Control (DNC) or simultaneous manufacture. In small groups, learners could carry out research on CAM systems by looking at CAM manufacturers. Many have detailed websites that contain useful information regarding manufacturing. Learners need to understand the influence of machine control systems and their relationship to material handling and operational control. Learners must be made fully aware of different control methods and the efficiency of these, particularly relating to lean manufacturing and improvement techniques. It is essential that you ensure throughout this unit that learners understand all the safety aspects of CAM systems.

For learning aim B, introduce the topics by discussing components that can be successfully programmed and manufactured on industrial CAM systems, such as printed circuit boards, additive manufacturing components, or fabrications punched and folded to give a final component, in a series of operations, within a cell or on a single machine. Show learners components created on a CAM system and demonstrate the planning and programming required to create these components. Explain basic component creation on a CAM package. In small groups or individually, your learners could then carry out small tasks to create various items such as a small model. These programs could be checked on a CAM or virtual reality representation of the machine tool. These could then be developed with the addition of radii and blended shapes, which include tooling requirements and speed and feed rate calculations, so that learners can meet surface texture and other quality requirements. Extend this learning with the introduction of the cycle 'Plan, Do, Check, Adjust' model. This leads to the consideration of cycle times, reducing waste, and optimising machining cycles. It is essential that you ensure throughout this unit that learners understand all the safety aspects of the CAM process.

For learning aim C, introduce the topics by demonstrating what can be achieved with correct planning and the benefits of using CAM. Have learners share their knowledge and experiences of working within different planning systems and manufacturing environments. You could then give initial input for your learners on the different planning systems, component planning and the parts involved, manufacturing capacity, and other considerations such as quantity, cycle times and minimising costs. Individually or in small groups, your learners could then carry out small tasks to plan the components they have previously created on a simulated or a virtual system, for a large quantity or small quantities and consider the cost reductions that could be achieved.

This would be a good point to demonstrate the benefits of different software systems and to start to consider aspects of scheduling. This could be followed by more detailed scheduling considering the aspects of Gantt charts, critical path analysis and how these would be used in a manufacturing environment. This could be finalised by creating a manufacturing plan for a product or a component specification, taking into account aspects such as manufacturing processes and tolerances. Again, it is essential that you ensure throughout this unit that learners understand all the safety aspects of the CAM process.

An industrial visit to an exhibition based around manufacturing machining and computer-aided manufacturing machines could support the learners' skill base. The most useful time for this is during learning aim A.

A guest speaker from a local company who could discuss Computer-aided Manufacturing and Planning would benefit both learning aims A and C.

Learning aim	Key content areas	Recommended assessment approach
A Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation	**A1** Benefits and applications of CAM systems **A2** Technology used in CAM systems	A report to investigate the benefits and technology used in industrial CAM systems that will improve the efficiency and effectiveness of the manufacturing operation. Evidence should include the benefits and applications that are related to the technology.
B Develop a virtual component on a computer-aided manufacturing system that simulates its manufacture	**B1** Model a component in preparation for manufacture **B2** Simulate the manufacture of a component **B3** Quality checks on a virtual component	To develop a CAD suitable for manufacture, and transfer to a CAM system, to simulate a component, using graphical or virtual reality. To verify and optimise the simulated component ensuring it meets the specification and is fit for the purpose intended. The evidence should include, CAD drawings, CAM program, screenshots of the processes, and inspection documentation.
C Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation	**C1** Manufacturing plan **C2** Schedule for manufacture **C3** Product and/or component specification for manufacture	To investigate planning documentation and create a range of comprehensive industrial production - planning documents to plan for customer demand and manufacture. To produce schedules for a range of products and order quantities. The report needs to justify and create the most appropriate planning and scheduling documentation for a CAM system. Evidence should include examples of planning and scheduling documentation.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be written reports, a printed portfolio of programs and drawings, planning, scheduling and inspection documentation and the annotated photographs of the process of creating a simulated or virtual reality CAM product or component. Learners should also keep and show screenshots to show processes and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence, the original learner-generated evidence must also support them.

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Getting started

This gives you with a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 40: Computer Aided Manufacturing and Planning

Introduction

Begin by introducing the unit to learners through a group discussion exploring their knowledge of the use of Computer-aided Manufacturing and Planning processes and the existing practical skills they have developed. This can be followed by outlining the learning aims of the unit.

Learning aim A: Examine the benefits, technology and applications of computer-aided manufacturing systems that improve the operation

- Ask learners to collaborate in small groups to come up with examples of different CAM processes that they have experienced.
- Ask learners to consider individually what they think are the advantages of CAM and the different types available. Lead a discussion on the various forms of CAM and Flexible Manufacturing Systems cells, and allow learners to research their features.
- In small groups, learners could then explore the physical resources, and the Direct Numerical Control of machine tools and simultaneous manufacturing.
- You could give input for your learners on the different types of CAM processes. Include how these relate to the size of the machine, logistical systems such as Automatic Guided Vehicles (AGVs), the use of rapid prototyping, or simultaneous manufacturing and the speed and complexity that components require. This will need linking to the different programming methods available.
- Using examples from earlier, your learners could then work in small groups to carry out research on CAM by looking at Flexible Manufacturing System manufacturers, and the disadvantages (such as costs) related to these, due to the software and hardware requirements. This research can then be developed to investigate the applications of the different processes, eg PCB manufacture, rapid prototyping and fabrication systems, punching and bending.
- You could then give input as the learners must also cover the parts of a system, such as the use of Automatic Guided Vehicles, conveyors, linking in robots, ongoing quality checks with Coordinate Measuring Machines (CMM) and feedback to computer controlled machine tools within the systems.
- You could give input as the learners must also cover the technology of the manufacturing control systems including computers, communication and control of the messages within the systems.
- Explain the required material handling systems that are applicable to different products, and how they relate to material movement and loading. Items such as the benefits of automatic pallet loading can then be introduced.
- Introduce items related to improvement techniques, such as Lean Manufacturing, which are used to reduce waste, and shorten lead times for products, ensuring that manufacturers have limited stock holdings of raw materials.
- Include the key features of health and safety regulations for CAM processes and the typical safe working practices required.

Learning aim B: Develop a virtual component on a computer-aided manufacturing system that simulates its manufacture
• This learning aim builds on the previous learning aim where learners should have gained an understanding of the philosophy of CAM machinery and systems. • You could give initial input for your learners on the different CAM machines or simulation systems available to them, and introduce them to the various options that they could create such as a PCB, additive machined part, or CNC component. • Introduce learners to the creation of a CAD drawing or graphic that can be uploaded into a CAM system. • Support learners as they develop their CAD drawings or graphics to input their idea into a CAM system. Then demonstrate various post processors and/or ways to load data into a CAM system. • You could give input on setting up the various parameters, such as datums, initiating the control system and loading tooling, and checking the data input into their chosen system. • This can be followed by a demonstration of the various simulated work holding devices and how the tooling must clear these at every pass and their relationship to a CAM machine and programming systems. • Build on the previous theory to explain to the learners the requirements of correctly setting tooling and referencing them to the component or machine datum. • This leads to an explanation and demonstration of the safe proving of a program by completing a dry run, or manufacturing in foam or wax, and demonstrating the use of override controls to reduce feed rates and spindle speeds. • As learners become ready to start their virtual reality or simulated task, it is essential that all safety issues are considered, guarding is in position and interlocks are operational if simulated on a machine tool. • Allow learners to develop their confidence and skills by simulating a small component. Learners can then start to download a small program for a component to prove on a simulation system. • This could be followed by simulating more complex parts that require multiple tooling and safe tool change positions. • You could explain quality procedures upon completion of a component. Many software packages have inbuilt instrument systems. • It is essential that learners complete all necessary quality checks and that these are recorded and amendments considered. • It is also essential that you ensure throughout this unit that learners understand all the safety aspects of the manufacturing process.
Learning aim C: Investigate planning documentation used to optimise the workflow and initiate manufacture in the operation
• This learning aim builds on learning aim A where learners looked at the technology and systems of Computer-aided Manufacturing. • Your first input could introduce your learners to the different types of CAM planning documentation required to effectively run a CAM or FMS system. • Learners could discuss the systems they have seen at work or that guest speakers have discussed. • This can be followed by a discussion of the different planning systems for one offs, batches and continuous manufacture. Detail the requirements for the different

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systems, using examples for a manufacturer producing a variety of bespoke components or systems, and balance this against a planning system used in manufacturing companies producing a continuous product.

- You could then introduce the various limitations such as having a limited manufacturing capacity, the availability of machine tools and resources such as programmers or tooling. Learners will need directing to relate the above factors to the time other components and products take to move through the manufacturing processes.
- The next logical step is to introduce manufacturing planning considerations, such as minimising costs as these can increase profits. This leads to a discussion on machine cycle times and inventory.
- Expand the introduction to the throughput of the workload and link to holding minimal inventories of raw material and ensuring proprietary components and/or the raw materials are available. The emphasis here is to maximise the use of machinery and equipment and reduce costs.
- Explain to the learners the purpose of creating a schedule, which is to attempt to balance three conflicting ideas:
  1. to ensure manufacturing jobs are completed just-in-time
  2. to minimise the amount of time required from the release of a work order to the manufacture of a quantity of a product, and
  3. to maximise the economic use of resources.
- Demonstrate the use of scheduling software. This can vary from specialist software to the different parameters set up on Excel.
- Support learners in developing their manufacturing schedules.
- Build on the previous theory to explain to the learners the necessary information and documentation to be accessed or created to create a product or component specification.
- The documentation required should consist of items such as component drawings, manufacturing processes and parameters, Bills of Materials (BOM) and finally the creation of a works order. These may be produced in a standard format used by the delivery centre, or use typical industrial documentation.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 5: A Specialist Engineering Project*
- *Unit 39: Modern Manufacturing Systems*
- *Unit 41: Manufacturing Secondary Machining Processes*
- *Unit 43: Manufacturing Computer Numerical Control Machining Processes*
- *Unit 45: Additive Manufacturing Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Videos

There are very many videos on video-sharing websites for CAM and FMS cells. Some examples are shown below.

CAM

- www.youtube.com/watch?v=LlFIf84fR2w
- www.youtube.com/watch?v=8I3diD1lpho
- www.youtube.com/watch?v=hyRBbGb2UDA

FMS

- www.youtube.com/watch?v=BBC2oswnrt0
- www.youtube.com/watch?v=hNGzFJqUnjE

Websites

Numerous versions and varieties of software are available that could be used to complete this unit. For example:

- www.solidcam.com
- www.mastercam.com/en-us
- www.grzsoftware.com

There is even free software available (not tried or tested):

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- www.freebyte.com/cad/cadcam.htm
  CAD/CAM.
- http://frepple.com
  Production planning.

There are many links available on the web to some of the many companies producing CAM and FMS machine tools.

Manufacturers

- www.plm.automation.siemens.com/en_gb/plm/cam.shtml
- www.tatatechnologies.co.uk/manufacturing/cam-computer-aided-manufacture
- www.autodesk.com/solutions/cad-cam
- www.makino.com/cells-and-systems
- www.smetoolkit.org/smetoolkit/en/content/en/907/Preparing-Your-Production-Plan

Unit 41: Manufacturing Secondary Machining Processes

Delivery guidance

Approaching the unit

This is a practical unit, which allows your learners to investigate the role that a range of traditional machining processes (such as drilling) and specialist machining processes (such as honing and lapping) play in producing machined components. The focus should be on the learners developing practical skills and understanding to be able to set up and operate traditional secondary machining processes in order to manufacture a component. Learners will also need to be able to review and reflect on the skills and processes used and pay due regard to aspects of health and safety.

You will need to hold skills development sessions for traditional secondary machining processes and your learners should be able to research these processes and apply the knowledge gained. In this way, they will learn what works and will be able to use this knowledge when they come to set up and carry out their own practical work.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim, A it would be worthwhile starting with a class discussion that introduces the range of traditional and specialist secondary machining processes to your learners. You could then ask each individual in the group to research a different process. You should ensure that all the processes listed under key content areas A1 and A2 of the specification are covered. Learners' research should cover machine types, features of components produced by each process and the accuracy obtainable. Due to the common need to consider tolerances and understand batch sizes in all machining processes, it would be appropriate for you to formally go through these with the whole class before they carry out the individual research activity. Once learners have collected their research information, you could ask each learner to give a simple PowerPoint presentation to the rest of the group, along with an accompanying set of handouts, which could be used to supplement class notes.

If possible, to support the delivery of this learning aim, it would be beneficial if you you could arrange visits to local industries where these processes are taking place. In addition, or as an alternative, you could ask a representative from a local industry, or a STEM ambassador, to attend the learner presentations. Having covered key content areas A1 and A2 in this manner, you should then explore formally the sustainability of these secondary machining processes. Your learners could be asked to reflect on the usefulness of these activities – this would help you prepare them for learning aim D (reflection and review).

Learning aim B builds upon some of the areas covered in learning aim A by looking in more depth at the practical aspects of traditional secondary machining processes. You do not need to develop any skills to set up, or in fact use, any specialist secondary machining processes with your learners. Instead, you could present a number of secondary machining workplace scenarios to your learners and ask them to carry out a risk assessment on each one. Obviously, it is critical that you support this practical approach with formal sessions outlining the key features of health and safety regulations or other relevant international equivalent and.involve your learners with the use of the health and safety executive website.

The skills development required for learning aim B goes hand in hand with that for learning aim C, which is about using traditional secondary machining processes to manufacture a component safely. To meet the assessment requirements of learning aims B and C, learners need to develop skills in the setting and use of at least two processes and use those skills on a least six features of a component that they will need to manufacture. According to the staffing levels in your workshops and the machines available, you will need to develop a strategy that allows your learners to achieve this. To ensure that you maintain a safe environment while skills development is taking place, you could split the group and give some of the learners desk type activities while the rest are engaged in the practical tasks. The activities could involve finding out and reporting back to the whole group about different tooling requirements for drilling, turning, milling and grinding, along with different work holding devices across the same processes. You should allow time to cover the theory required to work out speeds and feeds for these processes. Again, to help with the workshop management, you should allow some learners (those who are not carrying out machining skills development) to work in a safer part of the workshop in order to develop skills in the use of equipment to check dimensional accuracy and surface texture. During these practical skills development sessions, you need to ensure that learners work in a safe manner, so you need to consider carefully your staffing levels and learner to staff ratio, taking into account the tooling and equipment you have available.

Learning aim D allows your learners to reflect in a detailed way on how they have applied themselves during the rest of the delivery of this unit. There are two aspects to this reflection: the lessons learnt, which should include skills involved regarding health and safety, traditional machining and the more general engineering skills; and relevant behaviours, including initiative and responsibility, communications and problem solving skills. You could ask your learners to prepare a self-evaluative report and allow them to present this to either the rest of the group, invited representatives from industry or STEM ambassadors. To give an opportunity for peer assessment, you could allow other learners in the group to make a judgement about the accuracy of the self-evaluation to help differentiate between fact and opinion.

<table>
<tr><th>Learning Aim</th><th>Key content areas</th><th>Recommended assessment approach</th></tr>
<tr><td>A Examine the technology and characteristics of secondary machining processes that are widely used in industry</td><td>A1 Traditional secondary machining processes
A2 Specialist secondary machining processes
A3 Sustainability characteristics of secondary machining processes</td><td>A report focusing on three different traditional processes and an analysis of research case studies on three different specialist processes.</td></tr>
<tr><td>B Set up traditional secondary processing machines to manufacture a component safely</td><td>B1 Health and safety requirements when setting up secondary process machines
B2 Risk assessment
B3 Setting up secondary process machines</td><td rowspan="2">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 log book, risk assessment, observation records/witness statements, the finished component, annotated photographs and drawings, set-up planning notes, and complete quality control documents.</td></tr>
<tr><td>C Carry out traditional secondary machining processes to manufacture a component safely</td><td>C1 Features of traditional secondary machining processes
C2 Parameters of traditional secondary machining processes
C3 Quality control methods</td></tr>
<tr><td>D Review the processes used to machine a component and reflect on personal performance</td><td>D1 Lessons learnt from machining a component
D2 Personal performance while machining a component</td><td>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 generated while machining a component and reviewing the processes and reflecting on own performance.</td></tr>
</table>

Assessment guidance

This unit is internally assessed by means of a maximum of three assignments. The first assignment should cover learning aim A, the second learning aims B and C and the third should cover learning aim D. Each assessment should cover a whole learning aim; learning aims must not be split over assignments.

Learning aim A will be assessed thorough a written report which will need to include analysis of research of case studies on three different traditional and three different specialist processes. While preparing learners for this assessment, you will also need to facilitate the requirements of learning aim D as, for the third assessment, your learners will need to produce a portfolio of evidence which will be gathered together during all the activities associated with learning aims A, B and C. Learners will need to review the practical elements and reflect on their own performance in the activities, after the processes have been completed. The assessment requirements for learning aims B and C are practical in nature and you will need to select appropriate components that allow at least two different processes to be set up and used and that have at least six different features that need to be machined. You should also pay due regard to the accuracy requirements of the features/component. You will need to ensure that learners deal appropriately with the health and safety requirements including completing a risk assessment. The evidence will be gathered in a variety of ways, for example, written responses for the risk assessment, logbooks, witness statements/observation records, annotated photographs, personal accounts, the finished components or accuracy checklists.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 41: Manufacturing Secondary Machining Processes

Introduction

Many of the products and components we use daily rely on secondary machining processes. The use of traditional processes is usually easy to spot in manufactured components or products, but sometime more specialised processes are used.

The ultimate aim of this unit is for your learners to explore and safely carry out secondary machining processes to manufacture shapes by the removal of material.

Learning aim A – Examine the technology and characteristics of secondary machining processes that are widely used in industry

- This first learning aim is about raising awareness of the range of secondary machining processes used in industry and sets the scene for the other practical learning aims in this unit.
- You could begin by having a group discussion on the different processes used when manufacturing simple engineering products such as parts for a bicycle or parts of a car. Your learners will require initial input from you so that they have an awareness of the different traditional secondary machining processes covered by this unit.
- You could use a range of videos to show the dynamic operation of drilling, turning, milling and grinding.
- Once your learners are familiar with the capabilities of these processes, you could deliver formal sessions about tolerances and batch sizes that need to be considered in all machining processes.
- You could then split the learning by giving responsibility to different learners for different parts of the content. All learners will need to know about all the traditional secondary machining processes. A good way to do this would be to ask different learners to research different processes and report back to the whole group through the use of handouts and PowerPoint presentations. If any of your learners are struggling with this activity, you could ask them to work in pairs. You should ensure that the relevant technology and characteristics found under topic A1 in each case are covered.
- Next, your learners will require your initial input so they have an awareness of the different specialist secondary machining processes covered by this unit.
- You could use a range of videos to show the dynamic operation of presswork, electro discharge, broaching, honing and lapping machines and processes.
- You could again split the learning by giving responsibility to different learners for different parts of the content covering the specialist processes. All learners will need to know about all the specialist secondary machining processes. A good way to do this could be to ask different learners to research different processes and report back to the whole group through the use of handouts and PowerPoint presentations. Again, if any of your learners are struggling with this activity, you could ask them to work in pairs. You should ensure that the relevant technology and characteristics found under topic A2 in each case are covered.
- To provide an alternative and more engaging approach, you could ask a representative from a local industry or a STEM ambassador to attend the learner presentations.

- Once your learners are familiar with the capabilities of the processes, you could deliver formal sessions about the sustainability of the range of secondary machining processes.
- Your learners could be given a reflective activity, which would help you prepare them for learning aim D (reflection and review).
- Throughout the delivery of this learning aim, your learners would benefit from regular visits to the workshops to see the process under discussion. Alternatively, a visit to a local engineering company would be beneficial.
- Approaching the delivery of this learning aim in the suggested manner will give your learners an opportunity to practise skills involved in researching case studies, which form part of the assessment criteria for this learning aim.

Learning aim B – Set up traditional secondary processing machines to manufacture a component safely

- This learning aim builds upon some of the areas covered in learning aim A by looking in a practical sense at the setting up of traditional secondary machining processes. You should note that there is no need to develop any skills to set up, or in fact use, any specialist secondary machining processes.
- Furthermore, this practical work should be seen as associated with, and could be delivered concurrently with, learning aim C. However, before any attempt is made to set up and use traditional secondary machining processes, your learners will need to have a good awareness of the requirements of health and safety when using these processes. This should include the need to carry out and abide by risk assessments.
- You should make your learners aware of the relevance and range of regulations associated with the setting up and use of secondary machining processes. You could do this through group work and the use of the Health and Safety Executive [HSE] website. The regulations that need researching are: Personal Protective Equipment at Work Regulations 1992 (as amended); Manual Handling Operations Regulations 1992 (as amended in 2002); and Control of Substances Hazardous to Health (COSHH) Regulations 2002 (as amended).
- Each group could identify the relevant parts of the regulations that apply to each of the traditional secondary processes and report back to the whole group.
- Alternatively, this is something that you could do by demonstrating the use of the HSE website.
- Likewise, your learners will need to know how to carry out and use a risk assessment. Again, you could use the HSE website for this by accessing the Five Steps to Risk Assessment section on the website. It is important that your learners understand the difference between hazards, risks and measures.
- It may be appropriate that the delivery of the rest of this learning aim is combined with that for learning aim C.

Learning aim C – Carry out traditional secondary machining processes to manufacture a component safely

- The theoretical parts of learning aim B should have been dealt with earlier in this unit. The rest of learning aim B and all of learning aim C rely on demonstration, practice and skills development involving the setting up and using a range of traditional secondary machining processes, along with the use of quality control methods to establish 'fit for purpose' manufactured products.
- According to the staffing levels in your workshops and the machines available, you will need to develop a strategy that allows your learners to gather skills to manufacture components.

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- Each learner, as an individual, should develop skills in at least two processes and use those skills on at least six features of a component that they will need to manufacture.
- The skills development should not be rushed and the majority of delivery time is likely to be spent on these activities.
- Demonstration will form a large part of the skills development, but learners should be given plenty of opportunities to practise using these skills themselves.
- For learning aim B, your learners will be expected to set up tooling and work pieces. The correct selection of speeds and feeds will be important.
- Before learners attempt to set up the two traditional secondary machining processes, they could annotate the component drawing. The purpose of this is to indicate the range of features that require machining and other important information such as the tooling to be used. They should show positional elements to hold both the work and the tooling relative to the work. This way you will be able to establish whether the learner has the knowledge required to set up the machines properly. A similar approach regarding the safety features of the machine and the personal protective equipment [PPE] needed could be demonstrated.
- It could be appropriate to develop learner skills concurrently to carrying out the machining processes, as each learner will be working at a different rate.
- For learning aim C your learners will be expected to produce [machine] a range of features [at least six] when using the two processes.
- Learners should be given the opportunity to develop the skills necessary to be able to adjust parameters to achieve correct machining actions.
- It is important for learners to develop skills in using quality control equipment, such as external micrometers to check dimensional accuracy and comparators to check surface texture,.
- Once each learner has demonstrated a safe set-up procedure and has demonstrated a level of competence in the two machining processes, you could allow them to manufacture an engineering product independently. This activity would act as a trial or mock run before assessment.
- According to your facilities, you may find the strategy of workshop management easier if you can manage a smaller number of learners actually working on machines in the workshop. You could achieve this by having theoretical type activities involving speeds, feeds and quality control available for some learners in a safe environment within the locality of the workshop away from where the machines are located.

Learning aim D – Review the processes used to machine a component and reflect on personal performance

- This learning aim is about reflecting on what has been achieved throughout the unit with reference to two aspects: the lesson learnt from the practical elements of making an engineered component, and the learners' own personal performances.
- Your learners will require your initial input so that they have an understanding of the scope of reflection required to meet the needs of the unit. You could do this as a formal lecture which could include:
  - health and safety, machining skills, and wider engineering skills, such as the mathematics they used when deciding on speeds and feeds
  - personal performance, i.e. initiative and responsibility, communication, literacy skills, and problem solving skills.

- Your learners could reflect on their research activities from learning aim A and produce a simple report linking their outcomes to the practical activities they carried out during the machining of their component.
- You could ask your learners to prepare a self-evaluation report and allow them to present this to the rest of the group, invited representatives from industry or a STEM ambassador.
- To give an opportunity for peer assessment, you could allow other learners in the group to make a judgement about the accuracy of the self-evaluation to help differentiate between fact and opinion.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Meyers A and Slattery J – *Basic Machining Reference Handbook* (International Press Inc., 2001) ISBN 9780831131203.
  The Basic Machining Reference Handbook is intended to serve as a memory jogger for the experienced, as well as a reference for programmers and others who do not do the machining but do need to know exactly what is involved in performing a given machining step, a series of steps or a complete job. This is a good resource for the tutor not the learner.
- Walker J R – *Machining Fundamentals: From Basic to Advanced Techniques* (Goodheart–Willcox Co Inc., 2004) ISBN 9781590702499.
  This book has a range of illustrations and detailed instructions on how to set up many basic machining operations. Each section has the particular safety issues highlighted. There are several references regarding cutting feeds and speeds. This is a good resource for the tutor.
- Black B J – *Workshop Processes, Practices and Materials* 5th Edition (Routledge, 2015) ISBN 1138784727.
  This is a very good introduction for entry-level engineers and workshop technicians, and for learners with little or no practical experience. It contains detailed illustrations throughout and is presented in a simple, clear language. It is good for learners to use.
- Khire M and Bhandare A – *Electro Discharge Machining Studies* (LAP Lambert Academic Publishing, 2012) ISBN 9783848423828.
  This is a good resource for the tutor.

Websites

- www.hse.gov.uk/risk/assessment.htm
  The Health and Safety Executive web site providing information and templates about Risk assessment
- www.hse.gov.uk/work-equipment-machinery/standard.htm
  The Health and Safety Executive web site providing information about Machinery Standards
- www.stemnet.org.uk/ambassadors
  The STEMNET web site providing information and details about STEM Ambassadors for support.

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Unit 42: Manufacturing Primary Forming Processes

Delivery guidance

Approaching the unit

Many products we use on a daily basis rely on primary forming processes. The need to manufacture shapes with minimal waste is a focus for many organisations. The introduction of new materials and demands for quality within manufacturing has refined and specialised primary forming processes, allowing producers to create more accurate and more precise dimensioned components.

The knowledge and understanding delivered to learners in this unit will allow them to progress to apprenticeships, technician-level roles and higher education. They will investigate moulding processes for metals, ceramics and polymers. They will also take into account the processes that are potentially hazardous to health and the relevant procedures and protections that must be in place.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

In learning aim A, learners should examine how moulding processes involving metals, ceramics and polymers are used in industry. Learners should be given resources for the different types of moulding processes. Through collaborative work they could investigate each type, with a focus on the process, materials, additives, mould features and finishing.

Learners should become familiar with the sustainability of the casting processes. They should compare the use of coal and electric furnaces, water contamination, fumes and particle release. This could be through tutor-led discussions or independent research and report work. It would be beneficial for the learners to experience demonstrations of the different forming processes.

In learning aim B, learners should examine deformation processes involving metals and polymers. They will investigate the different deformation processes through independent research or a collaborative research project. Learners should experience demonstrations of the processes, eg extrusion, forging, rolling, presswork and metal spinning on ferrous and non-ferrous metal.

Learners should also become familiar with the deformation processes on polymers, and as with metals, experience demonstrations of the processes, eg vacuum forming, extrusion and calendaring. They should investigate the function of additives, mould features and parameters. This could be within the same research project suggested for the metal processes.

In learning aim C, learners will investigate the safe working practices required when manufacturing products using forming processes. They could investigate this through collaborative work following tutor-led instruction. They should cover the key features of health and safety regulations, focusing on those covered in the specification. Learners should also assess the risk of primary forming work, including investigating guidance from the Health & Safety Executive (HSE) and activities to reduce risk.

Learners should also justify the selection of forming processes by reporting on objective criteria used to determine the choice. They could perform this as part of a review process on their own work.

Learning aim	Key content areas	Recommended assessment approach
A Examine how moulding processes involving metals, ceramics and polymers are used in industry	**A1** Metal moulding processes **A2** Ceramic moulding processes **A3** Polymer moulding processes	A portfolio containing written responses and diagrams showing moulding techniques for each material type. This activity could be supported by a PowerPoint presentation.
B Examine how deformation processes involving metals and polymers are used in industry	**B1** Metal deformation processes **B2** Polymer deformation processes	A portfolio containing written responses and diagrams showing deformation processes for metals and polymers. This activity could be supported by a PowerPoint presentation.
C Investigate the suitability of forming processes to manufacture products using safe working practices	**C1** Safe working practices for primary forming processes **C2** Forming process selection	A portfolio containing a written commentary and diagrams justifying the selection of forming processes to manufacture a range of products, and about health and safety and risk reduction approaches that apply to the processes. Evidence could also be in the form of a PowerPoint presentation.

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Assessment guidance

The assessment evidence required for this unit is typical engineering documentation. Although much of the evidence will be in the form of reports, there are opportunities for practical observations and videos to be recorded. Annotated photos, planning notes and document portfolios would be more suited to the practical aspects of the unit. The evidence should be clear and concise, containing the information stated in the specification. Learners should produce evidence showing a solid understanding of manufacturing primary forming processes.

Each of the learning aims will be assessed through portfolios containing written reports and diagrams representing the moulding, deformation and forming processes required to manufacture a range of products. You need to ensure that learners have the opportunity to address the health and safety concerns for each process, including completing risk assessments. The evidence will be gathered in a range of ways such as written responses, diagrams, observation records, annotated sketches and photographs, personal accounts, quality checklists, PowerPoint handouts and presentation notes and logbooks.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 42: Manufacturing Primary Forming Processes
Introduction Introduce the unit to the learners, covering the aims and objectives. Produce an overview of the assessment for the unit, and give them an outline of the importance of the primary forming processes within engineering organisations. Discuss the processes that will be used throughout the unit to manufacture components using metal, ceramics and polymers. Discuss the evidence types that will be required for the assessment in the unit. Learners will be required to produce a portfolio for each learning aim, consisting of all the notes, sketches, observation records, photographs, annotations, written responses, reports, risk assessments and other documents they have produced during the course of the unit.
Learning aim A – Examine how moulding processes involving metals, ceramics and polymers are used in industry
• Introduce learners to metallic, ceramic and polymer moulding processes, and how they are used to manufacture products. Give learners the resources to research and investigate these processes. • You could begin with a tutor-led presentation or discussion on different processes and how they are used in manufacturing. • You could then present the learners with case studies on known organisations and products that use those processes. • For maximum impact on learning, give demonstrations of each or select processes, prompting learners to make notes of the processes.
Learning Aim B – Examine how deformation processes involving metals and polymers are used in industry
• Introduce learners to the different deformation processes involving metals and polymers. • You could begin by introducing the learners to different deformation processes with practical demonstrations. Ensure learners are aware of the risks involved in each process, asking them to make note of the steps you perform and enforce the risk measures you are following. • You could then ask learners to repeat the steps you followed and identify further risks that could be included in the risk assessment for that process. • Your learners should have comprehensive notes on the processes, which could be supported with formal presentations and discussions in a classroom setting on the processes and the health and safety implications. • It is important that learners understand the processes fully and can identify risks associated with each before moving on to the next learning aim.

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Learning aim C – Investigate the suitability of forming processes to manufacture products using safe working practices
• Ask learners to reflect on the safe working practices they observed through the demonstrations given for learning aims A and B. Learners should create a portfolio containing written commentary and diagrams justifying the selection of forming processes to manufacture a range of products. They should include evidence of investigation into the management of risk and adherence to health and safety regulations required to protect the operator, others and the organisation. • You could begin with examples of poor practice in forming processes. These could be written case statements for learners to analyse and suggest process improvements for or resources from the internet. • You could ask the learners to set up and form a product, using safe working practices. • You could assess this through photographs and observation records. The learner would have a checklist and risk assessment in place before carrying out the activity. • Learners should then reflect on the forming of their product and how they effectively carried out the steps, following their risk assessments. They could also adjust their risk assessment to include any risks they thought could occur during the process. They should reflect on the contributing factors outlined below. • You could then ask learners to evaluate the sustainability of the process they undertook and suggest areas that could be improved to reduce waste. • You could ask learners to produce a self-evaluation report on their actions and present it to the rest of the group. To give an opportunity for peer assessment, you could ask other learners to observe the process being carried out and offer their judgement and assessment of it.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 25: Mechanical Behaviour of Metallic Materials*
- *Unit 26: Mechanical Behaviour of Non-metallic Materials*
- *Unit 45: Additive Manufacturing Processes*
- *Unit 46: Manufacturing Joining, Finishing and Assembly Processes*
- *Unit 49: Aircraft Workshop Methods and Practice*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources needed for this unit are:

- access to metallic, ceramic and polymer processes
- access to a range of health and safety regulations, as required by the unit content.

Textbooks

- Meyers AR and Slattery TJ – *Basic Machining Reference Handbook, 2nd Edition* (Industrial Press Inc, 2001) ISBN 9780831102012.
  Basic Machining Reference Handbook is intended to serve as a memory jog for the experienced, as well as a reference for programmers and others who will not do the machining but do need to know exactly what is involved in performing a given machining step, a series of steps, or a complete job. This is a good resource for the tutor rather than the learner.
- Walker JR – *Machining Fundamentals: From Basic to Advanced Techniques, 8th Edition* (Goodheart-Willcox Co Inc, 2004) ISBN 9781590702499.
  This book has a range of illustrations and detailed instructions on how to set up many basic machining operations. Also, each section has the particular safety issues highlighted. There are several references regarding cutting feeds and speeds – this is a good resource for the tutor.
- Black BJ – *Workshop Processes, Practices and Materials, 5th Edition* (Routledge, 2015) ISBN 9781138784727.
  A very good introduction for entry level engineers and workshop technicians, as learners with little or no practical experience. It contains detailed illustrations throughout and is written in a simple, clear language – good for learners.
- Davidi G – Plastic forming processes of composite materials (Scholar's Press, 2013) ISBN 978-3639700848.
  A good resource for tutors.

Websites

- www.hse.gov.uk/risk/risk-assessment.htm
  The Health and Safety Executive website gives information and templates about risk assessment.
- www.hse.gov.uk/work-equipment-machinery/standard.htm
  The Health and Safety Executive website gives information about Machinery Standards.
- www.stemnet.org.uk/ambassadors
  The STEMNET website giving information and details about STEM Ambassadors for support.

Unit 43: Manufacturing Computer Numerical Control Machining Processes

Delivery guidance

Approaching the unit

This unit may be new learning for some learners or a subject where they have seen the process but never had to plan, program or practically use a CNC machine. This unit could follow on from units such *as Unit 40: Computer Aided Manufacturing and Planning* or *Unit 45: Additive Machining Processes*, or be taught concurrently with these units. Learners may also bring their knowledge of CNC technology via employment or previous experience, which may be useful for promoting discussion.

You should encourage learners to develop their theoretical knowledge of various processes and the related practical skills. This unit contains a considerable amount of potential for practical activities; encourage the learners to develop their rationale for completing CNC programming and manufacture in a specific way, so that the final components can be successfully machined.

To complete this unit your learners will need access to a CNC machining process and the associated resources, consumables and materials. You should ensure that learners understand and can apply strict safe working practices designed to protect them and their colleagues from various hazards that are inherent to the manufacturing process.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions on CNC manufacturing
- individual or group presentations– covering the practical manufacturing skills required
- demonstrations of the set-up and safety issues associated with CNC processes
- case studies illustrating components and joints created by CNC processes.

Learners may benefit from internet sources that contain training videos.

There are also specialist books available for CNC processes.

A visit to a manufacturing company or to a technological exhibition could also support the learners' skills base.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with CNC manufacturing and the benefits of industrial manufacturing. Perhaps pose the question ‘Can it live alongside additive machining?’. Learners need to consider how CNC manufacturing spans many areas of engineering from small jobbing companies to aerospace and automotive companies. You should discuss the major differences between traditional manual manufacture and CNC manufacture. You could then provide initial input for your learners on the different types of CNC manufacturing systems and how these relate to the size of the machine, materials, operational speed and complexity of the components generated. In small groups, your learners could then carry out research on CNC manufacturing by looking at CNC machine manufacturers and component manufacturers, many of which have detailed web pages that contain useful information regarding manufacturing. It is important that learners understand the function and influence of machine tool control systems and their relationship to open- and closed-loop systems. Learners must be made fully aware of different programming methods and the efficiency of each one. It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the CNC manufacturing process.

For learning aim B, introduce the topic by discussing components that can be successfully programmed and manufactured. You could then move on to the reduction in the use of specialist form tooling required within CNC manufacturing, due to the ability to generate radii and curved surfaces. Show learners components created on a CNC manufacturing system and demonstrate the programming required to create these components. Explain basic programming and coordinate systems. In small groups or individually, your learners could then carry out small tasks to program various items such as a nameplate or key tag. These programs could be checked on a CAM or virtual reality representation of the machine tool. These could then be developed by the addition of radii and blended shapes, and the inclusion of tooling requirements and speed and feed-rate calculations. This will enable learners to meet surface texture quality requirements. You could extend this learning with the introduction of canned cycles and sub-routines. The learners could then start to consider work-holding devices, and the relationship between the machine and the component datum.

It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the CNC manufacturing process.

For learning aim C, introduce the topic by demonstrating what can be achieved with CNC programming and the benefits of using CNC manufacturing. Have learners share their knowledge and experiences of working within different CNC and manufacturing environments. You could then provide initial input for your learners on the different CNC machines available and introduce them to setting up the various parameters, work-holding devices, tooling stations and turrets, and bar feeds. This could be followed by a practical demonstration of setting tool offsets or tool compensation. Individually or in small groups, your learners could then carry out small tasks to manufacture the components that they have previously programmed and proved, such as a nameplate or key tag, This would be a good point to demonstrate the benefits of a dry run and/or proving a program in wax or foam, with reduced feed rates. This could be followed by manufacturing more complex parts that require multiple tooling and safe tool change positions. It is essential that all safety measures are used: for example, ensuring that the guarding is in position and that interlocks are operational. You could provide an explanation of quality procedures; upon completion of a component, it is essential that learners complete all necessary quality checks and that the outcomes of these are recorded.

It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the CNC manufacturing process.

For learning aim D, direct learners to consider what went well and what did not go as well. The learners will need to examine their technical understanding of general engineering skills, CNC processes and safety issues. Direct the learners to evaluate lessons learned and consider any improvements that could have been included. Learners should be encouraged to examine their relevant behaviours during the unit: for example, taking initiative and responsibility for their own actions.

An industrial visit to an exhibition based around manufacturing machining and CNC machines could support the learners' skills base. The most useful time for this is during learning aim A.

A guest speaker from a local company who could discuss programming and setting would benefit learning aim B.

Learning aim	Key content areas	Recommended assessment approach
A Examine the control systems used in Computer Numerical Control machines and different computer programming methods	**A1** CNC machine tool control systems **A2** Open and closed loop feedback systems **A3** Part programming methods and program efficiency	A written report to investigate the control mechanism of a typical industrial CNC machine, based around open loop and closed loop systems, and its relationship to achieving accuracy via a computer program.
B Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely	**B1** CNC processes for milling and turning **B2** Tooling parameters **B3** Component parameters **B4** Machine set-up parameters **B5** Development of a CNC part program **B6** Sustainability considerations	Preparation activities and documents prior to CNC machining a product or component, to include: machine tool set-up sheet and a computer part program, and simulation of the program. Input the part program and set up the CNC machine, to produce a component, using multiple tooling. Carry out quality control checks to verify that the component meets the specification and is fit for the intended purpose.
C Carry out Computer Numerical Control machining processes to manufacture a component safely	**C1** Manufacture of a component using a CNC machine **C2** Safe working practices **C3** Component quality checks	
D Review the processes used to machine a component and reflect on personal performance	**D1** Lessons learned from programming and machining a component **D2** Personal performance whilst machining a component	The evidence will focus on what went well and what did not go so well when programming and machining a component, and a conclusion of improvements that could be made. The portfolio of evidence will be generated whilst machining a component and reviewing the processes and reflecting on own performance.

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Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, with two covering one learning aim each and one covering two learning aims.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be reports, printed or plotted portfolios of drawings and programs, planning documentation, calculations and the annotated photographs of the process of creating a CNC machined component. Learners should also produce screenshots to show process and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 43: Manufacturing Computer Numerical Control Machining Processes

Introduction

You could introduce the unit to learners through a group discussion exploring their knowledge of the use of CNC manufacturing processes and the practical skills they may have already developed. This could be followed by outlining the learning aims of the unit.

It is essential that you emphasise all the safety aspects of the CNC manufacturing process and the typical safe working practices required throughout this unit.

Learning aim A – Examine the control systems used in Computer Numerical Control machines and different computer programming methods

- Ask learners to collaborate in small groups to come up with examples of different CNC manufacturing processes that they have experienced.
- You could ask learners to individually consider what they think are the advantages of CNC machining and the different types available. Lead a discussion on the various forms of CNC machining, and allow learners to research the basic features. In small groups, learners could then explore the physical resources, the associated materials and the different types of input and output.
- You could then provide input for your learners on the different types of CNC manufacturing processes. This input could include how these relate to the size of the machine, materials, operational speed and complexity of the components generated. This will need linking to the differing programming methods available.
- Using their examples from the initial discussion, and continuing in small groups, your learners could then carry out research on CNC manufacturing by looking at machine manufacturers and component manufacturers. This research could then be developed to investigate the applications of the different processes and programming systems.
- You could then explain to learners about the possible machine tool control systems, including transduction of the signals to the associated drive mechanisms and their relationship to open- and closed-loop systems.
- Explain the required safe working practices, and the key features of health and safety regulations for CNC manufacturing processes and the typical safe working practices required.

Learning aim B – Develop a Computer Numerical Control set-up sheet and part program to manufacture a component safely

- This learning aim can begin by exploring the advantages of CNC manufacturing processes over traditional secondary manufacturing processes.
- Ask learners to consider the manufacture of the same component using traditional methods of manufacture and compare with CNC manufacturing. This could be related to a reduction in manufacturing time or an increase in time for a one-off as programming is involved. Consider the high capital costs of the machine tools, but the possible reduction in tooling costs as the need for form tools for complex shapes is eliminated.

- You could then introduce programming and coordinate systems. Direct learners to create simple programs using simple commands such as G00 and G01 using absolute and then relative (incremental) programming. It may be beneficial to prove these programs on a simulation package.
- You could then introduce more detailed programming and coordinate systems by directing learners to create more complex programs that use canned cycles and absolute and then relative (incremental) programming. It may be beneficial here to use a simulation package.
- You could then direct learners to create more complex programs that use M codes for tool changes and involve secondary axes.
- Your next phase of input could explore sustainability considerations by looking at safe and efficient disposal of cutting fluids and swarfe, and ensuring that safe working practices are reinforced.
- It is essential that you emphasise all the safety aspects of the CNC manufacturing process throughout this unit.

Learning aim C – Carry out Computer Numerical Control machining processes to manufacture a component safely

- This learning aim builds on the previous one in which learners may have coded CNC programs for computer-controlled machinery.
- You could then provide initial input for your learners on the different CNC machines available and introduce them to setting up the various parameters, datums, initiating the control system and entering coded data.
- This can be followed by a demonstration of the various work-holding devices available, for example chucks, rotary tables and bar feeds, and how they are integrated into CNC machine and programming systems.
- You could then introduce the various tool-holding devices on different machines: for example, tooling stations, multi-position turrets on lathes to hold drills and cutting tools, and the various bar feed mechanisms.
- You could build on the previous theory to explain to the learners the requirements for setting tooling correctly and referencing this to the component or machine datum. This could lead to an explanation and demonstration of the safe proving of a program by completing a dry run, or manufacturing in foam or wax, and demonstrating the use of override controls to reduce feed rates and spindle speeds.
- As learners become ready to start their practical task, it is essential that all safety considerations are used, for example, ensuring that guarding is in position and that interlocks are operational.
- Allow learners to develop their confidence and skills by manufacturing a small component. Learners can then start to input a small program for a component previously proved on a simulation system. They could then carry out a dry run in free space, wax or foam, with reduced feed rates.
- This could be followed by manufacturing more complex parts that require multiple tooling and safe tool change positions.

  You could provide an explanation of quality procedures. Upon completion of a component, it is essential that learners complete all necessary quality checks and that these are recorded.

Learning aim D – Review the processes used to machine a component and reflect on personal performance
• You could direct learners to consider what went well and what did not go as well. • Explain to the learners that they will need to examine their technical understanding of general engineering skills, CNC processes and safety issues. • You could then direct the learners to evaluate the lessons learned and consider any improvements that could have been included. • You should direct learners to examine their relevant behaviours during the unit: for example, taking initiative and responsibility for their own actions.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 39: Modern Manufacturing Systems*
- *Unit 40: Computer Aided Manufacturing and Planning*
- *Unit 41: Manufacturing Secondary Machining Processes*
- *Unit 42: Manufacturing Primary Forming Processes*
- *Unit 45: Additive Machining Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are:

- access to CNC lathes, CNC milling machines, or a machining centre, as required by the learning aims and unit content
- auxiliary equipment (such as that listed in the content under 'tooling' and 'work-piece holding devices')
- a range of equipment suitable for measuring the dimensional accuracy and surface texture of the work pieces to be machined
- access to a range of health and safety legislation (HASAWA) and regulations, as required by the learning aims and unit content.

There are numerous versions and varieties of software that could be used to complete this unit. It is impossible to list every textbook and video but a few particularly useful ones are listed below.

Textbooks

Various textbooks are available for the CAD and graphics packages software command structure, and learning materials are available for the different companies that supply CAD software and the different versions of the software packages that they produce. Books and magazines are available on CNC manufacturing.

- Smid P – *CNC Programming Handbook, 3rd Edition* (Industrial Press, 2007) ISBN 9780831133474.
  A comprehensive coverage of CNC programming, this book covers both milling and turning programs. Coverage of some of the calculations tends to be American based and uses examples in imperial measures.
- Smid P – *CNC setup for Milling and Turning: Mastering CNC Control Systems* (Industrial Press Inc., 2010) ISBN 9780831133504.
  This book looks at the relationship between the machine tool and the CNC control system.

Videos

There are many videos available on CNC manufacturing. Some examples are shown below.

- www.youtube.com/watch?v=WuGKnL0q1ps
- www.youtube.com/watch?v=Gu0EWKYzXpM

Websites

There are many links available on the web to some of the many software houses producing CNC programming software and machine tools. Most of these packages will allow a graphic simulation of the learners' programs, through dedicated software or on the control systems of the machines.

- www.haas.co.uk
- http://website.denford.ltd.uk
- www.techsoft.co.uk
- www.fanuc.eu/uk/en
- www.heidenhain.co.uk

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Unit 44: Fabrication Manufacturing Processes

Delivery guidance

Approaching the unit

In this unit, you will provide learners with the opportunity to develop the knowledge and practical skills required to carry out the manufacture of a sheet metal fabricated product. To introduce the technology and processes involved in fabrication you will need a number of example products and related case studies detailing their manufacture.

You will need to provide learners with access to workshop facilities with a range of hand tools and equipment. It is anticipated that general workshop equipment will be adequate for the majority of practical tasks to be undertaken. Little specialist sheet metal fabrication equipment is needed but a forming press and shear are considered essential. You should ensure that your facilities are capable of manufacturing the components and fully assembled products that you plan to ask learners to make safely and accurately.

This unit will give you the opportunity to develop links with local industrial partners who are involved in the manufacture of fabricated sheet metal products. A site visit early in the delivery of the unit will help provide the industrial context for the activities that learners will undertake during its delivery. This will help to engage learners and retain their interest.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

In learning aim A you will provide learners with the background knowledge necessary to underpin the activities carried out in the rest of the unit. An industrial visit early in the delivery of this learning aim will assist greatly in providing an overview of the fabrication processes being studied. It will also help to provide an insight into how industrial processes for high volume manufacturing differ from those that learners will use later in the unit to manufacture a single product.

When trying to identify suitable local industrial partners, start by looking in the press or at recruitment events to find those currently recruiting technician level apprentices. Often companies appreciate the opportunity to promote themselves and their industry to potential trainees and, in return, are willing to support the delivery of relevant engineering courses.

This learning aim covers a range of tools, processes and techniques. These should be taught using a combination of teacher-led presentations, product analysis, short demonstrations and practical exercises involving the tools and equipment available in your workshops. You should try to use hands-on practical activities, wherever possible, to maintain learner engagement and introduce some of the skills, tools and equipment that they will need later in the unit.

Learning aims B and C are closely linked and will eventually be assessed together in the same assignment. In learning aim B you will discuss relevant health and safety regulations that apply to the use of the fabrication processes introduced in learning aim A. This can be supported by independent learner research via the Health and Safety Executive (HSE) website or other resources.

Prior to the delivery of the unit, you must ensure that all your centre risk assessments for the activities to be undertaken by learners are up to date. These will be helpful when planning the delivery of content on risk assessments and preparing learners to carry out their own on the workshop, tools and equipment they will be using.

Learning aim B focuses on the activities necessary to prepare for the manufacture of a fabricated product. Learners will be expected to read and accurately interpret given engineering drawings and develop component blanks. These blanks will then be used to model formed components in card. This will allow any problems or mistakes to be identified and then rectified prior to manufacturing.

Once accurate blanks have been developed, you will need to introduce the equipment used to accurately mark out sheet metal. The skills required to use these effectively can be practised in a series of simple practical exercises.

In learning aim C, learners will need to develop the practical and hand skills required to carry out the fabrication processes necessary to manufacture a complete product. They need to become proficient at using tools and equipment safely and accurately prior to completing the assignment tasks for this learning aim. This can be achieved through the use of a series of skill-based practical tasks. Learners should be able to gauge their own progress as their skills develop. They should do this by assessing the quality and accuracy of the outcome of each of these tasks, using appropriate measurement and inspection techniques.

The product that learners are asked to manufacture might be a toolbox, desktop computer or console casing or it may be a barbecue or wood burning camp stove. The product will need to engage the wider interests of learners so that, when it is completed, they will want to keep and use it. This will encourage them to make every effort to ensure that the quality of final outcome is as good as possible. They may even wish to use it to demonstrate their practical skills when applying for a technician level role or engineering apprenticeship on completion of the course. However, you should note that time is not allocated in this unit for learners to design their own product.

Finally, learning aim D gives learners the opportunity to review the processes and techniques that they used in the manufacture of fabricated products and consider where these might be improved. They will also perform a critical analysis of their general engineering and fabrication skills and how their behaviour and personal attributes contributed to the success of the outcome.

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 have a conclusion discussing improvements that could be made. The portfolio of evidence will be generated while fabricating a product, reviewing the processes and reflecting on personal performance.

Assessment guidance

Evidence for learning aim A will most likely be in the form of a written report. A combined portfolio of evidence will be used to assess learning aims B and C together. Evidence for learning aim D will most likely be in the form of another portfolio which will draw upon and refer to elements of the evidence generated for learning aims B and C. However, there is flexibility in the forms of evidence that are acceptable as long as the work submitted fulfils the necessary requirements of the assessment criteria and is individual to each learner.

Evidence for learning aim A is most likely to be in the form of an illustrated written report that will include appropriately referenced images and diagrams to support the text. You should encourage learners to use standard referencing methodologies such as Harvard or APA to enhance the presentation and professionalism of their written reports.

It should be noted that the distinction assessment criteria for this learning aim makes specific reference to the use of 'vocational and high quality written language'. This precludes the use of certain types of evidence such as a video narrated by the learner unless a transcript of the narration is also provided.

Evidence for learning aims B and C will be presented together. These involve a significant amount of practical work, so evidence will most likely be in the form of a portfolio that should be well organised and structured logically. Evidence is likely to include: written elements explaining applicable health and safety regulations, risk assessments, calculations and development of blanks from component drawings, details of manufacturing aids such as forming gauges, card models, workshop logbook, explanatory notes, annotated drawings, photographs, sketches, inspection records and observation records to support evidence of practical activities. It would be acceptable for learners to present other forms of evidence as part of their portfolio, for example a presentation or learner narrated video.

Evidence for learning aim D will most likely be in the form of a portfolio which will refer back to the evidence generated for learning aims B and C. It should include a series of reflective written and illustrated evaluations of the processes carried out by learners when fabricating their product. Further written elements will reflect on the general engineering and fabrication skills developed by learners during this unit and how their own attitudes and behaviour affected the outcome. It would be acceptable for learners to present other forms of evidence as part of their portfolio, such as a presentation or learner narrated video.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 44: Fabrication Manufacturing Processes

Introduction

Fabrication of sheet metal is an important and commonplace manufacturing process used in a range of engineering sectors from aerospace and automotive to white goods and consumer electronics.

This unit aims to give your learners an understanding of the tools, techniques and processes involved in fabrication. They will develop practical skills and learn the importance of safe working practices when carrying out a range of fabrication processes. You will find that the high proportion of hands-on practical activities in this unit will help to engage learners and retain their interest.

In addition, learners will reflect upon and evaluate the fabrication processes they have carried out, making suggestions on how they might be improved. You will also work with them to help develop an awareness of themselves as learners and the importance of reflecting upon and improving personal performance. This will reflect the value that employers place on the use of reflective practice by their employees to identify and address priorities in their own development.

Your planning and delivery of this unit will be greatly enhanced by the involvement of an industrial partner. They may be able to support you in the development of case study material, provide examples of sheet metal products they manufacture or facilitate site visits or visiting speakers to help contextualise the unit content.

Learning aim A – Examine the processes and technology used in sheet metal fabrication that are widely used in industry

- You might begin learning aim A by introducing several examples of fabricated sheet metal products, components, unformed component blanks and raw materials. If you establish links with local companies early in the planning of the unit, they might provide some of the sample products and materials used in your introduction.
- These can be the focus of a class discussion to cover what types of products are best suited for fabrication from sheet metal, how they are constructed and the types of materials appropriate in different circumstances. Learners could then be asked to work in groups to identify the stages necessary to complete a product from raw stock sheet material. This will lead into your introduction of cutting, forming, joining and finishing processes.
- Early in your delivery of this learning aim, it would be useful to arrange an industrial visit so that learners can see the industrial processes used to fabricate products similar to those used in your introduction. This will help learners to contextualise the content of the learning aim and the unit as a whole. If learners have a good appreciation of the links between what they are being taught and real industrial practice, it will help stimulate and retain their interest.
- You will need to discuss each stage of fabricating a product in detail including a consideration of accuracy and sustainability. For example, a discussion of accuracy when forming a component might include the problems caused by material spring back and the use of forming gauges. Sustainability in this context will be concerned mainly with the efficient use of material and the wastage associated with different processes.

- As this learning aim is, predominantly, a theoretical overview of the processes involved, a high proportion of the content will be delivered through presentations and other classroom-based exercises such as independent learner research. However, for areas where appropriate equipment is available in your centre, you should also use demonstrations and short practical exercises to enhance and reinforce the topics covered.
- Once a good understanding of materials and processes has been established, you might then introduce a series of product analysis activities. These will develop the analytical skills required for learners to identify, justify and evaluate the use of particular processes in different circumstances. The differences between high- and low-volume production techniques should be emphasised. For instance, when forming a single component, a bench mounted box former might be appropriate or small batches might use a CNC press brake whilst large quantities might be formed on a dedicated hard tool.
- Once you are satisfied that learners have an in-depth knowledge of a wide range of processes and equipment including their limitations, accuracy and applicable batch sizes, you should issue the first assignment that covers this learning aim.

Learning aim B – Carry out the preparation necessary to manufacture a fabricated product safely

- You might introduce learning aim B by discussing the regulations that ensure the safety of fabrication processes. This can be supported with independent learner research via the HSE website or other resources.
- Case study examples of serious accidents involving a shear or forming press will help illustrate the human and financial costs of workplace accidents. These should focus learners on the importance of safe working practices.
- The HSE website also provides useful resources when introducing risk assessments and their importance when managing safety in the workplace. Learners can access a guide on the Five Steps to Risk Assessment that the HSE advocates and download HSE approved proforma for producing risk assessments themselves. You should use a series of practical examples to enable learners to become familiar with risk assessment methodology. It would be useful to discuss the risk assessments maintained by your centre on the use of workshops, tools and machinery. However, do be aware that, during the assessment activities for this learning aim, learners must carry out their own independent risk assessments on the processes they choose to include in their evidence.
- At this stage you can introduce engineering drawings of example products similar to those to be used in assessment activities. It is important that learners are able to read and accurately interpret information on engineering drawings and this might be the focus of a teacher-led discussion with the group.
- Learners will then need to translate the required dimensions of formed components into component blanks using appropriate bend allowance formulae. This part of the learning aim could be delivered using a series of mini practical exercises. Learners could use card to model the component blanks they have developed and ensure that these give the required component dimensions once formed up. Where a problem is encountered, learners will need to develop refined card blanks until the issue is resolved.
- There is an opportunity for learners to work collaboratively to produce a card model of a complex assembly. You could allocate a single component drawing to each learner or to several small groups. Ask each of them to develop a blank and produce an accurate card model of the formed component. These could then be brought together and joined into a complete assembly. The class can then assess the completed model and work together to analyse and then rectify any problems they encounter.

- The final element of this learning aim considers the preparation and accurate marking up of sheet stock material. You might demonstrate the use of appropriate equipment before issuing a series of short practical exercises to develop the required skills. Learners will need time to practise marking up metal sheet material accurately prior to assessment activities.
- During these exercises, you should also encourage learners to always make efficient use of sheet materials to minimise waste.
- The knowledge and skills developed in learning aim B will be assessed in combination with learning aim C. The second assignment will not be issued until the content of learning aim C has been delivered.

Learning aim C – Carry out fabrication processes to manufacture a fabricated product safely

- Learning aim C is almost entirely practical in nature and involves the use of some of the tools and processes introduced in learning aim A.
- To deliver this learning aim, you will need to provide learners with access to a range of tools and equipment to enable the fabrication of a sheet metal product. Many of these have the potential to cause serious injury. It is your responsibility to ensure that all tools and equipment are safe and appropriate for learners to use under your supervision. Learners will require appropriate training and must follow safe working practices. During your introduction to each activity, you should discuss your centre's risk assessments for the activities being undertaken. Carrying out fabrication processes safely is essential and is a specific requirement of the assessment criteria for the unit.
- In this unit, learners will need to develop their practical skills using a range of fabrication processes prior to the required assessment activities. You might achieve this by demonstrating the safe and accurate use of the equipment you have available in your centre. Subsequently, a series of short, focused practical tasks can be used to develop the required levels of competency and skill.
- The components manufactured in this phase of learning might be a repeat of those modelled in learning aim B so that the required blank sizes are already established and learners are familiar with the components. You should ensure that learners also have the opportunity to use trial assembly techniques and a range of work holding methods before joining components into a larger assembly.
- A quality inspection procedure should be carried out on completion of each component. This will require the use of appropriate measuring equipment and the use of inspection record sheets. You should encourage learners to use the results of each inspection to inform the manufacture of the next component so that mistakes are not repeated.
- When you are satisfied that learners have developed the knowledge and skills to complete the fabrication of a product safely from a given set of engineering drawings, then you should issue the second assignment. This assignment will cover both learning aim B and learning aim C.

Learning aim D – Review the processes used to manufacture a fabricated product and reflect on personal performance

- You might introduce learning aim D by asking learners to review what they have actually learnt from completing the unit so far. This might be facilitated by using spider diagrams to analyse their experiences using health and safety, fabrication skills and general engineering skills as headings.
- You should also give learners the opportunity to reflect on the influence that their personal attributes and behaviours had on their performance. Again, this might be

supported using spider diagrams or mind maps to help analyse their experiences, with headings such as using initiative, working independently, problem solving, communication etc.

- As well as evaluating how new learning and technical skills were applied in practice and suggesting improvements, learners must be prepared to reflect upon and suggest improvements to their own behaviours that influenced performance.
- In industry, professional engineers are expected to carry out such reflective and developmental exercises on a regular basis as part of their continued professional development (CPD). In all professional occupations, being a reflective practitioner with good self-awareness and the ability to identify areas requiring further development is essential.
- Throughout this unit, learners should keep in mind the requirements of learning aim D. You should ensure that they write detailed notes that describe what went well and what did not go well during all practical activities. This will assist in completion of the assessment for this learning aim.
- When you are satisfied that learners have sufficient insight to allow the effective evaluation of the fabrication processes and their personal behaviours, you should issue the third assignment that covers this learning aim.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Fournier R – *Sheet Metal Handbook* (HPBOOKS, 1987) ISBN 9780895867575.
  This is a useful practical handbook covering many traditional metal forming techniques used in low-volume manufacturing.
- Timings R – *Fabrication and Welding Engineering (*Routledge, 2008) ISBN 9780750666919.
  This book provides comprehensive coverage of sheet metalworking and welding in the manufacture of fabricated products.
- Wakeford R – *Sheet Metal Work (Workshop Practice) (*Special Interest Model Books, 1987) ISBN 9780852428498.
  This is a useful practical guide to working with sheet metal.

Websites

- http://britishmetalforming.com
  This is the homepage of the Confederation of British Metalforming, a trade body representing the interests of the metal forming industry.
- www.hse.gov.uk
  This is the homepage of the Health and Safety Executive that provides a wealth of information including guides to health and safety regulations and risk assessment, *HSE.*
- www.qualitytool.com/resources/Design-Handbook-Rev3.pdf
  Quality Tool is a useful guide to industrial cutting and forming processes.
- http://thelibraryofmanufacturing.com/index.html
  This is a useful online resource that covers a range of manufacturing processes including sheet metal fabrication.

Unit 45: Additive Manufacturing Processes

Delivery guidance

Approaching the unit

This unit may be new learning for many students or a subject where they have seen the process but never had to design or manufacture using it. This unit could follow on from units such as *Unit 10: Computer Aided Design in Engineering* or *Unit 43: Manufacturing Computer Numerical Control Machine Processes*, or could be taught concurrently with one or both of these. Learners may also bring their knowledge of non-industrial 3D printers. They may not realise that the aeronautical industry produces components for modern aircraft from titanium using additive manufacture. Learners may also have experienced the use of CAD through previous education or perhaps as employees.

You should encourage learners to develop their theoretical knowledge of various processes and materials as well as the practical skills. A third of the content of this unit comprises practical activities. Encourage learners to develop their rationale for completing tasks in a specific way, so that the final product can be successfully manufactured on the hardware and software that they are able to use. They should consider the ways in which this enhances or limits the models that can be created.

To complete this unit your learners will need access to computer software and additive manufacturing hardware. It is envisaged that most centres will use Fused Deposition Modelling 3D printers for the practical activities.

You can use a range of delivery methods in this unit, such as:

- discussions – class and small group discussions on additive manufacturing
- individual or group presentations– covering the practical drawing skills required
- demonstrations of the set-up and safety issues associated with additive manufacturing
- case studies illustrating components created by additive manufacturing.

Learners may benefit from internet sources which provide training videos.

There are also specialist books available for additive manufacturing, which mainly cover 3D printing.

An industrial visit to a manufacturing company or to a technological exhibition could support the learners' skills base.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, introduce the topic by demonstrating what can be achieved with additive manufacturing and the benefits of industrial manufacturing. Perhaps pose the question 'Will it replace subtractive machining?'. Learners need to consider how additive manufacturing spans many sectors, from health care to aerospace, and explore the different processes and materials used. Learners can share any prior knowledge and experiences of working with 3D printers or with items created by these printers. You could then provide initial input for your learners on the different types of additive manufacturing systems and how these relate to the size of the machine, materials, operational speed and complexity of the components generated. In small groups, your learners could then carry out research on additive manufacturing by looking at machine manufacturers, component manufacturers and hobbyist websites, many of which have detailed pages that contain useful information regarding manufacturing. It is important that learners understand the influence that materials and product design have on the different processes. It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

For learning aim B, introduce the topic by discussing the major differences between subtractive manufacture and additive manufacture. Discuss components and assemblies that can be manufactured in one piece against using a separate manufacturing and assembly process for products created using subtractive manufacture. You could then move on to discuss the reduction, or in some cases the lack, of specialist tooling that is required within additive manufacturing. Show learners components created in an additive manufacturing program that demonstrate the reduction in component mass, compared with similar components created using traditional subtractive machining.

Compare these to the disadvantages, such as high start-up costs, for some industrial applications, against the relatively low cost of 3D printers. Introduce ideas like ‘topology optimization’ and the reduction of mass within a design space, possibly using the finite element analysis (FEA). Alternatively, allow the learners to use ‘design iteration’ to improve their models and overcome manufacturing problems and issues. Explore what can be achieved with 3D printers compare with industrial additive manufacturing. It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

For learning aim C, introduce the topic by demonstrating what can be achieved with a CAD or graphics package and the benefits of creating additive manufacturing components to businesses across different sectors. Follow this with links to an additive manufacturing process. Invite learners to share any knowledge and experiences of working within different additive manufacturing environments. You could then provide initial input for your learners on the different CAD or graphics packages available and introduce them to setting up the various parameters such as swept volume, allowance for shrinkage and any support requirements. In small groups, your learners could then carry out short tasks to draw or download various items such as nameplates or key tags. This could be followed by developing more complex parts and assemblies of multiple parts. These should aim to show the support requirements, so that components and assemblies do not collapse. Explain the time requirements related to manufacture, cooling time and the amount of finishing processes required to create an acceptable final product. Particular skills will need to be demonstrated and explained. Setting the machine's resolution, time management, and control of aliasing will all need consideration, particularly with the final components in mind. Learners will need an explanation of how to set up a 3D printer to give the required resolution, product orientation, datum and moulding temperatures.

It is essential that learners choose to develop the final assembly within an area they are familiar or conversant with.Alternatively, you could provide learners with suitable ideas for a 3D model to draw or give them a 2D representation of one.

It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

An industrial visit to a design exhibition based around additive machining and 3D printers could support the learners’ skills base.

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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 additive manufacturing 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 product or component design considerations and finishing processes required to effectively manufacture a component 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 log book, observation records/witness statements, the finished component, annotated photographs and/or drawings, set-up planning notes, and complete quality control documents.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover one entire learning aim and it is essential that a learning aim is assessed as a whole and not split into tasks or sub-tasks per criterion. There are three suggested assignments for this unit, each covering one learning aim.

All learners must independently generate individual evidence that can be authenticated. The main sources of evidence are likely to be reports, a printed or plotted portfolio of drawings, and the annotated photographs of the process of creating an additive machined component or assembly. Learners should also produce screenshots to show process and editing. BTEC assessors should complete observation records and learners' colleagues in placements or part-time work could complete witness statements. Note that observation records alone are not sufficient sources of learner evidence; the original learner-generated evidence must also support them.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 45: Additive Manufacturing Processes
Introduction You could introduce the unit to learners through a group discussion exploring their knowledge of the use of additive manufacturing processes and the practical skills they may already have developed. This could be followed by outlining the learning aims of the unit.
Learning aim A – Examine the technology and characteristics of additive manufacturing processes as used in industry
• You could ask learners to collaborate in small groups to come up with examples of different additive manufacturing processes that they have experienced. • You could ask learners to consider individually what they think are the advantages of additive machining and the different types available. Lead a discussion on the various forms of additive machining, and allow learners to research the basic features. In small groups, learners could then explore the physical resources, the associated materials and the different types of output, and link the different additive manufacturing processes to their respective sectors. • You could then provide input for your learners on the different types of additive manufacturing processes. This could include how these relate to the size of the machine, materials, operational speed and complexity of the components generated. This will need linking to the differing manufacturing volumes of the various processes. • Using learners' examples from earlier, and continuing in small groups, your learners could then carry out research on additive manufacturing by looking at machine manufacturers, component manufacturers and hobbyist websites. This research could then be developed to investigate the applications of the different processes. • You could then provide input on the different technologies available to manufacturers, such as material extrusion (FDM). Learners may be partially familiar with this as it is a commonly used process, for home or small project 3D printing. • Learners could extend their knowledge by means of research to cover some of the industrial processes, such as selective laser sintering or photo polymerisation. They could then look at wire deposition and related industrial processes, particularly within the aerospace industry. These processes will need relating to component requirements such as surface texture and tolerances. Learners should consider why some processes are suitable for manufacturing certain components and others are not. • These processes will need to be linked to manufacturing capacity. Some processes are capable of producing large components relatively quickly whilst processes with small footprints are limited in production size. Learners should understand how accuracy is related to processing speed and the large differences in processing speed between different processes. • Learners can then link these process to how FDM is used for personalised fabrication, home and machine repairs and biomedical products (for example, dental work and prosthetics) and the materials that are available for use.

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- You could then explain how materials can be used sustainably, for example the recycling of metallic powder and polymer-based materials as part of the powder bed fusion process. Learners should understand that limited waste material is produced by some of these processes. You could start a class debate relating to the statement 'that less energy is required to manufacture components using additive machining'.
- You could then explain and demonstrate the finishing techniques, the structural support and post-processing activities, sustainability and safe working practices, relating to the different processes of manufacture.
- You should explain the required safe working practices, and the key features of health and safety regulations for additive manufacturing processes and the typical safe working practices required.
- It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process, including items such as COSHH, necessary PPE and related safety hazards.

Learning aim B – Investigate component design changes and finishing processes required to effectively use additive manufacturing processes

- You can begin this learning aim by exploring the advantages of additive manufacturing processes over traditional secondary manufacturing processes.
- Ask learners to consider the manufacture of the same component and then to consider traditional methods of manufacture and compare these with additive manufacture. This could be in relation to a reduction in mass. You could follow this up with a consideration of possible reductions in cost. Introduce the subject of time taken to manufacture a component and compare with the time taken to manufacture the same component using traditional subtractive techniques.
- Direct learners to explore the integration of parts and the ability to manufacture assembled items as one piece, which cannot be achieved using traditional processes without multiple operations and an assembly process.
- You could explain and demonstrate, through products and case studies, how assembled items can be manufactured as one piece and how this impacts on the design process. This often involves optimising a design for 3D printing and testing, after an initial manufacture, to ensure that the product is as strong and as stable as a conventional product.
- Use a case study. A typical example, such as a door hinge, could be used. Conventional manufacture would require three separate parts to be manufactured – a frame side plate, a door side plate and a central hinge pin. These would need to be assembled using either a manual or automated process. With additive manufacture (provided a suitable material could be sourced), the complete assembly can be manufactured in one operation.
- Use the case study to discuss the factors that a designer needs to consider. For example, when manufacturing an item such as a door hinge by additive manufacture, the designer should consider:
  - what suitable materials are available
  - clearances within the hinge
  - whether the product is an improvement over the traditional design
  - that there is a cost reduction due to drill jigs or assembly fixtures not being required
  - that complex moulds will not be required due to the removal of the casting operation.

- Introduce the disadvantages of additive manufacturing processes over traditional manufacturing processes, including: products and components may need to be redesigned to realise the advantages; the choice of materials may be limited by the process; and the initial capital cost is quite high and has a low process speed.
- Allow learners to investigate, the advantages of additive manufacturing processes over traditional manufacturing processes, including: reduction in mass and cost can be achieved by redesigning the component; and the ability to manufacture assembled items together that cannot be manufactured together using traditional processes without multiple operations.
- Consider a case study to show that many components using traditional sources need multiple operations to produce them. For example, having a tooth crowned at the dentist is a long process. A crown is a cap that is cemented on top of a damaged tooth, and the process usually involves the dentist drilling into the damaged tooth to obtain a good fit. After drilling, a mould is made of the tooth, and this mould is sent to a laboratory, where the tooth is cast in a temporary material. The cast is returned to the dentist who makes any modifications needed before the final cast is made. This process traditionally takes two weeks and, in the meantime, you walk around with a temporary crown in place. With 3D printing, a scan can go directly to the 3D printer and be ready within an hour, as you sit in the waiting room.
- Direct the learners to research and report to the group on the common finishing processes such as shot-blasting, vibro-energy and chemical processes.
- It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process.

Learning aim C – Develop a component using additive manufacturing processes safely

- This unit builds on previous units in which learners may have used CAD/graphic packages, and computer controlled machinery. Learners can start by creating designs and being introduced to the basic machining parameters.
- Build on the previous theory to explain to the learners the requirements of a product's structural integrity, for example: laminar structure; allowing for product shrinkage and warping; and any support requirements for overhanging surfaces.
- Learners could then start to develop a design for a component or product suitable for an additive manufacturing process, with consideration of the complexity of its form and ensuring that suitable materials are available.
- You could use a practical demonstration to explain the machine's parameters during operation, its swept volume and the capacity of the machine. In addition, use the demonstration to explain how stepping (aliasing), surface finish and accuracy are affected by the resolution selected.
- You could use a practical demonstration to demonstrate data transfer from a CAD or graphics package, and follow this with a typical component set-up.
- You could demonstrate the necessary finishing processes for the machine and material in use.
- You should allow learners to develop their confidence and skills by manufacturing a small component, so they can appreciate the relationship between design and machine parameters.
- You should explain any quality control checks that will be required and where and how to record them.
- It is essential that you emphasise, throughout this unit, that learners should understand all the safety aspects of the additive manufacturing process and the typical safe working practices required.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

The special resources required for this unit are:

- access to additive manufacturing machines, 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 additive manufacturing process
- auxiliary equipment, for example equipment required to finish the components or those needed for the additive manufacturing process
- a range of equipment suitable for measuring the dimensional accuracy, for example Vernier callipers
- access to a range of health and safety regulations, as required by the learning aims and unit content.

There are numerous versions and varieties that of software that could be used to complete this unit. It is nearly impossible to list every textbook and video but some particularly useful ones are listed below.

Textbooks

Various textbooks are available for the CAD and graphics packages' software command structure. Learning materials are available for the different companies that supply CAD software and the different versions of the software packages that they produce. Books and magazines are available on additive manufacturing, particularly 3D printing.

- Barnatt C– *3D Printing: The Next Industrial Revolution* (CreateSpace Independent Publishing Platform, 2013) ISBN 9781484181768.

- Hopkinson N, Hague R and Dickens P (Editors) – *Rapid Manufacturing: An Industrial Revolution for the Digital Age* (Wiley-Blackwell, 2005) ISBN 9780470016138.

Videos

There are many videos for CAD, graphics packages, 3D printing and additive manufacturing. Some examples are given below.

- www.youtube.com/watch?v=s9IdZ2pI5dA
- www.sciaky.com/additive-manufacturing/electron-beam-additive-manufacturing-technology

Websites

There are many links available on the web to some of the many software houses producing CAD and graphics software. Many of these provide free educational software. There are also numerous links to additive manufacturing pages inclusive of commercial processes and 3D printing. Some examples are listed below.

- www.autodesk.co.uk
- www.solidworks.co.uk
- www.solidworks.com/sw/products/draftsight-getting-started-guide.htm
- www.turbocad.co.uk/windows-range/turbocad-deluxe-2d-3d

The links below are for CAD blogs and online magazines. Some require a subscription, some are free, and some allow limited use prior to a subscription.

- http://caddprimer.com/magazine
- www.caduser.com/

Additive machining

There are also numerous links to additive manufacturing pages inclusive of commercial processes and 3D printing. For example:

- www.stratasys.com/
- www.renishaw.com/en/additive-manufacturing-systems--15239

Unit 46: Manufacturing Joining, Finishing and Assembly Processes

Delivery guidance

Approaching the unit

From the industrial revolution to the space age, engineers have been using a wide range of techniques to join, finish and assemble components into fully working systems. In this unit, learners will develop their theoretical knowledge and practical skills to join and finish materials or products. They will also investigate the manual, automatic and robotic processes used to assemble products. As well as technical aspects of the different assembly processes, learners will consider how the assembly process affects the social and economic lifestyles of those involved.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, learners should be given the opportunity to investigate the mechanical joining methods used in a variety of products. This should include the safe practical disassembly of products that use a range of fastenings. The products that are to be taken apart could be artefacts that no longer function and have little financial value. By making use of a range of products, a group of learners will be able to see the range of mechanical fixings used. This practical investigation should then be supported by taught theoretical aspects of the characteristics of the fixings used.

The nature of adhesive joining methods means that they do not lend themselves to the disassembly approach used for mechanical fasteners. Learners should complete research into different applications of adhesive joining methods and present their findings to their peers. In this way, learners will be exposed to a wider range of situations. These investigations should then be supported by teaching of the theoretical aspects of the characteristics of the adhesives used.

Following on from the research aspects of the learning aim, learners should be taught how to safely produce joints using a range of mechanical and adhesive methods. Having gained the skills required to produce these joints, learners should be given the opportunity to demonstrate their application independently.

At this stage, learners will need to be provided with equipment to test the mechanical properties of the specimen joints. By limiting the size of the joints, the forces required to test the joint to destruction can be minimised. The joints should be designed so that the joint, rather than the material being joined will fail under testing. You will need to teach the learners how to use the equipment safely, and how to record and interpret the results.

For learning aim B, learners should be provided with the opportunity to explore an environment to observe and record the types of finishes that have been applied to buildings and objects within the environment. Learners should be encouraged to consider what the types of finish are and why they have been applied. Learners should be directed to find examples of hot, anodising, plating and paint finishes.

Learners should then be taught, with appropriate reference to manufacturers' data sheets and environmental legislation, how to safely apply different finishes for given applications. Learners should then be given the opportunity to demonstrate their ability to independently and safely apply a range of finishes to appropriate standards.

For learning aim C, the use of case studies will allow learners to develop some of the knowledge required to successfully complete this learning aim. Starting with an investigation into manual assembly methods, learners should look at how the layout of a manual assembly workstation can affect the efficiency of the process and how repeated operations can affect the health of the operatives involved. Learners could make use of any products disassembled as part of learning aim A to consider how a workstation could be economically designed to reassemble them.

Having established the requirements for manual assembly, learners should then move on to consider the equipment available to manufacturers to facilitate both automatic and robotic assembly processes. When learners are familiar with the technicalities of the assembly processes, they can then start to consider why a manufacturer would select a particular assembly process and the associated social and economic impact this would have for both employers and employees. Analysis of employment opportunities associated with each type of assembly process will allow learners to make informed comments about the social and economic effects for employees. Learners should be provided with a scenario where a product needs to be assembled in various quantities. Learners should then gather and analyse information about equipment suppliers to investigate the economic decisions that would need to be taken by the manufacturer.

Throughout all of the learning aims, there are numerous opportunities to engage engineering employer support, especially when considering adhesive joining methods and finishing/automatic/robotic assembly processes.

Learning aim	Key content areas	Recommended assessment approach
A Explore the joining processes that are often used to connect components into sub-assemblies and products	**A1** Mechanical joining processes **A2** Adhesive joining processes **A3** Safe working practices when using joining processes **A4** Perform joining and testing processes	A series of practical activities to join components together and test their mechanical properties. Evidence will include test results, a logbook, images, and observation records. A written report on the characteristics of at least two different types of joining process and how they might be applied based on the operating requirements of researched case studies.
B Explore the finishing processes that are used to improve the appearance and function of products	**B1** Hot finishing processes **B2** Anodising finishing processes **B3** Plating finishing processes **B4** Paint finishing processes **B5** Safe working practices when using finishing processes **B6** Perform finishing processes safely	A series of practical activities to finish materials or artefacts. Evidence will include a logbook, images, and observation records. A written report on the characteristics and environmental considerations of at least two different types of each finishing process and how they might be applied based on researched case studies.
C Investigate the processes used to assemble products and the economic and social consequences associated with them	**C1** Manual assembly processes **C2** Automatic and robotic assembly processes **C3** Selection of assembly processes **C4** Social and economic effects of assembly processes	A written report considering the physical resources required for different assembly processes, the reasons for manufacturers choosing particular assembly methods and the social and economic effects that different assembly methods have on organisations and employees.

Assessment guidance

For learning aim A learners must demonstrate their ability to produce and test joints. Learners will need access to the necessary equipment and materials in order to achieve this.

Learning aim B will require access to the equipment needed to apply two different finishes, eg painting and powder coating.

The processes used to complete the tasks for these two aims should be recorded by each learner, with photographic or video evidence used to support their written evidence. Each learners should then produce a report that considers the characteristics of the processes.

The assignment for learning aim C will take the form of a written report. For this, learners will need access to assembly case studies, equipment manufacturers' websites, and information about the skills, qualifications, working conditions and financial rewards for those people working in the industry. Learners will also need to consider how organisations determine which type of assembly process to use, based the cost of the equipment and profits to be made.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 46: Manufacturing Joining, Finishing and Assembly Processes
Introduction Learners should be provided with a product that includes examples of joining, finishing and assembly, for example a redundant personal computer. Working in groups, learners should be asked to consider which joining, finishing and assembly processes would have been used to manufacture the product. Learners could then repeat this analysis to consider what different joining, finishing and assembly processes might have been used to produce the contents of the room they are working in. This investigation can then be expanded into the room itself, the building the room is in, or the exterior surroundings of the room. This activity will bring to learners' attention that the unit will provide them with an awareness that joining, finishing and assembly processes have been used to manufacture a very wide range of the objects they make use of every day.
Learning aim A – Explore the joining processes that are often used to connect components into sub-assemblies and products
• An introduction to mechanical fasteners. • Learners should be organised into groups to work collaboratively. Each group is provided with a range of mechanical fasteners. The choice of fasteners should include examples from any sectors the group have a particular association with. Learners should be asked to analyse the fasteners and identify why the key features are present. • You should use feedback from the groups to introduce tutorials on mechanical fasteners, for example physical form and mechanical properties. • Learners should then work independently to research examples of the design requirements for mechanical joints. • You should discuss the design requirements and sustainability considerations of mechanical fasteners with the learners, with a focus on any particular sectors the group are associated with. • Having considered the theoretical aspects of mechanical fasteners, learners should proceed to develop the practical skills required to utilise a range of fasteners. • Before completing the practical tasks, you should ensure that learners are aware of the safe working practices associated with the tasks they will perform. • You should demonstrate appropriate methods of producing a range of mechanical joints. • Under your supervision, learners should then practise the application of these methods. • Having produced the joints, learners should then be taught, through tutor demonstration, how to safely use the available test equipment to perform comparative destructive tests on these joints. They should also be shown how to record and analyse the results of these tests. • Under your supervision, learners should then perform, record and analyse tests on the joints they have produced. • Following a similar sequence of events, learners should investigate adhesive joining techniques.

- Having gained the skills and knowledge required to complete learning aim A, learners should be set the assessment tasks. These will require tutor supervision of the practical elements.

Learning aim B – Explore the finishing processes that are used to improve the appearance and function of products

- An introduction to paint finishes.
- You should use either images or real objects to show learners a range of products that have been painted. Learners should work in groups to discuss why each particular paint finish has been used.
- Explain application methods to your learners and discuss the types of materials that can be applied.
- Learners should complete individual research into the environmental advantages and disadvantages of paint coatings in given specific situations.
- You should then deliver a series of workshop sessions that will provide learners with the skills and knowledge required to produce a painted finish. Learners should be provided with an appropriate material sample to paint, for example a 300mm square of 1mm steel sheet. The choice of finish to apply should reflect any particular sector the learners have an association with. In order to produce the paint finish learners should be taught:
  - how to select appropriate materials and application equipment; in order to achieve this, learners should be provided with material data sheets and information about the equipment available
  - the safe working practices, and environmental legislation, associated with the materials and equipment
  - how to prepare the surface of the material to be finished
  - how to prepare and use the materials and equipment required for the finish
  - how to clean and store the equipment after use.
- A similar pattern of delivery should then be followed for a second finishing technique that the centre has the resources to deliver.
- The remaining two finishing processes do not require learners to complete the practical element, so a different approach will be appropriate.
- This is an opportunity for learners to visit organisations that produce these finishes to observe and record the commercial application processes. This will allow them to contrast the differences in the scales of production.
- Having gained the technical knowledge and skills in the application of different finishing techniques, learners should undertake independent research into the characteristics and environmental considerations of each of the techniques. This research should require learners to focus on why particular methods are chosen for a range of situations, for example why a particular finish would be chosen for a marine, domestic or automotive environment.

Learning aim C –Investigate the processes used to assemble products and the economic and social consequences associated with them

- An introduction to manual assembly methods.
- Learners should work in groups to produce a presentation on the nature of manual assembly methods used in a manufacturing sector of their own choice. Learners should include, in their presentation, information about how changes to an assembly process has increased efficiency. Learners should be directed to sources

of information such as case studies, videos, academic research and equipment manufacturers' brochures.

- Provide the learners with information on the methods used to prevent ill health for assembly workers. This should include similar sources of information to those used previously as well as that published by organisations such as the HSE.
- Learners should be given the opportunity to assimilate the information provided about operator safety and asked to produce a written summary.
- Using the knowledge and experience gained above, learners should suggest how they would lay out a workstation, including the tools and equipment required, to assemble a product, for example a PC. Learners should be presented with the component parts of the product to support their suggestions.
- Learners should conduct independent research into the employment opportunities, and their associated conditions of employment, for manual assembly employees. Using this information, learners could be asked to summarise the likely lifestyles of the people employed to complete manual assembly processes.
- Having become familiar with manual assembly techniques, learners should conduct independent research into the automatic hardware devices used in given sectors. Learners should research the specific devices listed in the specification, for example part-feeding devices and power systems.
- Using the knowledge gained through independent research, learners should be placed into teams to produce and deliver a short presentation that combines the results of their research. The tutor should ensure that the number of learners in each group, and the range of sectors covered, provide all learners with the opportunity to actively participate and learn from each other. Learners should be encouraged to include video recordings of the automatic and robotic assembly processes being completed as this will be an effective method of conveying the actions of the devices to their peers.
- Having become familiar with automatic and robotic assembly equipment, learners should then consider the social and economic attributes of the techniques for both employer and employee.
- Learners should investigate the employment opportunities available in both assembly methods. For example, enterprises such as ABB Robotics LTD have 140,000 employees worldwide. Learners should consider the levels of education, skill and experience required by the staff and link this to their salaries and lifestyles.
- Learners should then consider cost–benefit analysis of automated and robotic assembly methods.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *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 42: Manufacturing Primary Forming Processes*
- *Unit 44: Fabrication Manufacturing Processes*
- *Unit 45: Additive Manufacturing Processes*
- *Unit 47: Composites Manufacture and Repair Processes*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Brynjolfsson E and McAfee A – *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies, First Edition* (W. W. Norton & Company, 2014) ISBN 9780393239355.
  This book reviews the social and economic impact linked to the adoption of modern technologies.
- Ford M – *The Rise of the Robots: Technology and the Threat of Mass Unemployment* (Oneworld Publications, 2015) ISBN 9781780747491.
  This book reviews technology and the threat of mass unemployment.
- Groover M – *Fundamentals Of Modern Manufacturing: Materials, Processes, and Systems, Fourth Edition* (John Wiley & Sons, 2010) ISBN 9780470467008.
  This book contains chapters on finishing, mechanical and adhesive assembly, manual, automatic and robotic assembly.
- Kalpakjian S and Schmid S – *Manufacturing Engineering and Technology, Sixth Edition* (Prentice Hall, 2009) ISBN 9780136081685.
  This book contains chapters on finishing, mechanical and adhesive assembly, manual, automatic and robotic assembly.

Journals

- International Federation of Robotics Press Release
  For example, the article 'Positive Impact of Industrial Robots on Employment', by Metra Martech February 2013.
- HSE
  For example, 'Cost–benefit studies that support tackling musculoskeletal disorders', by Andy Nicholson, Calum Smith and Arran Mitchel. There are also a number of case studies that compare costs.

Websites

- www.assemblymag.com, bnpmedia.com
  This is a free source of news and articles about a wide range of assembly topics from the USA.
- www.bara.org.uk
  The British Robotic and Automation Association aims to promote the use of robotics and automation in industry. The site provides a wide range of resources.
- www.ergonomics.org.uk
  The Chartered Institute of Ergonomics and Human Factors website gives information about using ergonomics to bring together safety and efficiency.
- www.globalrobots.com
  This UK retailer of second-user robots provides resale prices for second-user robots.
- www.hse.org.uk
  The Health and Safety Executive provides an extensive range of documents related to safe working practices for all aspects of the unit.
- www.ifr.org
  The International Federation of Robotics,provide a range of information and statistics about robotics.
- www.rnaautomation.com
  This UK supplier of automatic assembly equipment provides case studies and videos for automatic and robotic assembly methods.
- www.robotics.org
  This is an American website that provides a range of resources related to robotic assembly.
- www.robotraders.co.uk
  This UK retailer of new robots provides prices for new robots, ancillaries and training.
- www.robots.com
  This is an American supplier of robotic equipment. The site provides technical and economic data.
- www.tcq.co.uk
  This manufacturer of automatic assembly systems provides access to videos and case studies related to automatic assembly.

- www.tfautomation.co.uk/SPC/calculator
  This is a website that provides a comparison of assembly costs.
- www.solutions.3m.co.uk
  This is the website of an adhesive manufacturer where you can find technical information and data sheets related to 3M products.
- www.u-pol.co.uk
  This website of a manufacturer of automotive refinish products provides a wide range of information about their products.
- http://semta.org.uk/
  SEMTA, the skills council for the advanced manufacturing and engineering sectors, provides links to apprenticeships related to the content of this unit.

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Unit 47: Composites Manufacture and Repair Processes

Delivery guidance

Approaching the unit

This unit will provide learners with a working knowledge of fibre-reinforced polymer (FRP) composites. It deals with their structure and the characteristics that have led to FRP composites replacing traditional materials in a range of industrial applications. The main focus of the unit is on the processes used to manufacture FRP composites and the types of repair that are possible if components are damaged in service. Learners will have the opportunity to carry out wet or dry lay-up manufacturing processes and repair existing components using a range of techniques.

As there is a high degree of practical work involved in this unit, you will need appropriate workshop facilities and the necessary specialist equipment and materials required to manufacture FRP composites safely.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A will introduce learners to FRP composites, their characteristics and applications. You will probably deliver much of this learning aim in the classroom using a range of teacher presentations, research activities and case study materials. Wherever possible, you should obtain material samples and example components to help support teaching. Samples of glass fibre matting and the polyester resin that make up glass fibre-reinforced polymer (GFRP) can be readily obtained. These are widely used commercially in roofing and automotive repair and are available from high street retailers. Carbon and aramid fibre samples are less readily available but can be obtained in material sample packs, designed for use in education, from specialist suppliers or through links with an industrial partner.

You should consider seeking the involvement of an industrial partner to assist in the preparation and delivery of this learning aim and the unit as a whole. FRP composite materials are used extensively in a range of engineering sectors from safety critical structural applications in aerospace to roofing and promotional signage. Liaison with industry experts during the preparation of teaching materials, followed up with an industrial visit, would greatly enhance learner interest and engagement.

A good place to start looking for an industrial partner in the UK would be the composites industry trade body, Composites UK, or the National Composites Centre. They may be able to put you in contact with appropriate companies in the composites industry from your area.

Learning aim B will provide learners with an overview of specific processes used in the manufacture and repair of FRP composite components. Due to the potentially hazardous nature of the materials used, you should initially consider the regulations and working practices necessary to work with them safely. You could then introduce the characteristics of the wet and dry lay-up processes that learners will actually carry out in learning aim C. This will include the relative merits of the two techniques and the materials, equipment and potential problems that might be encountered in their manufacture. You will need to work with learners to develop the analytical skills required to compare and contrast these processes.

To deliver the content on repairing FRP composites, you should first introduce the types of physical damage that are easily detected without specialist equipment. Ideally, this should be supported with examples of components that have suffered impact damage.

You should explore the importance of effective damage removal methods and then introduce the characteristics of different repair techniques and where these might be applied. Examples of repaired components will help to support your delivery of this topic.

Learning aim C will give your learners the opportunity to apply the manufacturing and repair techniques introduced in learning aim B. You will require appropriate tools and equipment for learners to carry out wet lay-up or dry lay-up processes to manufacture composite components. Ideally, learners should have the opportunity to carry out both but this will depend on the resources and equipment available in your centre.

Learners will also carry out appropriate repair processes on examples of damaged components. Each learner will require a number of damaged components for use in teaching and learning to develop their practical skills and during assessment activities. You are likely to need to have these prepared in your centre by inflicting deliberate surface and through-hole damage to preprepared material samples.

Learning aim	Key content areas	Recommended assessment approach
A Examine the characteristics and applications of fibre-reinforced polymer (FRP) composites that are widely used in industry	**A1** Characteristics of fibre materials **A2** Characteristics of polymer resin matrix materials **A3** Structure and mechanical properties of FRP composites **A4** Applications of FRP composites	An illustrated written report covering the characteristics and applications of FRP composites. Where possible, case study material should be used to illustrate the applications of fibre-based composites where they have replaced traditional materials.
B Investigate the processes used to manufacture and repair fibre- reinforced polymer (FRP) composites	**B1** Safe working practices for FRP composites **B2** Characteristics of wet and dry lay-up manufacturing processes **B3** Repairing FRP composites	A written report to evaluate wet and dry lay-up manufacturing processes and those used to repair damaged components.
C Carry out processes to manufacture and repair fibre- reinforced polymer (FRP) composite components	**C1** Applying wet and dry lay-up manufacturing processes **C2** Applying FRP composite repair processes	A written report, including annotated sketches and photographs, showing learners manufacturing an FRP composite component using wet or dry lay-up processes and applying appropriate repair processes to worn or damaged fibre-based composite components. Learners' evidence should be supported with observation records.

Assessment guidance

The assessment evidence for this unit is likely to be in the form of written reports for learning aims A and B, and a written report or portfolio for learning aim C. There is flexibility in the forms of evidence that are acceptable as long as the work submitted fulfils the necessary requirements of all the assessment criteria and is individual to each learner.

Evidence for learning aim A is most likely to be in the form of an illustrated written report that will include appropriately referenced images and diagrams to support the text. You should encourage learners to use standard referencing methodologies such as Harvard or APA to enhance the presentation and professionalism of their written reports.

Evidence for learning aim B is most likely to be in the form of an illustrated written report that will include appropriately referenced images and diagrams to support the text. Alternatively, evidence could be in the form of a presentation. Once delivered to an audience, a copy of the presentation, including detailed presenter notes, should be submitted by the learner. Where presentations are used, you should provide an observation record detailing their content and effectiveness to support other evidence. This will greatly assist you when formally assessing the evidence and during any subsequent internal verification.

Evidence for learning aim C is likely to be in the form of an illustrated written report. This might form part of a portfolio of evidence relating the practical activities carried out by the learner. It should be well organised and structured logically. Observation records should be used to support evidence relating to the practical activities carried out by the learner. Video evidence of learners carrying out manufacture or repair processes could also be included in the portfolio.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 47: Composites Manufacture and Repair Processes

Introduction

Composites combine matrix and reinforcement materials to provide components with enhanced mechanical properties over and above those possible when using either constituent material on its own. Their excellent mechanical properties have led to them replacing traditional materials in a range of applications from wind farms to passenger aircraft.

You should make it clear to learners that there are a huge number of composite materials available to engineers. In this unit, you will only consider a manageable selection of FRP composites. The most common of these are glass fibre-reinforced polymer (GFRP) and carbon fibre-reinforced polymer (CFRP). It is anticipated that an understanding of these two materials will be the primary focus of this unit. However, if you consider other FRP composites to be more appropriate for your centre, and have particular expertise and facilities, they may be used. These might include those using aramid (Kevlar) or natural fibres as the reinforcement material.

Prior to the delivery of this unit, you will need to ensure that you have in place the necessary material and component samples, appropriate specialist equipment and consumables, component designs and associated moulds for completing the requirements of the learning aims.

During the teaching, you will need to develop learners' practical, research and analytical skills prior to the issue of assignments. Learners will need to appreciate the importance of safe working practices during practical work and apply these effectively at all times.

Employers place great importance on the interpersonal and organisational skills that learners will develop during the delivery and assessment of units such as this. Your delivery should emphasise the importance of learners working effectively with their colleagues, having a well-organised approach to their studies and meeting assignment deadlines.

Learning aim A – Examine the characteristics and applications of fibre-reinforced polymer composites that are widely used in industry

- You might introduce learning aim A by defining what is meant by a composite material. The scope of this unit in dealing with only FRP composites can then be explained. Composites are unusual in that the material itself is created during the manufacture of a finished component. Prior to manufacture it exists only in its constituent parts, in this case, fibre strands or matting and a polymer resin. You should initially consider these separately.
- You should discuss the types and mechanical properties of common fibres used in composites, using appropriate samples of raw fibre materials to support your teaching. Learners will require a qualitative understanding of how the properties of the fibres compare to each other and their relative cost, availability and environmental impact. You might ask learners to work in small groups to research some quantitative data relating to the properties of common fibre materials, e.g. density, tensile strength, stiffness and/or ductility. They could then compare these with the properties of metals such as steel or aluminium that learners will be more familiar with. This will help identify some of the advantages, as well as potential problems, of using the fibres in practice and lead on to a brief discussion of the role of a polymer matrix material in the finished composite.

- You should carry out a similar exercise to introduce the properties and qualities of common polymer matrix resin materials that are used in combination with fibres in FRP composite materials.
- A more detailed analysis of the distinct roles played by the fibre and polymer matrix when used in combination in a composite can then be carried out, using samples of completed composite materials to support teaching.
- Learners will also need an understanding of the processing parameters that can be used to tailor the exact mechanical properties required in the finished component, e.g. fibre alignment in the direction in which the component will be loaded. Factors such as these can be illustrated by using examples of finished components, e.g. a carbon fibre bicycle frame, squash racket or fishing rod.
- You will need to guide the development of a good qualitative understanding of the mechanical properties of common composites once they are moulded and cured. This should also include factors, such as cost and maximum service temperatures, that will influence material selection for a particular application.
- In the next topic, which covers the industrial and commercial applications of FRP composites, you might work with learners to develop their independent research skills. You could ask them to investigate a range of applications that use different FRP composite materials. They should research the traditional materials that they replaced and the reasons for their adoption. The results of their research could then be shared with the class and provide the focus for peer review to help develop their analytical skills.
- The delivery of this learning aim would be enhanced with the involvement of a local industrial partner. A site visit, enabling learners to see the industrial processes used to manufacture FRP composite materials in practice, would be very useful. An industrial partner might also provide examples of components that can then be the focus for case studies for use in teaching and learning activities. Once learners are able to see the commercial importance of composites in a real-life local industry, it will enhance their interest and engagement with this learning aim and the unit as a whole.
- In the delivery of this learning aim, you should help develop a working knowledge of a range of FRP composite materials and the ability to analyse and evaluate their application in specific circumstances. When you are confident that your learners are able to do this, you should issue the first assignment that covers this learning aim.

Learning aim B – Investigate the processes used to manufacture and repair fibre-reinforced polymer composites

- To start learning aim B you could reintroduce some of the fibre and resin samples first seen in learning aim A. Manufacturer's data sheets for these will provide information on the potential dangers relating to their use. These can be used as the focus for a class discussion of applicable health and safety regulations and the importance of safe working practices.
- You will need to provide learners with an overview of wet and dry lay-up processes. This could be achieved through practical demonstrations, educational videos or other resources. Once you have established a basic understanding, you can build up the learners' knowledge by discussing the characteristics of each process. Relative advantages and limitations should be considered in detail and related back to the types of materials used in each case.
- An understanding of potential processing errors that might lead to poor component strength will also be required. If you can support teaching with examples of components with visible evidence of inclusions, voids or perhaps low-fibre content, it will help reinforce understanding. It is straightforward to produce examples such as these using GFRP during your preparation to teach this learning aim.

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- Variations on wet and dry lay-up techniques are also used in the repair of damaged composite components, which is covered in the next topic.
- You might introduce the repair FRP composite materials by showing learners examples of components and/or material samples exhibiting typical wear or impact damage. Damaged components might be obtained through your links with an industrial partner, for example accident damaged GFRP automotive body panels. Alternatively, suitable samples could be prepared in house by deliberately damaging preprepared pieces of composite material.
- Learners will need to be able to recognise the types of damage caused by high- and medium-energy impacts through visual inspection. You should also discuss the non-destructive testing methods that are used to detect internal material flaws, such as hidden voids and inclusions, as well as internal damage caused by low-energy impacts.
- You should remind learners that some damage might be too extensive to repair effectively and a whole component might need to be replaced. In addition, a repair, however carried out, always weakens a component to some degree. Where a component is load bearing and safety critical it may be need to be replaced as a matter of routine if even slight damage is identified.
- Teaching about safe damage removal and preparation for repair can be more effective if you demonstrate the techniques required.
- Learners will need to understand a range of different repair types, their characteristics and the situations in which they might be used. The relative advantages and limitations of each repair type should be covered in detail.
- Examples of repaired components will help to support your delivery of this topic. These can be prepared during your preparation to deliver this learning aim. If some examples are sectioned so that the internal structure of the repair can be seen by learners it will help them to understand how they work and their relative strength.
- When you are satisfied that learners have a sound understanding of the characteristics, advantages and potential weaknesses of these manufacturing and repair process, you should issue the second assignment which covers this learning aim.

Learning aim C – Carry out processes to manufacture and repair fibre-reinforced polymer composite components

- In learning aim C you will guide learners to develop the practical skills necessary to safely and accurately carry out the processes introduced in learning aim B.
- During the assessment of this learning aim, learners will be required to carry out the repair of components with through-hole and surface damage and manufacture a component using wet or dry lay-up. You will need to demonstrate the techniques necessary for them to achieve this safely and accurately.
- You should demonstrate all of the manufacturing processes and repair techniques discussed in learning aim B. The necessity for an autoclave when using dry lay-up can be avoided by using materials that do not require elevated pressures during curing. These are available from specialist suppliers at reasonable cost (see Resources section for links to potential suppliers).
- In the preparation for this unit, you will need to design some basic components and make a series of moulds that will enable their manufacture. Moulds should be made of a robust, stable material such as aluminium to ensure that they can be re-used effectively. Drawings of the components should be available and include critical dimensions, component thicknesses and required fibre alignment (where applicable).

- You should guide learners to use component drawings and appropriate equipment to develop their practical skills by safely manufacturing a series of components. Once the components are cured, learners should compare them against their design drawings and carry out a visual inspection for manufacturing flaws. Where problems are identified, learners will need to take action and/or develop the application of practical techniques until they are resolved in subsequent component manufacturing activities.
- A similar approach should be taken when learners are developing the skills required to carry out effective repairs on damaged components. Each learner will need a number of damaged components. It is impractical to obtain the quantities required from real examples of damage caused in service. It will be necessary to have suitable components prepared and deliberately damaged prior to delivering this learning aim.
- When learners have developed the skills necessary to carry out manufacturing and repair techniques safely and accurately, resolving any problems they might encounter as they work, you should issue the third assignment that covers this learning aim.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacturing*
- *Unit 26: Mechanical Behaviour of Non-metallic Materials*
- *Unit 46: Manufacturing Joining, Finishing and Assembly Processes*
- *Unit 49: Aircraft Workshop Methods and Practice*
- *Unit 52: Airframe Construction and Repair*
- *Unit 55: Aircraft First-Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Mazumdar S – Composites Manufacturing: Materials, Product, and Process Engineering (Taylor & Francis, 2001) ISBN 9780849305856.
  A useful resource.

Websites

- https://compositesuk.co.uk
  This is the homepage for the UK's composites trade association, *Composites UK*.
- www.easycomposites.co.uk
  This is a valuable resource for instructional videos, information and the supply of materials, tools and consumables for manufacturing composites.
- www.nccuk.com
  This is the homepage of the UK's National Composites Centre, NCC.

Unit 48: Aircraft Flight Principles and Practice

Delivery guidance

Approaching the unit

This unit introduces the fundamental science and operation of heavier than air, sustained and controlled flight vehicles. It should be expected that the learners are not familiar with aircraft beyond their own personal experience of being transported in them. Further to this, you will be expected to guide them through significant portions of fluid mechanics as well as control engineering, both of which are also likely to be novel as well as demanding. Aircraft are inherently interesting to the vast majority of people. You should seek to exploit this interest by contextualising at every available opportunity all portions of theory by connecting it to real aircraft. For example, when discussing aspect ratio, use gliders, when discussing load factors, use combat jets, when discussing flow control, show them vortex generators on real aircraft.

Practical activity as a means of demonstrating the principles to be covered should be pursued wherever possible. You will note that the specification requires, mandatorily, that experiments be performed in a wind tunnel with associated force measurement apparatus. Since this apparatus will therefore be present, it seems sensible to utilise it for other portions of this unit beyond the mandatory assessment criteria that call for it. For example, induced drag magnitude as a function of aspect ratio might be explored through the drag measurement of several wing models of varying AR. You should also, as an essential tool, acquire an aircraft model of reasonable dimensions, preferably with moving surfaces. This is an invaluable tool when explaining modes of motion and stability responses. The ability to accurately visualise the principles is key to the learner's comprehension.

If at all possible, arrange for the learners to view and inspect a real aircraft at close quarters. This will be an excellent means of connecting otherwise nebulous design features with real aircraft construction and performance. It is also recommended that you arrange for a visit from an active pilot. This is an excellent means of developing knowledge of aircraft operation from the operator perspective. This will be particularly fruitful during those portions of the unit that deal with stability and manoeuvring.

You should begin by ascertaining why your learner cohort is pursuing this unit. Are they destined for maintenance, ground operations, design, manufacture, piloting, higher education etc. From this perspective, you can begin by drawing out their expectations and most importantly, develop their awareness of the fact that the aerodynamics and operation of aircraft are of critical importance irrespective of which of the above fields the learners are destined for.

As suggested previously, contextualisation is important. You might prepare ahead of delivery by developing a suite of aircraft images such that when you arrive at a particular juncture you will have examples of application to hand.

Invariably, given the content, you will require the learners to sketch two particular things repeatedly in relation to multiple theories. One is an aerofoil and the other is 1 of the 3 views of a generic aircraft (longitudinal, lateral, directional). Both these items are notoriously hard to sketch unless you are artistic. You may wish to produce templates or preferably stencils, ahead of lessons, which the learners can utilise. This will save an enormous amount of time over the academic period and improve the quality of learner-generated sketches, thus improving their comprehension.

A survey of the learning aims will quickly show that much of the unit could be delivered through laboratory activities. From a planning perspective the primary focus should be on those assessment criteria that stipulate the conduction of experiments. The entirety of the assessment criteria for learning aim B requires access to specific apparatus. Namely, you will require:

- an open or closed circuit wind tunnel of reasonably low turbulence intensity
- a two component force balance compatible with the tunnel (three component would be preferable)
- at least two different aerofoil models
- pitot tubes
- manometers
- a thermometer and laboratory grade barometer.

Beyond these mandatory requirements, it is recommended that, if possible, the following apparatus be sourced (note that each of the following devices, while generic in description, do exist as specific instructional devices and are readily available to buy and ready for immediate use):

- viscometer
- smoke injection rake
- wind tunnel model bodies of identical axial CSA and shape but differing longitudinal profile and surface texture
- wing models of differing aspect ratio and planform shape
- aerofoil model with adjustable flap.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

The unit opens with an exploration of the atmosphere, its constitution according to altitude, and phenomena that occur. This is an obvious starting point given that aircraft must operate in this environment and it is sensible to introduce the topic in this light. Invite the learners to offer their own impressions on the dimensions and constitution of the atmosphere before proceeding to show them the true complexity. Some of the recent stunning photographs of the atmosphere looking toward the horizon taken from the International Space Station would make excellent scaffolds to build this detail upon. Such images not only indicate the dimensions in relation to the curvature of the earth, but also the composition.

Graphical representations of temperature, pressure and density can easily be generated from ISA data and used to explain the variation in these properties. It would be sensible to introduce lapse rates at this point. Such graphics might also be used to indicate the relative positions of the various atmospheric events and dangers aircraft are exposed to. Following this, you might invite the learners to suggest why, given what they have learned, all transonic commercial aircraft operate at the same specific altitude. Give learners a copy of the ISA and draw

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their attention to how this data could be used to establish altitude for given temperature or pressure. Ensure they understand that the ISA is a statistical numerical model. Link to altimeters and their operation in relation to the ISA.

Introduce the Characteristic Gas Equation (CGE) and its applications. With access to a barometer and a thermometer, you may wish to have the learners compute the density of the air from the recorded data using the CGE. Ensure that the learners understand that this particular task will need to be repeated prior to the aerodynamic experiments to be conducted later in the unit. Stress the need for accuracy. Invite the learners to compare their computed values with the ISA values local to your altitude and offer explanations as to why the values are different. This will encourage analysis and evaluation.

Finally, for this portion of the learning aim, introduce learners to airspeed, both true and equivalent and indicate the differences. Proceed with the speed of sound equation and Mach number. Have the learners compute the speed of sound at different altitudes and then the consequent Mach number for a given airspeed. Without labouring the importance of the Golden Mach number of 0.7, invite the learners to explain why it is advantageous to fly a transonic aircraft at M = 0.7 at high altitude as opposed to low.

Commence the next section by making the learners understand the fundamental connections between the laws that govern solid mechanics and those that govern fluid mechanics. At each stage prompt them to offer any observations regarding the familiarity of these fluid equations with those they have seen for solids. In this way you may explain the adaptation of the physical laws such that we can perform calculations on fluids. This will make tasks such as applying Newton’s laws to aircraft motion less daunting for the learners. Both continuity of momentum and Bernoulli’s equation can be demonstrated excellently with the wind tunnel. A simple contracting and diverging test section and a pitot probe could be used to demonstrate the relationship between total, static and dynamic pressure. Comparison of experimental results with continuity can be used to illuminate the shortcomings of Bernoulli’s equation, namely that it is an inviscid solution. You might have the learners conduct the experiment using Bernoulli’s theorem and present the data. Then have them use continuity for the same ends and leave them to observe the different result. Have the learners investigate why the data diverges. During such experiments, you could have the learners use a U tube manometer to record the total and static pressures and hence reinforce any learning regarding hydrostatic pressure.

The final stage in this subsection deals with acceleration, force and moments. Arguably, much of this will be previously learned prior to the commencement of this unit. However, it will still be important to draw the learners' attention to the connection between these principles and the learning aims to be covered further in the unit. For example, centripetal acceleration in regards to load factor.

This part of the learning aim is predominantly concerned with the balance of forces on an aircraft and how these relate to motion. You should begin by revising the concept of equilibrium with the learners. From here, introduce a body suspended freely in air and invite them to determine what forces and in what relative magnitudes would be required to hold it in place. From here you can link that lift requires forward momentum (thrust) and introduce this force, before introducing the by-product force of drag. With the inter-relationships established, guide the learners to explore how the relative position or rate of motion of the body could be altered by altering the forces. What will happen to the others as a consequence? The same paradigm can be extended to moments and the principle of static longitudinal stability. From here, re-introduce a representative aircraft as the body and illustrate the generation of forces due to manoeuvres. Link this to acceleration and hence load factor. You may wish to give learners an example manoeuvre envelope and have them compute maximum rates of turn for the given limits of the diagram. This exercise could be extended to constitute assessment.

The remainder of this learning aim is concerned with the causes, symptoms, and prevention strategies of unplanned or accidental damage to the airframe. Broad reference to photographic examples would best illustrate these points and FAA manuals for both construction and repair are an excellent source of these.

Learning aim B could be thought of in two parts. The first is two dimensional, and the second is three dimensional. A traditional problem in teaching flight mechanics is the leap from two dimensional phenomena to three. It is imperative that the learners be shown that two dimensional (sectional) modelling allows the computation of three dimensional (total) force, and that the shortfalls are accommodated at the three dimensional level. Begin with establishing the standard nomenclature. You may wish to introduce some standard aerofoil sections at this stage to illustrate the changes in these measures.

The next section, while extremely brief in the specification, is of prime importance to all the following learning aims. The nature and behaviour of the boundary layer is notoriously difficult for learners to grasp. You should ensure that you leave adequate time to cover this concept thoroughly and slowly. Link the no-slip condition and viscosity to shear stress and the resulting velocity distribution in the fluid. Visual aids for this are essential and you should take care to produce adequate images to explain the theory. Once the basics have been established, you can proceed to the differences between laminar and turbulent flow and use the concept of the streamline to indicate these. Link the flow types to energy states and proceed to pressure gradients. Show that adverse pressure gradient dictates the rate of momentum loss and hence the risk of separation. Invite the learners to hypothesise why turbulent boundary layers are more resilient to separation than laminar ones. Conclude by showing the ramifications of separation on both lift loss and drag gain.

Using Bernoulli’s equation and the continuity equation, illustrate how the camber of the aerofoil constricts the stream tubes and causes an ultimate reduction in static pressure (lift). Indicate that this pressure change is active around the entire aerofoil and give learners graphic illustrations of these pressure distributions. Link to lift. Draw attention to the stagnation point movement, broad changes in magnitude, movement of pressure peak and therefore of pressure centre for changes in angle of attack and velocity. Link separation to wing stall on these same graphics. Linking back to mean camber, indicate the relative lift production of a range of aerofoil shapes. All of this section could be supported excellently with flow visualisation if available. Smoke injection in the wind tunnel would be the obvious choice. It may be sensible to carry out a demonstration of the wind tunnel operation at this point. Show how the lift can be measured from the balance. Show how the lift value changes according to angle of attack and velocity.

Three dimensional wings can now be introduced. Begin by superimposing the pressure distributions of the aerofoil on to the wing. From here, the concepts of downwash and spanwise lift distribution can be explored. You may wish to introduce the concept of the wing tip vortex at this stage since it is a product of this lift distribution. Show how planform effects the lift distribution. Repeat for aspect ratio.

With the concepts of shear stress and separation (thus wake) already established, you should begin the discussion of drag from here. Ensure that the learners understand that laminar and turbulent flow tend to have one drag type more dominant than the other. Prompt the learners to justify why they think that laminar or turbulent flow would be best for given scenarios. Reinforce the idea that shear stress drag is dominated by surface quality, and wake drag is dominated by shape.

This would be an ideal point to perform another experiment. The classic experiment of different bodies of the same flow-wise CSA and shape but differing longitudinal shape and surface texture is an excellent way to demonstrate the differences between the two drag types. This will also allow the demonstration of the drag measuring axis of the wind tunnel balance. The specific drag structures caused by aircraft geometry can now be discussed. Since induced drag is the fundamental drag mechanism, it would again be worth performing an experiment. One would be the use of a number of wing models (with a tip free in the tunnel section) of differing aspect ratio. Another would be different planform shapes but with the same area (rectangular, elliptical, trapezoidal etc.)

Lift and drag interaction should be explored graphically since the interpretation of such graphs is the basic design tool used. Ensure that the learners understand how to reduce data recorded from the wind tunnel to complete such graphs. Indicate the fundamental points of interest in these graphs and discuss their importance.

The learners are now in a position to carry out the assessable experiment. Something to note here is that the specification calls for only three angles of attack to be tested. This would not be sufficient to produce lift slopes and drag polars of any sensible use. Particularly not if the learners are to analyse combined lift/drag plots. It is strongly recommended that you perform the experiment yourself first to establish the full range of angle of attack to encapsulate lift at zero AoA, the limit of the linear relationship of the lift curve slope, AoA at C_{Lmax} and AoA at full stall. Assuming full stall occurs at around 12 to 15° AoA, it would be sensible to record data at 2° increments from zero.

The final learning aim relates to control and stability. You may wish to reverse the order of delivery to cover control first and stability last. The specification calls for stick-free stability only and learners are apt to confuse “stability” with control input if they are not first fully versed in what control is and how it is achieved.

All the primary controls operate on the principle of altering the camber of the surface on which they are found. This should be the fundamental starting point for your learners. An experiment utilising an aerofoil with an adjustable flap will brilliantly display this. Have them investigate the correlation between mean camber change and lift change. Guide the learners to recall previous learning as to how lift is effected by camber. In particular have them consider the problem of separation and drag. Proceed to the more exotic control surface types and trim tabs from the same basis. Link the lift changes on the specific surfaces to the resultant motion of the aircraft. This is the stage at which a fully functioning model is most useful for demonstration purposes.

The purpose and drawbacks of flaps according to type can now be explored. NACA technical reports (which are public domain) have excellent data for reviewing the relative merits of each flap type.

Aircraft stability can be difficult to communicate. It is therefore advisable to start with a discussion of stability of any generic body. A marble, a bowl, and a table top make for an excellent demonstration of basic stability. Particularly the problematic conceptual differences between static and dynamic stability. The learners should, by this stage, already be comfortable with the rotational axis of the aircraft. Simply connect the concepts of basic stability to the three axes and allow the learners to explore the resultant motions. You can now introduce the concept of perturbations as the driving catalyst in displacements from stable conditions and again prompt the learners to suggest how these might be corrected. Prompt them to focus on lift and drag force production. Could these be used (without pilot input) to return the aircraft to its stable condition? How, and from where on the aircraft? From here you can introduce design solutions that augment the stabilisation of the aircraft. This is the point at which a catalogue of aircraft images can be enormously useful.

Learning aim	Key content areas	Recommended assessment approach
A Examine the atmospheric, mechanical and fluid principles affecting flight	**A1** The atmosphere, the International Standard Atmosphere (ISA) and its effect on flight **A2** Fluid flow and mechanical principles **A3** Application of mechanical principles to aircraft flight	Evidence covering the atmosphere, the analysis of atmospheric parameters, mechanical and fluid principles and their effect on flight and continuing airworthiness.
B Explore safely the lift and drag force generation and interaction that create aircraft flight	**B1** Subsonic airflow over aerodynamic surfaces **B2** Aircraft lift, drag and their interaction	A portfolio of results gathered by experimentation when investigating airflow over aerofoil surfaces, and lift and drag generation and interaction. Supported by images, observation records, graphs and mathematical analysis.
C Investigate the nature and methods used to stabilise and control aircraft	**C1** Fixed-wing aircraft stability **C2** Fixed-wing aircraft control	Evidence covering the operation of flight control devices, the nature of stability and the implications and justification for the methods used for fixed-wing aircraft control and stabilisation.

Assessment guidance

The unit specification details the fundamental requirements of what must be contained within the assessment reports submitted by the learner. In line with that specification, it is recommended here that you deliver and assess the unit in three parts.

For learning aim A the learners must calculate atmospheric properties according to changes in altitude. This might be posited as a realistic scenario. A pilot, flying at some unknown altitude and wishing to know their altitude, records the ambient temperature (given by you) and pressure (given by you). Show how they calculated their altitude. This will require that you give them a copy of the ISA. Note that the criteria requires plurality. Thus you will have to give more than one scenario. Perhaps make one high altitude and the other low altitude. You are also required, in the same criteria, to assess effects of these changes on aircraft flight. You could have the learners explore the effect on Mach number for example. In your scenarios, stipulate that the pilot maintained a constant airspeed at all altitudes. What was the effect on Mach number by changing altitude?

The second part of the assessment for this learning aim requires an explanation of BOTH fluid and mechanical principles that enable flight. It is hard to see how this might be achieved in one question. You may wish to cover the two demands separately. In the first part, you might direct the learners to show how continuity and Bernoulli's equation can be used to explain how an aerofoil generates lift. In the second part you could either posit a hypothetical scenario involving an aircraft in a steady balanced turn of a particular velocity and turn radius and have the learners calculate centrifugal force, or, give them a manoeuvre envelope and have them derive the maximum rate of turn for a given velocity. This second option is attractive as it links directly to the final criteria in this learning aim. They must explain the nature of the loads and their parameters on airframe structural response. Using the same manoeuvre envelope you might direct the learners to calculate maximum rates of dive, climb and turn.

Learning aim B specifically requires a series of experiments be conducted and results recorded before the data is reduced and interpreted. Witness statements and/or video recording of these experiments will constitute evidence that the experiment was conducted. It is recommended that you produce a thorough brief for the learners that they can have access to in advance of the actual experiment. This will ensure preparation prior to conducting the experiment. Ensure that the apparatus is prepared in advance and that the learners are made aware of any time constraints prior to commencement. Encourage the learners to record everything, whether stipulated in the brief of not. Perhaps suggest that they should photograph the apparatus and include these images in their report submission. Given the nature of the two experiments stipulated, it is recommended that both be conducted in the same session. The assessment should stipulate that the learner show how they reduced the data and explain the results derived.

Learning aim C begins with a requirement to explain primary controls, secondary controls, lift augmentation and drag augmentation devices. It seems sensible here to have a list of devices and have the learners identify their operation and effect on flight. Alternatively, you might posit a list of requirements and ask the learners to suggest what device might be used to satisfy the requirement and explain why this device would be suitable. For example, an aircraft must be re-designed to shorten its runway requirement at take off. What device would be most suitable? Note that this question implies that they must recognise that you have asked for a lift augmentation device, but one that clearly doesn't augment the drag severely.

The second part of learning aim C could best be satisfied by asking the learners to describe each of the three axial modes of stability. For example they must report that directional stability is concerned with changes in yaw. This could then be followed by asking the learner to suggest a mechanism for improving the stability and explaining why this would help.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 48: Aircraft Flight Principles and Practice

Introduction

This unit will be significantly demanding on any learner who has no previous knowledge of fluid mechanics or aircraft operation. Wherever possible, you should endeavour to contextualise the theories in relation to real aircraft and draw on the curiosity that most individuals have regarding them.

Link the materials to the likely activities of employment in the aerospace sector. Ensure that the learners appreciate the need to develop understanding of fluid mechanics and aircraft flight regardless of whether they will be employed in maintenance or manufacture.

Where practical demonstration is available, you should seek to illustrate the more complex, or less familiar, aspects of this unit in ways that allow the learners to physically link observations to flight parameters.

Learning Aim A – Examine the atmospheric, mechanical and fluid principles affecting flight

The atmosphere.

- Composition of the air in the earth's atmosphere. Discuss the nature of the gases, particularly with regards to the combinations necessary to sustain life.
- Layers of the earth's atmosphere to include the troposphere, stratosphere, mesosphere, thermosphere and exosphere. Link to vehicle types that operate in these zones.
- Changes to the atmospheric air pressure, density and temperature. Show the changes graphically as well as in raw data form (ISA).
- Danger to flight due to severe atmospheric events. This can be covered with visual materials to indicate the severity of the phenomena. Link to design requirements applied to mitigate these events.

The International Standard Atmosphere (ISA).

- The need for and functions of the ISA. Discuss the application to flight devices as well as basic aircraft design data.
- Define pressure (barometric, atmospheric, absolute), temperature (Kelvin, Centigrade, Fahrenheit, absolute), density, density ratio, dynamic viscosity, kinematic viscosity and sonic velocity. This might require basic instruction in the variables first. What is pressure? What is viscosity? If access to a viscometer is possible, it is strongly recommended that practical demonstrations be carried out. Discussion of pressure measuring devices should start with a basic U tube manometer before proceeding to the more complex types utilised on aircraft.
- Significance of and numerical values for the tropopause, temperature lapse rate, the temperature in the stratosphere.
- Standard ISA values for the properties of air at ground level and their changes with altitude, to include pressure (p), density (ρ), temperature (T) dynamic (absolute) viscosity (μ), kinematic viscosity (v) sonic velocity (a).
- Definition and use of the characteristic gas equation (CGE) must start with the basic gas laws first. Learners must be guided to see the inter-relationship between

volume, pressure and temperature before proceeding to the CGE. Show that the CGE is based on energy states of gases.

- The use of ISA tables to find changes in pressure, density, absolute viscosity, kinematic viscosity and sonic velocity, for varying altitudes.
- The density ratio (σ), and its relationship to the equivalent airspeed (EAS) and true airspeed (TAS) at varying altitudes.
- The use of the temperature lapse rate equation ($T = T_0 - Lh$), the sonic velocity approximation $a = \sqrt{\gamma RT} = 20.05\sqrt{T}$ and the density ratio, to determine properties of air at varying altitudes.

Fluid flow and mechanical principles.

- Newton's laws, including second law and its relationship to forces generated by aircraft acceleration. Third law and its relationship to flight forces and to the generation of aircraft lift. This should really be left to topic A3 when flight forces are covered.
- Continuity equation for laminar constant incompressible steady flow, volume flow rate given by $Q = A_1v_1 + A_2v_2$ and for unsteady variable density flow, the mass flow rate is given by $m = \rho_1A_1v_1 = \rho_2A_2v_2$. This can be covered theoretically in preparation for practical activity where learners can use this method to determine what the velocity distribution in a converging diverging duct should be.
- The Venturi principle and the nature of flow through a Venturi tube. It would be sensible to introduce the concept of the streamline at this stage.
- The Bernoulli equation for incompressible steady flow $\rho gh_1 + 1/2\rho v^2{}_1 + p_1 = \rho gh_2 + 1/2\rho v^2{}_2 + p_2$ also for total energy in a steady stream $p + 1/2\rho v^2 = c$. Link to the U tube manometer and pitot tubes and proceed with experiment to determine velocity distribution in a duct.
- Centripetal and centrifugal accelerations where $a = v^2/r$ and resulting forces where $F = mv^2/r$. Couples and turning moments where torque $T = F \times r$. Principle of moments and balancing forces. Again, these should all be left to topic A3.

Flight forces.

- Begin here with Newton's laws. Reinforce learning surrounding the principle of equilibrium.
- Position and equality of lift, weight, thrust and drag forces for straight and level flight. Link to Newton's laws.
- Flight force couples (lift/weight and thrust/drag), action about centre of gravity (CG) and centre of pressure (CP).
- Balancing aerodynamic force from tailplane. This should really follow the treatment of equilibrium of moments.
- Using the principle of moments, determine balancing forces needed to maintain aircraft in static equilibrium.

Flight forces in steady manoeuvres.

- Introduce centripetal and centrifugal acceleration here.
- Diagrammatic arrangement for system of forces and their components during gliding flight, diving flight, climbing flight and turning flight where $L\sin\theta = mv^2/r$ and $\tan\theta = v^2/gr$. Link diagrammatic explanations to a model. Ensure the learners comprehend the practical range of motions of an aircraft and how these are actually achieved.
- The definition and significance of load factors. Introduce learners to V-n diagrams. Show that different aircraft types have different limits on load factor.

- Analytical solution of flight force parameters, during flight manoeuvres. Perform exercise using V-n diagrams.
- The effects of excessive manoeuvre loads on airframe structure, including pulled rivets, skin buckling, fuel and oil leakage, visual structural cracking, asymmetry of structure. This can be displayed with photographic materials. Consider the use of flight accident reports.
- Methods used to prevent the loss of aircraft structural integrity in the event of overstressing damage, including: failsafe, safe life and on-condition structure, redundancy, radiation shields, planned maintenance, maintenance frequency.
- Post-flight checks after flight through severe atmospheric events, including examination of aircraft structure for damage, symmetry, examination for lightning and high intensity radiation field (HIRF) damage, instrument damage and degaussing, controls freedom of movement.

Learning Aim B – Explore safely the lift and drag force generation and interaction that create aircraft flight

The nature and effects of subsonic airflow over aerofoil sections.

- The nature of subsonic airflow, including streamline, laminar and turbulent flow, compressibility effects at higher subsonic speeds. If access to apparatus which can display laminar and turbulent flow is available, it is recommended that it be used here. Reynold’s number should be introduced at this point/
- Aerofoil terminology to include aerofoil profile, camber, upper, lower and mean camber lines, chord line, leading and trailing edge, thickness/chord ratio or finess ratio, angle of attack (AOA), angle of incidence (AOI).
- Viscosity effects and the boundary layer, including resistance to motion, velocity gradient, shear rate, boundary layer separation (transition point, separation point). Care should be taken over this section as it is both difficult to comprehend and is of significant importance to all the following segments. Ensure that the learners understand the nature of the boundary layer and in particular the parameters that dictate attachment or separation.
- Flow over aerofoil sections, including free stream, laminar and turbulent flow, relative airflow, up and down wash, stagnation point, separation.
- Pressure and flow changes at low, medium and high angles of attack and aerofoil stall effects. Link to the boundary layer. Use experimental visualisation studies if available.
- Airflow and aerodynamic shape, to include aerofoils (flow over thin, medium, thick and symmetrical aerofoil sections), wings (aspect ratio, generation of tip vortices). Again, if available use demonstrations to illustrate these concepts.

Lift, drag and their interaction.

- Lift:
    - Factors affecting lift including aerofoil shape, lift coefficient, angle of attack, air density, airspeed and stall. Link back to the boundary layer again. Link the pressure gradient to the camber.
    - Centre of pressure and lift force. Use visual material to illustrate this point.
    - Parameters and use of the lift equation, $L = C_L 1/2\rho v^2 S$. Give learners graphical data and perform basic calculations.
    - Wing plan form designs for aircraft subject to low subsonic, high subsonic and transonic speed airflows. Discuss effect of sweep, aerofoil thickness ratio and supercritical profiles.

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- Effects that wing plan forms have on the generation of lift. Discuss the loading conditions on wings and link to both planform shape and aspect ratio.
- Use and types of wind tunnel apparatus, eg air blowers, lift and drag balances, open and closed section tunnels, flow visualisation equipment, airflow pressure and speed-measuring devices, aerofoil sections and whole aircraft models. This should be done by direct demonstration as the learners will be required to operate this equipment as part of their assessment.
- Measurement of lift forces using wind-tunnel apparatus.
- Significance and interpretation of pressure plots for varying angles of attack and airspeed.

- Drag:
  - Types of drag including total, induced (trailing vortex), profile skin friction, profile form, interference. Experimental studies would be advisable here. Different bodies with different shapes and surface textures. Ensure the learners comprehend the difference between surface friction drag and drag due to wake formation. Link back to laminar and turbulent flow.
  - Factors affecting drag including aerofoil shape, angle of attack, drag coefficient, airspeed, streamlining, damage to lift producing surfaces, ice and frost accretion. Link back to the previous section regarding shape and surface effects.
  - Drag reduction methods including polished surfaces, fairings.
  - Parameters and use of the drag equation $D = C_D 1/2 \rho v^2 S$.
  - Significance and interpretation of profile, induced and total drag plots verses airspeed. Ensure the learners can see how such plots are generated as they will need to produce these as part of the assessment.
  - Measurement of drag forces using wind tunnel apparatus.
  - Theoretical determination of drag forces.
- Lift and drag interaction:
  - Significance and interpretation of lift and drag plots. Again, present learners with published data and show them how to read such graphs and interpret the data. Polar plots of lift coefficient against drag coefficient and their interpretation. Plots of profile drag and induced drag (total drag) against airspeed. Minimum drag, the lift/drag ratio and aerofoil efficiency. Optimum angle of incidence (AOI).
- Interpretation of aircraft model wind tunnel test results for lift, drag and pitching moment. This is assessment criteria B, therefore perform the assessment at this juncture.

Learning Aim C – Investigate the nature and methods used to stabilise and control aircraft

Fixed wing aircraft stability.

- Nature of stability, including reaction to a disturbance for stable, unstable and naturally stable bodies, static and dynamic stability. Begin with basic stability of any body. Progress to the difference between static and dynamic stability.
- Definitions for lateral, longitudinal and directional stability.
- Longitudinal static stability, including trim and stability, centre of pressure and aerodynamic centre movement, use of tailplane, CG position and limits for stability, effect of loading of stores and cargo. For the following three requirements it is suggested that you have a pre-prepared suite of aircraft images ready. These

images can be used to indicate how real aircraft design embeds the discussed requirements in order to produce a stable aircraft.

- Lateral static stability, including yawing stability (yawing motion or weathercocking, use of fin, keel surface and wing dihedral), rolling stability (use of high wings and sweepback), use of anhedral.
- Nature of dynamic stability, including longitudinal stability (short period pitching oscillations and damping, phugoid motion and damping) and lateral stability (roll damping, spiral mode, Dutch roll and the effect of the fin and side slip on damping).

Fixed-wing aircraft control.

- Purpose and operation of primary controls, including ailerons, elevators, rudder. Begin by linking back to the relationship between change in camber with change in lift. Illustrate the principle using a wing model with movable flap in the wind tunnel.
- Secondary controls including canards, stabilisers, elevons, tailerons and flaperons. Ensure that the learners appreciate that these are not actually secondary controls, but rather primary controls which happen to be somewhat more exotic than the standard controls. Lead the learners to appreciate why such control types might be adopted in preference to more standard types.
- Purpose and operation of control tabs, including trim, aerodynamic balance and anti-balance, balance panels, servo, spring, mass balance.
- Lift augmentation devices, purpose, operation and interaction, including flaps (plain, split, slotted, fowler, multi-slotted fowler, Krueger), slots, slats, vortex generators, wing fences, winglets. Link to high-speed flight. Ensure the learners understand the penalty to lift production of designing a wing primarily for transonic cruise and why this necessitates lift augmentation devices.
- Purpose, operation and interaction of drag inducing devices, including spoilers (lift dump and roll), airbrakes. Begin by describing a typical flight envelope. What are these devices for? When are they used?
- Control and stability interaction and aircraft design features for flight at transonic speed, including use of anhedral, sweepback, wing fences, delta wings, area ruling. This section should really occur in topic B2 where high speed wings are first discussed.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 52: Airframe Construction and Repair*
- *Unit 53: Airframe Mechanical Systems*
- *Unit 54: Aircraft Electrical and Instrument Systems*
- *Unit 55: Aircraft First Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Barnard RH & Philpott DR – *Aircraft Flight, 4th Edition* (Prentice Hall, 2010) ISBN 978-0273730989.
  This text gives an excellent balance between analytical treatment and anecdotal, making it particularly useful for learners new to the theme. The level of the text is set at approximately the correct level for learners at level 3.

Unit 49: Aircraft Workshop Methods and Practice

Delivery guidance

Approaching the unit

As stated in the unit specification, this unit is designed to develop operator skills and knowledge of appropriate practices with regards to the fitting and inspection of airframe hardware. The future, or indeed present, employment of your learners is likely to be either in manufacture or in maintenance. You should begin by ascertaining the specific motivations of your learners. This will allow you to tailor the learning aims toward the specific skills and learning most needed by them. It would also be sensible to survey what fabrication or fitting skills the learners may already have. This will allow you to plan the rate of delivery and where to focus available time on skills development.

Clearly, a large volume of the learning aims are intended to be delivered via practical activity in a suitable workshop environment. With this in mind, you should prepare for subsequent delivery by assuring access to facilities, tooling and consumables. If Personal Protective Equipment (PPE) is to be supplied by your institution or organisation, you must ensure that this is acquired and distributed to the learners prior to any workshop activity. It is also recommended that you, as the tutor, should have recognised first aid training and access to appropriate first aid supplies. Failing this, direct contact details and the location of the designated first aiders for your institution should be established and prominently displayed in the workshop being used.

Throughout the delivery of this unit you should make every effort to link the activities to common processes as carried out in industry. For this reason you should make efforts to secure industrial visits to either aircraft manufacturing and assembly companies (OEMs), and/or maintenance and repair centres (MROs). This will allow the learners to absorb, first hand, just how their developed skills will be used in real employment roles.Considering the nature of the learning aims as well as the assessment criteria, you should consider maximising the potential for practical delivery and guided activity wherever possible. Those learning aims which require development of technique to certified standards and methodology should be delivered through guided practical example, followed by learner practice, feedback and appraisal, and repetition as necessary. This will clearly require, as stated previously, access to a suitable workshop, a full suite of appropriate tooling and stores of necessary consumable materials. With regards to the workshop, ensure that prior to commencement of the unit, a full risk assessment is carried out and displayed prominently within the workshop. Ensure that all necessary hazard signage is present, at least one fully stocked first aid kit is present and accessible, chemical cleansing stations if required are functioning, controlled and appropriate storage for hazardous materials is available, fire-fighting equipment is present and serviced, all guards are present on machine tools, demarcation lines are clearly visible, basic washing facilities are functioning and evacuation protocols have been agreed.

In addition to those learning aims that deal specifically with compliance to recognised standards, many of the learning aims would, in a professional context, be carried out specifically in compliance to established standards or certification requirements. Wherever an activity is being pursued that would normally be subject to compliance, you should make reference to typical standards as part of the learning process. This should also include reference to the typical format and demands of work instructions. For example, if your learners are enrolled on an apprenticeship programme for a specific company, you should request some examples of work instructions from that company which can then be used as reference material during lessons.

Prior to delivery, you should create a suite of supporting documentation and literature. FAA circulars, manuals of best practice, and of course certification requirements are all in the public domain. It would also be advisable to select one aircraft workshop practice text as the recommended resource for the learners and make this readily available in either hardcopy or electronic format. There are many versions of these which are free to download from the internet including an excellent text by the FAA. Basic aircraft science texts which connect the manufacture and maintenance of airframe to the operation of the aircraft should also be utilised. Connecting and emphasising the ramifications of tolerancing, accuracy and method to aircraft operation is fundamental. All too often the connection between fitting or fabrication processes and the safe and efficient operation of the aircraft is not appreciated by technicians. You may wish to make reference to some of the examples of catastrophic failure that have occurred due to poor or negligent manufacturing or maintenance. Copies of relevant EN and BS standards should be resourced prior to commencement also. Be aware that these must be purchased.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Appropriately, the learning aims open with an exploration of workshop safety and housekeeping. You should approach this segment not simply as a learning objective but as an essential precursor to any fabrication or fitting activity. You could begin by taking the learners to the workshop and indicating briefly all the activities they will be carrying out over the duration of the unit. Invite them to consider and identify the potential hazards. Guide them to identify and comprehend those hazards which they have not noticed or appreciated. Invite them to suggest risk eliminations or controls and how they would invoke these in the workshop. The level of detail you go into should reflect their previous knowledge. If a specific health and safety unit is being pursued simultaneous to this unit, you may wish to engage with the tutor for the H&S unit in collaborative exercises. H&S units usually require the generation of risk assessments. The learners might be asked to generate a risk assessment for their workshop. Fundamentally, you require the learners to operate within the workshop safely and appreciate the need for maintaining that safety for the duration of their studies. You may wish to institute a repeat exercise that is carried out prior to every workshop lesson. Deliberately cause a hazard (controlled or simulated of course) prior to each lesson. Have the learners identify and rectify it. By doing this prior to every single lesson you will engender a habitual sense of awareness in your learner group. As part of this exercise you should strive to create an environment in which the learners understand that they are responsible for the maintenance of safety. This should extend to their maintenance and use of their own PPE.

Specific H&S legislation requirements (national or local to your location) should be made available to your learners. Indicate how each requirement is satisfied for every aspect of the workshop.

Aircraft manufacture and maintenance are controlled stringently by certification requirements. This unit calls for the learners to have an appreciation of these requirements. You should again seek to survey the other units being delivered on this course. Units such as *Unit 52: Airframe Construction and Repair*, which would be a likely component of a course, place a great deal of emphasis on airworthiness. Airworthiness is assured through compliance with standards and certification. You may wish to collaborate with the tutor of this unit to develop concurrent learning activities that enhance the learning in both units and potentially reduce the volume of assessment. Dependant on the likely, or potentially already secured, employer, you should seek to focus on the standards and certification requirements most relevant to them. You should, however, not dispense with the other standards as an awareness of the range of standards is an important aspect of this unit. In order to reinforce the relevancy and importance of these standards you should make efforts to secure a visit lecture or lectures from a quality assurance engineer from a relevant employer. Such an individual could elaborate on the fundamentals and how these impact typical day to day operations in manufacture or maintenance. 'Why must a rivet be fitted thus?' 'What can happen if it is not fitted correctly?' 'What do the certification requirements demand?'

The learning aims surrounding tool management practice would best be delivered by adopting the standard practices of a relevant employer. This should include any recording methods and associated bureaucracy. This will not only give an opportunity to learn appropriate methods, but methods which are in current use. This would constitute a direct employment skill, particularly with the employer from whom you have borrowed the standard practices. These practices should be maintained throughout the duration of the course to habitualise the learners to the processes. This learning aim then proceeds to the tools themselves and the appropriate operation of them. This will be most effectively achieved through demonstration, followed by learner practice, followed by inspection and feedback. You may wish to consider the manufacture of some generic piece of structure which requires the application of all the tooling listed in the specification. This will give a real sense of development and eventual achievement for the learners. Clearly, this example structure could be built throughout the unit such that other learning aims and even assessment criteria could be satisfied. If at all possible, you may wish to consider having the learners manufacture different parts which will come together in some larger sub-assembly. This will encourage maintenance of standards as the parts must obviously fit together. If this sub-assembly were a section of fuselage barrel complete with a number of frames, stringers etc, the assembly could be used to attach the cable runs and fluid lines to as part of the assessment criteria. This again would facilitate a sense of continuous progress and achievement for the learners. Note this would require the alteration of the running order of the unit since sheet metal and fabrication techniques would have to, by necessity, occur before fluid transmission and electrical cable runs for example.

Alternatively, for the sake of clear assessment differentiated for each learner, you may prefer a smaller sub-assembly. Each learner begins with an assembly rig. They build up some generic segment of a barrel. One segment of skin (perhaps kept flat for simplicity), one segment of frame, a small number of stringer segments etc. This would have to be large enough to accommodate the fitting of fluid transmission lines and electrical cable runs.

Note that in either case (one large assembly with each learner responsible for certain discrete portions, or individual smaller sub-assemblies, each built by individual learners), you will need to ensure that the design of the structure can incorporate every piece of hardware or consumable stipulated in the learning aims as well as the assessment criteria.

The teaching and learning of hardware and consumable components will require access to said materials. The actual activities should be delivered in the same way as outlined above for tool management and practice. As a suggested exercise, you may wish to invite an inspection technician from a local aircraft company to visit your institution and have them scrutinise the learner's work. Allow the learners to experience the application of inspection processes and techniques first hand and receive real feedback, including remedial actions, from an active professional. You may wish to leave such an activity to the following segments regarding mechanical hardware inspection and fitting.

Learning aim B involves the fitting of parts, as per specifications, and the inspection of those parts. Learning aim C has precisely the same requirements except that it involves electrical hardware specifically. Both these learning aims are assessed by practical activity. Once again, you may wish to make this part of an overall construction project.

Learning aim D deals predominantly with critical feedback. Note that the feedback is to be generated by the learner. You are to encourage them to carry out critical reflection of their own work and to recognise how they might adapt to improve performance. You may wish to adopt a logbook strategy to satisfy this requirement. This idea implies that the learning aim be applied throughout the duration of the unit. At the end of every session, where the learner has carried out some practical activity, the logbook will require updating. What the learner did, what techniques were used, what calculations were performed, what drawings were referred to, what standards were referred to, what the health and safety requirements were, what was the end result, what problems were encountered, how were these solved, and how retrospectively the operation might have been performed better given all these observations. You may wish to produce a proforma of the logbook such that the learner must generate responses to all stipulated points. If carried out repeatedly, as suggested, the end effect should be to develop a habitual sense of self assessment and evaluation as well as critical thinking and problem solving. You could periodically invite the learners to state key findings in the class for all the learners to digest. This will encourage communication as well as providing peer learning.

Note that such a logbook would constitute direct evidence for the purposes of assessment.

Learning aim	Key content areas	Recommended assessment approach
A Explore safe working practices and suitable component selection in an aircraft workshop environment	**A1** Workshop safety procedures and housekeeping **A2** Workshop information sources and standards **A3** Tool management **A4** Hardware and consumable components	A report focusing on the nature and use of information sources including safety procedures and standards covering aircraft workshop mechanical and electrical working practices, together with the results from recognition exercises to select aircraft hardware and consumable components.
B Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness	**B1** Preparation for mechanical hardware inspection and fitting processes **B2** Mechanical hardware inspection and fitting processes	A series of practical workshop tasks to safely undertake mechanical and electrical inspection and fitting processes. Evidence will include: finished components, observation records/witness statements, annotated photographs and drawings and completed record of quality control measures needed to complete the fitting processes.
C Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness	**C1** Preparation for electrical hardware inspection and fitting processes **C2** Electrical hardware inspection and fitting processes	
D Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance	**D1** Lessons learned from workshop inspection and fitting processes **D2** Personal performance while carrying out workshop inspection and fitting processes	The evidence will focus on what went well and what did not go so well when carrying out mechanical and electrical inspection and fitting processes, and a conclusion of improvements that could be made. The portfolio of evidence will be generated while exploring and reviewing aircraft workshop inspection and fitting processes and reflecting on own performance.

Assessment guidance

The recommendations for assessment as stated in the unit specification suggest that learning aims A and D be evaluated separately in the form of written evidence. If done in this way, the advantage presented is one of staged achievement. The learner can see that certain criteria have been achieved and are now 'banked'. This tends to promote continued motivation and engagement. Further to this point, keeping these assessments separate will also allow focus of attention upon the key points without colouration from other requirements. In other words, any potential confusion of purpose that might be experienced by the learner is ameliorated.

Alternatively, a study of these assessment criteria indicates a deal of commonality that suggests they might be better performed, from a learning perspective, together. Remember that assessment should not simply be about 'examination' of knowledge. Assessment can be a learning tool in its own right. Assessment criteria for learning aim D requires the learners to record their actions and how these actions were directed by best practice, health and safety, quality requirements and certification and standards requirements, before proceeding to analyse the results. Assessment of learning aim A requires the learner to explain how the above noted requirements are applied to the activities. If a logbook, constructed such that it must be completed in a specific manner and contain specific recorded data and reflections, were compiled by the learners over the duration of the unit, this could be used as an aspect of the assessment evidence of both learning aims A and D. The added advantage here is that the learners are engaged in a constant process of both awareness of parameters and controls, and of critical thinking and self assessment throughout the duration of the unit. This concept is detailed in the previous section, 'Delivering the learning aims'.

The unit specification deliberately links the assessment criteria for learning aims B and C together. This is entirely sensible given that the criteria are identical save for the hardware in question. You should note that in the recommendations for assessment approach, it is suggested that the learners produce recorded evidence of 'Annotated photographs and drawings and completed record of quality control measures needed to complete the fitting processes'. This could, arguably, be achieved through the suggested logbook approach above. Simply add a requirement for photographs to the proforma.

The practical tasks are mandatory. These could be performed in isolation on prepared rigs. However, given the vast quantity of practical based learning material which must surely involve practical activity for the sake of effective learning even if not directly assessed, it would be worthwhile to adopt a larger project based solution, part of which will constitute the practical assessment criteria of learning aims B and C. The core concept being espoused here is to make the assessment another outcome of the broader learning experience. Since the focus is on the learning, this concept is detailed in the previous section, 'Delivering the learning aims'.

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Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 49: Aircraft Workshop Methods and Practice

Introduction

This unit offers an abundance of opportunity for practical based learning and if this approach is adopted, motivation, engagement and effective learning can be realistically assured. The more academic aspects such as health and safety legislation, standards, and certification requirements can be made less tiresome if they are integrated into the practical activities, eg "Here is what we are going to do, and here is why we are going to do it this way."

At every possible opportunity, make the associated practice of referring to health and safety and standards a part of every single lesson. Promote a habitual awareness and application of the principles in practice. Draw connections to real world employment so that the learners come to associate such requirements with the inherent strictures of real employment.

Learning aim A – Explore safe working practices and suitable component selection in an aircraft workshop environment

Workshop safety procedures and housekeeping.

Safety procedures, or other relevant international equivalents, and action to be followed, including:

- Awareness of local workshop electrical safety hazards and actions.
    - Utilise the workshop environment that you have. Guide the learners through every one of the electrical tools in the workshop they will have to employ. Reinforce the point that they will use these tools, hence it is their safety under discussion.
    - Indicate the control measures used to eliminate or control risk.
    - To deliver first aid treatment you might utilise the first aid training staff that your institution doubtless has.
- Care and handling of low/high pressure gases, including compressed air lines, gas bottles, special precautions when handling oxygen and cryogenic substances. Control of hazardous substances, including handling and storage of hydraulic fluids, lubricants, fuels, paints, cleaning fluids and corrosive substances. Safety equipment to be used and procedures to followed when working at height.
    - All of the above should be considered as training for the use of the tools the learners will operate. Making reference to the relevant legislation, ensure that the learners understand that this is not simply an exercise in compliance but a necessary set of conditions for safe operation within the workshop. Stress the need to consider the safety of others as well as themselves.
- Compliance with workshop health and safety provision and procedures, including:
    - The care, application and use of fire-fighting equipment, positioning of fire points and fire drills. This will be dictated by the protocols of your institution and the equipment supplied. Ensure that you know the precise procedures before communicating these to the learners.
    - First aid facilities and equipment, local procedures, accident/incident recording. Draw attention to the first aid equipment and supplies. Indicate the information, shown prominently, on how and where to contact the first aider.

- Compliance with manual handling operations and personal protection regulations, including:
  - use of protective clothing
  - hand, eye and ear protection when handling sheet metal, cutting tools and corrosive substances, and using workshop machinery and tools
  - personal hygiene, and use of barrier creams
  - each of these points pertains to the learner's own PPE and how to use it appropriately. You may wish to acquire a manikin that can be placed prominently somewhere in the workshop. Dress this manikin in the PPE and accustom the learners to comparing themselves to the manikin prior to every activity.

Workshop information sources and standards.

- Awareness of and compliance with civil and military information sources or other relevant international equivalents. Awareness of and compliance with standards or other relevant international equivalents.
  - As mentioned previously, you should ensure that you have a complete library of all and any standards or certification documentation that will be pertinent to the learner activities. Indicate that you will be drawing their attention to each of these documents as the activities progress and that they should note which ones are being used and why. You should also at this point introduce the standard documentation from a relevant company that is used to direct and record activity and how these must be completed. Indicate that you will expect the learners to complete these documents following every activity.
  - If a logbook method is being used, show the learners where and how to record the information, including where and how to make reference to any compliance documents.

Tool management.

Tool control, care and use including:

- Tool control methods, including shadow boards, portable servicing kits, toolboxes, tool tags, electronic coded labelling, booking in/out systems. Missing tool and loss article actions.
  - If you have acquired standardised documents or electronic systems from a company, this would be the time to introduce them and indicate how they will be used. While it may seem somewhat ridiculous to use a booking system for tools which are doubtless contained within the workshop itself, the idea is to make such activity automatic, so that in employment the learner will have developed disciplined habits.
- User precautions, pre-use and safety checks for workshop tools.
  - Guidance on the preparation and safety checks for tool usage should be an inseparable part of the training in how to use the tools for fabrication. Thus, you should deliver this training concurrently with the tool use segments of the unit.

Hardware and consumable components.

- Recognition, care and use of hardware components.
  - As suggested in the delivery guidance, you may wish to deliver this portion through demonstration followed by activity by the learners. If you are planning on eliminating some of the components from the project build, you should still endeavour to acquire sample pieces so that the learners can be familiarised with these items and how they are fitted.

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- Identification and use of consumable components.
  - Ideally, every one of these components should be present on any project build. While it is possible that in employment they might never encounter items such as hydraulic lines, they will need to use all the fasteners listed in the specification. Careful design of the project build item will ensure that every fastener is needed.
- Consequences of non-compliance with information sources and standards, tool management and hardware and consumable components when carrying out mechanical and electrical inspection and fitting processes.
  - This portion might best be accomplished through an industrial visit or a lecture(s) from a guest expert such as a quality engineer. Linking compliance and quality control to the airworthiness of the aircraft is extremely important.

Learning aim B – Carry out processes to inspect and fit aircraft mechanical hardware safely that will help to ensure airworthiness

Preparation for mechanical hardware inspection and fitting processes.

- Consult information sources to determine aircraft mechanical hardware inspection and fitting processes, including standards. Identify and select all required consumables and hardware components for designated mechanical inspection and fitting activity, from information sources. Comply with laid-down processes, including tests and inspection checks, for designated mechanical fitting activity
  - Considering the skill development stipulated in topic B2, you may wish to swap the running order to pursue B2 first.
  - Irrespective of the manner in which you have decided to conduct the practical assessment, this requirement concerns the identification, planning, inspection and compliance of the activities. If a logbook approach has been adopted, ensure that the learners clearly understand the need to reference the relevant documentation and reference how this documentation will dictate activity. How did they inspect the work on completion? What quality measures did they use? etc.

Mechanical hardware inspection and fitting processes.

- Mechanical hardware component inspection and fitting processes.
  - This part is again directly assessed. The activities should be pursued and recorded in precisely the same manner as the other assessed activities. While the specification does not indicate any greater importance of this section than any other, you should anticipate that the training/learning involved in the sheet metal and fastener exercises will be more demanding and time consuming than those other portions. This is a direct result of the degree of skill required. Ensure that you plan for sufficient time to be available to spend on it.
- Quality control checks including:
  - Fitting activities in compliance with information source procedures, standards and limits. Visual and physical inspection checks, eg wear, serviceability, correct fitting and assembly, security of attachment, locking, freedom, sense and range of movement, tolerances, limits and fits. Mechanical inspection and fitting checks, including dimensional accuracy, tolerance, critical dimensions, joint quality, surface finish.
  - As with the sheet metal exercises, you should anticipate that this segment will require more time and attention to detail than the specification suggests. With regards to quality control checks, you may opt to involve a professional from an outside source as was suggested previously. How is quality measured and maintained in a real world industrial environment?

Learning aim C – Carry out processes to inspect and fit aircraft electrical hardware safely that will help to ensure airworthiness
Preparation for electrical hardware inspection and fitting processes. ● Consult information sources to determine aircraft electrical hardware inspection and fitting processes including standards. Identify and select all required consumables and hardware components for designated electrical inspection and fitting processes from information sources. Comply with laid-down processes, including tests and inspection checks, for designated electrical fitting processes. ○ Once again, as part of the assessment, stress the need to accurately and fully compile the logbook. Ensure that the learners reference the appropriate documentation. Electrical hardware inspection and fitting processes. ● Electrical hardware inspection and fitting processes. Quality control checks. ○ Follow the same process and plan as before. Demonstrate, practice, inspect, feed back, repeat as necessary, proceed to project build, document everything.
Learning aim D – Review mechanical and electrical workshop inspection and fitting processes and reflect on personal performance
Lessons learned from workshop inspection and fitting processes. The scope of the lessons learned should cover: ● Health and safety skills, to include familiarity and compliance with laid down health and safety procedures and hazard prevention actions when carrying out mechanical and electrical inspection and fitting processes. With the suggested logbook approach, there might be a section requiring the learners to reference the relevant H&S procedures prior to activity. This might also include a section for the recording of accidents or near misses. Perhaps the logbook should include a section for critical reflection. Were there any unanticipated hazards? What were they? How might these be controlled in future? ● Aircraft workshop mechanical and electrical inspection and fitting skills, eg to include interpreting information sources, tool care, control and use, selection of hardware and consumables components, good husbandry of the work area, sustainability, eg efficient use of hardware, energy usage and waste products. Once again, could the logbook contain sections for completion that prompt the learners to reflect on these aspects? What did you do? Why did you do it that way? What improvements could be made? ● General engineering skills, eg mathematics and interpreting drawings. Personal performance when carrying out workshop inspection and fitting processes. Understand relevant behaviours for working in an aircraft workshop, including: ● Taking initiative and responsibility for their actions when applying knowledge and practical skills to mechanical and electrical inspection and fitting processes. This is so that they are safe, efficient and independent, eg selecting and using appropriate tools and hardware components. This could be assessed simultaneously with criteria B and C. The learners have the brief. They know the outcome. Let them plan the activity. Let them select the tools and processes. Importantly, have them validate (argue) why they selected the approach they adopted. ● Communication and literacy skills to interpret and comply with workshop health and safety processes, to follow and implement instructions appropriately and to explain their intentions to others. Following on from the suggestions for the previous segment, you may wish to have the learners produce a presentation to be delivered

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in front of the rest of the learners. Allow them to question the candidate. 'Why are you planning on doing things that way?' - 'This is why I will be doing things in the way I explained'.

- Problem-solving issues as they occur, eg when correct tensioning of a control cable after installation results in the turn barrel being out of safe alignment.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 52: Airframe Construction and Repair*
- *Unit 53: Airframe Mechanical Systems*
- *Unit 54: Aircraft Electrical and Instrument Systems*
- *Unit 55: Aircraft First Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Reithmaier L and Sterkenburg R – *Standard Aircraft Handbook,* 7th Edition (McGraw-Hill, 2013) ISBN 978-0071826792.
  This handbook is a compendium of every possible airframe manufacturing process (excluding composites). It is separated logically into sections concerning tools, materials, operations (separated into mechanical, electrical, hydraulic etc), drawings and standard parts. This is an excellent resource for learners to refer to throughout workshop practice. It is written in simple clear English and avoids unnecessary theoretical background. The focus is simply on the activities.
- Kroes MJ, Nolan MS and Rardon JR – *Aircraft Basic Science, 8th Edition* (McGraw-Hill, 2013) ISBN 978-0071799171.
  This text contains excellent theoretical background to the devices and components to be used during the unit. It is pitched precisely at the aviation manufacturing and maintenance sector, and at level 3 learners. Note that this text will most likely be of fundamental use to learners in other units likely to be being pursued simultaneous to this unit.

Websites

- www.faa.gov/regulations_policies/handbooks_manuals/aircraft/
  Aircraft Handbooks & Manuals, Federal Aviation Administration (FAA). From this website you can download any number of best practice manuals pertaining to airframes and airframe systems. These are free to download and make an excellent supplementary resource for teaching and learning.

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Unit 50: Aircraft Gas Turbine Engines

Delivery guidance

Approaching the unit

This unit should give the learner an understanding of the scientific principles, operation and performance of aircraft gas turbine engines including their impact on the environment.

It would be most effective to deliver the unit learning aims in order. Delivery should cover the operation and construction of Turbojet, Turbofan, Turboprop and Turboshaft engines. Depending on available resources, you may not be able to cover the full range of engine types through practical activities. However, you will need to give opportunities for the learners to identify the components/construction of an actual engine where possible. Visits to manufacturers could help to achieve this.

You can use a range of delivery methods for this unit, such as:

- individual or group presentations covering the operation and performance of selected aircraft gas turbine engine types
- industrial visits to an engine manufacturer or maintenance organisation to examine an actual turbine engine installation and identify the systems/components discussed in class
- case studies of different engines and systems
- practical demonstrations and, if a small gas turbine test rig is available, exercises such as oil temperature and pressure monitoring or the use of engine controls
- videos
- if learners are in relevant employment, they should be encouraged to use the resources available to them at their workplace
- use of simulators for the investigation of engine operation and performance.

Where group work is allowed you must ensure that each learner produces their own evidence and that it is sufficient for assessment when at this stage.

Before any visits or practical activities are planned, you should ensure that the learners are aware of the health and safety issues and precautions to be taken with aircraft fuels and pressurised fuel systems.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A you should introduce the topic by giving a brief history of aircraft power plant development from piston engines to gas turbines. You should then introduce the scientific principles underlying the operation of a gas turbine engine. The gas laws and thermodynamic processes should be explained and developed into thermodynamic cycles leading to investigation of the theoretical and actual Brayton cycles. In the course of this investigation you should explain the use of pressure/volume (PV) and temperature/volume (TV) diagrams. The learners should then be required to research the Brayton cycle and investigate the features of a practical working cycle (the animations available on www.thermofluids.net could be used to aid this).

Further input will be required to introduce Newton's laws and develop the concept of thrust and the thrust equation. The learners should be required to solve a range of problems involving engine thrust calculations.

You should then introduce the four types of gas turbine engine (Turbojet, Turbofan, Turboprop and Turboshaft). The learners should be required to investigate each engine design and produce a presentation describing the components, construction and applications of each type. They should then make comparisons between designs, highlighting advantages and disadvantages of each.

For learning aim B you should introduce the topic by giving an overview of gas turbine engine components including compressors and fans, combustors, turbines, intakes and exhausts. The learners should be required to research and develop a report describing the function and operation of each component in more detail. This could be supported by an industrial visit to an engine manufacturer or maintenance organisation.

Further input will be required to introduce starter and fluid systems to ensure coverage of the unit content. The topic of fluid systems should include fuel, oil and air systems. Fluid systems are also covered in more depth in *Unit 51: Aircraft Propulsion Systems*, and if this unit is being delivered, there is the opportunity to consolidate delivery of this area of content for both units. You should try to ensure that theoretical concepts are reinforced by exposure to actual engine components and availability of a range of these would enhance delivery.

For learning aim C you should give input on measures of engine performance and the effect of gas turbine cycle parameters on performance. The learners should then be required to complete a practical activity using an engine simulator to investigate the factors affecting engine performance and efficiency leading to an investigation of the impact of efficiency on fuel consumption. Further input will be required to introduce thrust enhancement methods.

Finally, you should introduce the environmental impact of the operation of gas turbine engines in terms of noise and emissions. The learners should be required to work in groups to research noise measurement, noise sources and reduction and produce a presentation of their findings. You will need to give further input to cover the process of combustion in basic terms to ensure that the learners are aware of the products of combustion related to the operation of aircraft gas turbine engines.

Learning aim	**Key content areas**	**Recommended assessment approach**
A Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust	**A1** Scientific principles relating to gas turbine engines **A2** Types and operation of aircraft gas turbine engines	A report covering the scientific principles, function and operation of two engine types selected from turbojet, turbofan, turboshaft and turboprop gas turbine engines.
B Examine the function and operation of gas turbine engine components and systems that produce thrust	**B1** Function and operation of turbine engine components **B2** Function and operation of engine starter and fluid systems	A report covering the function and operation of aircraft gas turbine engine components, and starting and fluid systems.
C Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion	**C1** Aircraft gas turbine engine performance **C2** Environmental impact of gas turbine engines	A report covering the factors that affect the performance of aircraft gas turbine engines and the nature of, and measures being taken to help reduce, the adverse effects of gas turbine engine pollutants.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover at least one entire learning aim. There are three suggested assignments for this unit, each covering one of the learning aims. All learners must independently generate individual evidence that can be fully authenticated.

For learning aim A evidence is likely to be in the form of a written report incorporating detailed research into the thermodynamic cycle on which the operation of an aircraft gas turbine engine is based. The report should include an explanation of each process involved in the Brayton cycle and should be supported by calculations using the appropriate gas laws, Newton's laws and the thrust equation. The report will further explain and analyse the function and operation of two types of gas turbine engine detailing how each component affects the properties of the working fluid on its passage through the engine. The text should be supported by relevant drawings, schematics and photographs. The report will include a fully referenced bibliography.

For learning aim B evidence is likely to be in the form of a written report incorporating detailed research covering the function and operation of gas turbine engine components including compressors, combustors, turbine, intakes and exhausts. Further evidence will include an explanation of engine starter systems and fluid systems including fuel, oil and air systems. The text should be supported by relevant drawings, schematics and photographs. The report will include a fully referenced bibliography.

For learning aim C evidence is likely to be in the form of a written report incorporating an explanation of the factors affecting engine performance in terms of thrust and fuel consumption with example calculations. Further research will explain thrust enhancements methods. The report will consider the environmental impact of the operation of aircraft gas turbine engines with respect to noise and emissions. Further analysis will review the methods used to limit these effects.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 50: Aircraft Gas Turbine Engines

Introduction

Introduce the unit to the learners through a group discussion explaining various aircraft roles and the type of engine installed, eg turbojet, turbofan, turboprop and turboshaft. Discuss the unit content, learning aims and assessment methods to be used. Where learners are in relevant employment they should be encouraged to make use of the resources available at their place of work when performing the activities suggested below.

Learning aim A – Examine the scientific principles and operation of aircraft gas turbine engines that produce thrust

- Introduce this learning aim by discussing the gas laws and develop this further to examine thermodynamic processes. The Brayton cycle should then be examined covering both the theoretical and actual cycles and the differences between them. Newton's laws should then be explained and linked to the thrust equation. You should emphasise the calculation of mass and volumetric flow rates.
- You should reinforce the theoretical concepts discussed above with calculations and exercises to verify the concepts. This could be in the form of group or individual work. Ensure that the learners appreciate the importance of the use of correct units in any calculations and tests for reasonableness of answers.
- As a further activity, you could ask the learners to work in small groups to investigate the factors affecting engine performance by running simple simulations using 'EngineSim' (from NASA) or any available simulation software.
- Ask learners to work in groups to research the features of the four basic aircraft gas turbine engines - turbojet, turbofan, turboprop and turboshaft. The groups are then to deliver their presentations, which will be followed by a group Q & A session to develop/reinforce any points raised by the presentations.
- Give further input to reinforce the research from the previous activity and fill in any missing areas of function or operation of gas turbine engines.
- It would be engaging for the learners at this point if you were to arrange either an industrial visit to an aircraft manufacturer or maintenance organisation or a guest speaker from one of these organisations to talk about the features and design of gas turbine engines.
- You should then assign a final activity where the learners are required to perform a simple engine design exercise perhaps using the features of the TEST website. The aim of the activity should be to appreciate the factors involved in the generation of thrust and torque.

Learning aim B – Examine the function and operation of gas turbine engine components and systems that produce thrust

- Introduce this learning aim by discussing the basic components of an aircraft gas turbine engine, eg intake, compressor, combustor, turbine, exhaust. This website, http://html.investis.com/R/Rolls-Royce/corp/interactive-games/journey03/ can be used to support this presentation.
- Ask the learners to work in small groups to research each of the basic components of a gas turbine engine and produce a presentation to explain its features, function

and operation. You may need to give further input to ensure the learners have covered all of the unit content.

- Introduce engine starter systems and fluid systems (air, fuel and oil).
- Ask the learners to work in small groups to investigate engine starter systems and produce a detailed presentation of the function and operation of each system. The Boeing 767 videos listed in the resources section could be used to illustrate some of these features. Access to starter system components and location on a gas turbine engine should be used to link theory with practice.
- Ask the learners to work in small groups to investigate engine air systems and produce a detailed presentation of the function and operation of each system. The Boeing 767 videos listed in the resources section could be used to illustrate some of these features. Access to air system components and location on a gas turbine engine should be used to link theory with practice.
- Ask the learners to work in small groups to investigate engine fuel systems and produce a detailed presentation of the function and operation of each system. The Boeing 767 videos listed in the resources section could be used to illustrate some of these features. Access to engine fuel system components and where possible airframe fuel systems should be used to link theory with practice and encourage learners to identify each component.
- Ask the learners to work in small groups to investigate engine oil systems and produce a detailed presentation of the function and operation of each system. The Boeing 767 videos listed in the resources section could be used to illustrate some of these features. Access to oil system components and location on a gas turbine engine should be used to link theory with practice.

Learning aim C – Investigate the factors affecting the performance and environmental impact of aircraft using gas turbine propulsion

- Introduce this learning aim by providing an overview of measures of engine performance and reviewing the environmental impact of gas turbine operation.
- Give input to define measures of performance, the impact of gas turbine parameters and the effects of thermal efficiency. Ask the learners to work in small groups to solve problems related to performance and efficiency stressing the importance of the correct use of units.
- As a further activity, ask the learners to work in small groups to research methods of thrust enhancement and produce a presentation explaining their findings. Reinforce the results of the research with a question and answer session.
- Hold a class discussion to review possible environmental effects of gas turbine operation ensuring that noise and emissions are covered. Support the discussion with input defining the decibel rating and giving a basic overview of the combustion process.
- Ask the learners to work in groups to research sources of aircraft noise and methods used to reduce this. The groups should then report back to the class.
- Ask the learners to work in small groups to research gas turbine engine emissions and the methods used to reduce them. The groups should report back to the class and discuss their findings in a question and answer session.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 29: Principles and Applications of Fluid Mechanics*
- *Unit 48: Aircraft Flight Principles and Practice*
- *Unit 51: Aircraft Propulsion Systems*
- *Unit 55: Aircraft First Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Gunston B – *The Development of Jet and Turbine Aero Engines, 4th Edition* (Patrick Stephens Ltd, 2006) ISBN 978-1852606183.
  This book gives a comprehensive overview of the development and types of gas turbine aero engines.
- Jeppesen and Atlantic Flight Training **–** *Powerplant JAA ATPL Training, 2nd Edition* (Jeppesen and Atlantic Flight Training, 2007) ISBN 978-0884874928.
  Contains several chapters on gas turbine engines and systems with useful diagrams.
- Jeppesen and Atlantic Flight Training **–** *Airframes & Systems JAA ATPL Training* (Jeppesen and Atlantic Flight Training, 2007) ISBN 978-0884874546.
  Contains useful chapters on aircraft fuel systems, ice protection and fire protection systems with good diagrams.
- Rolls Royce – *The Jet Engine, 5th Edition* (Wiley-Blackwell, 2015) ISBN 978-1119065999.
  Contains a readable account of all the major engine systems and gives coverage of the content for a large part this unit.
- FAA, 2012 – *Aviation Maintenance Technician Handbook – Airframe, Volumes 1 and 2, FAA* [Online]. Available at: www.faa.gov/regulations_policies/handbooks_manuals
  These handbooks have detailed chapters on airframes including aircraft fuel systems with excellent illustrations.
- FAA, 2012 – *Aviation Maintenance Technician Handbook – Powerplant, Volumes 1 and 2, FAA* [Online]. Available at: www.faa.gov/regulations_policies/handbooks_manuals/aircraft
  These handbooks have detailed chapters on power plants with excellent illustrations.

Websites

- www.animatedengines.com/jets.html
  This website has simple animations of the main types of gas turbine engine.
- www.grc.nasa.gov/www/K-12/airplane/ngnsim.html
  This website which is maintained by NASA has an engine simulator that may be used to investigate gas turbine engine performance. The simulator uses Java and may need some IT input to install.
- www.grc.nasa.gov/WWW/K-12/airplane/shortp.html
  This is the Propulsion Index page of the NASA education website that contains many useful aeronautical resources.
- www.thermofluids.net
  Known as TEST (The Expert System for Thermodynamics), this is an excellent site containing many useful animations/problems of varying complexity related to gas turbine engines.
- http://html.investis.com/R/Rolls-Royce/corp/interactive-games/journey03/
  This site offers a good overview of the construction of aircraft gas turbine engines.

Unit 51: Aircraft Propulsion Systems

Delivery guidance

Approaching the unit

This unit should provide learners with an understanding of the construction and operation of the aircraft propulsion systems that support the operation of the aircraft power plant.

It would be most effective to deliver the unit learning aims in order. Where possible, you should provide a comparison between different types of gas turbine engine and their systems.

You will need to provide activities for the learners to identify the components of the various systems on an actual engine, where possible. Visits to manufacturers could provide opportunities to achieve this.

You can use a range of delivery methods for this unit, such as:

- individual or group presentations covering the function and operation of specific aircraft propulsion systems
- industrial visits to an engine manufacturer or maintenance organisation to examine an actual turbine engine installation and identify the systems/components discussed in class
- case studies of different engines and systems
- practical demonstrations and, if a small gas turbine test rig is available, exercises such as oil temperature and pressure monitoring or the use of engine controls
- videos.

Where group work is allowed, you must ensure that each learner produces their own evidence and that it is sufficient for assessment.

Before any visits or practical activities are planned you should ensure that the learners are aware of the health and safety issues and precautions to be taken with aircraft fuels and pressurised fuel systems.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Delivery of this unit will benefit from links to the aviation industry, ideally local to your centre. You could contact the Training, Human Resources or Marketing Departments of aircraft manufacturers, aircraft maintenance organisations or engine system manufacturers to investigate whether they would be able to provide a guest speaker or contribute to a technical workshop on a topic relevant to this unit (the topic chosen will depend on the availability of appropriately qualified staff within the organisation). You could engage them further by inviting them to contribute ideas for activities that could be used in the assessment and delivery of the unit.

For learning aim A, you should introduce the topic by giving a brief history of aircraft power plant development. This will lead into the different fuels used by aircraft power plants and the properties and characteristics of aircraft engine fuels. Learners should then research the identification and marking systems used for each fuel type.

You could then introduce types of gas turbine engine and how engine power is controlled (by fuel supply). The aircraft fuel system could then be examined from the storage system (e.g. tanks, pumps, transfer and jettison), to the engine fuel system and finally the engine control system. Videos, case studies or a guest speaker could be used to reinforce the features of aircraft fuel systems and the safety aspects of their design (e.g. analysis of the accident report conclusions for TWA Flight 800 (a Boeing 747-131) which crashed due to a fuel tank explosion in 1996). Learners could then be required to research the fuel system for a given aircraft type and produce a presentation detailing the system design, function and components. The group could then compare and discuss any differences between the selected systems.

Further input will then be required to introduce engine control systems starting with mechanical systems and components, advancing to more automatic electrical and electronic systems/components and leading to an overview of the functions of a Full Authority Digital Electronic Control (FADEC) system.

For learning aim B, you should introduce the topic by giving an overview of engine lubrication and internal air systems. The learners should then be required to research the function of engine oil systems, types of lubricant and types and properties of additives used in engine lubrication systems. This activity could be in the form of an employer-led technical workshop. The learners could then produce a presentation of their results. A group discussion could then be used to ensure coverage of the unit content.

Further input will be required to introduce the basic components of an engine lubrication system and the learners could then be required to review a lubrication system schematic to identify the components used and the function performed by each one. Learners will need to develop the ability to use and interpret schematic diagrams for a wide range of aircraft systems.

You should then introduce engine internal air systems and ensure that the main functions of this system are identified (i.e. cooling, sealing and bearing load control). Cutaway drawings of engine components could be used to identify applications of internal air which could be reinforced by examination of an actual gas turbine engine, where possible.

For learning aim C, you should provide input giving an overview of fire protection systems, introducing the main components used for fire detection. The learners should then research the system for a specific aircraft/engine combination and produce a report identifying the detection zones, function and operation of detectors used for both fire and smoke and the indications available to the crew.

A further activity could then identify the classes of fire and types of extinguishing agents used, with a description of the systems installed on the given aircraft, including the function and operation of the system components.

Finally, you should provide an overview of ice formation mechanisms and ice protection systems. The learners should then research engine anti-icing and de-icing systems, identifying the function and operation of components/systems used.

Learning aim	Key content areas	Recommended assessment approach
A Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation	**A1** Aircraft fuels and fuel supply systems **A2** Engine fuel systems **A3** Engine electromechanical and electronic control systems	A report covering the properties of aircraft fuels, the function and operation of aircraft fuel supply systems, engine fuel and control systems and their components, and their contribution to power plant operation.
B Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation	**B1** Engine lubrication systems **B2** Engine internal air systems	A report covering the nature of aircraft engine lubricants, the function and operation of engine lubrication, internal air systems and their components, and their contribution to power plant operation.
C Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation	**C1** Fire protection systems and components **C2** Ice protection systems	A report covering the function and operation of aircraft fire and ice protection systems and their components, and their contribution to safe aircraft power plant operation.

Assessment guidance

This unit is internally assessed through a number of independent activities. Each activity should cover at least one entire learning aim. There are three suggested assignments for this unit, each covering one of the learning aims. All learners must independently generate individual evidence that can be fully authenticated.

For learning aim A, evidence is likely to be in the form of a written report incorporating detailed research covering fuels and additives, airframe and engine fuel systems and finally engine control systems, both electromechanical and digital (FADEC). The text should be supported by relevant drawings, schematics and photographs. The report should include a fully referenced bibliography.

For learning aim B, evidence is likely to be in the form of a written report incorporating detailed research covering the types and properties of lubricating oils, explanation of the function and operation of an engine lubrication system and its components, and an explanation of the function and operation of an engine's internal air system. The text should be supported by relevant drawings, schematics and photographs. The report should include a fully referenced bibliography.

For learning aim C, evidence is likely to be in the form of a written report incorporating detailed research covering fire and ice protection systems. The text should be supported by relevant drawings, schematics and photographs. The report should include a fully referenced bibliography.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 51: Aircraft Propulsion Systems

Introduction

You could introduce the unit to the learners through a group discussion explaining various aircraft roles and the type of engine installed. Discuss the unit content, learning aims and assessment methods.

Learning aim A – Examine the function and operation of aircraft fuel and engine control systems that support safe aircraft power plant operation

- You could introduce this learning aim by discussing the requirements of a gas turbine engine fuel and fuel system, the types and properties of fuels used for gas turbine engines and the management of fuel flow to control engine power or thrust.
- Explain the effects air temperature and aircraft speed on required fuel flow rate. Reinforce this by an activity using an engine simulator such as 'EngineSim' available from the NASA website. This activity should be used to demonstrate the effects of air temperature and aircraft speed on fuel flow.
- As a further activity, you could ask the learners to work in small groups to identify the types of fuel and additives used, their properties and reasons for use. The learners should also determine the identification codes and equipment colour markings for gas turbine engines.
- Provide learners with an overview of the aircraft and engine fuel systems ensuring that they are able to identify the components and methods listed in topic A1. Briefly describe automatic fuel control systems including pressure control, flow control, acceleration and speed control and pressure ratio control.
- You could ask learners to work in small groups to research the features of the airframe and engine fuel system for a given aircraft to identify the function and operation of the system components. The groups could then deliver their presentations, which could be followed by a group Q & A session to develop/reinforce any points raised by the presentations.
- Provide input to discuss fuel spray nozzles, which are the final components in the fuel supply chain.
- Further input will be required to introduce engine control systems and the link with fuel systems.
- Finally, you could ask the learners to work in groups to research an engine mechanical control system and identify the function, operation and layout of its components. The learners should then research electronic control systems and report on the components used, describing their function and operation. The last activity should be to describe the function and operation of the components of a FADEC control system.

Learning aim B – Examine the function and operation of aircraft engine lubrication and air systems that support safe aircraft power plant operation

- You could introduce this learning aim by discussing the requirements of a gas turbine engine lubrication system including the types and properties of oils used for gas turbine engines. Discuss the two basic re-circulatory systems (i.e..pressure relief valve and full flow). Comment on the use on some engines of a total loss system.

- Ask the learners to work in small groups to identify the types of oil and additives used, their properties and reasons for use. The learners should also identify and describe the identification codes and grading systems used for turbine engine lubricating oils.
- As a further activity, you could ask the learners to work in small groups to research the features of the engine lubrication system for a given aircraft to identify the function and operation of the system components. The groups should then deliver their presentations, which will be followed by a group Q & A session to develop/reinforce any points raised by the presentations.
- Further input will be required to introduce the engine internal air system and its function in cooling, sealing and controlling bearing loads.
- You could ask the learners to work in small groups to research the cooling, sealing and control of bearing loads provided by the internal air system and produce a presentation of their findings.

Learning aim C – Examine the function and operation of aircraft fire and ice protection systems that support safe aircraft power plant operation

- You could introduce this learning aim by providing an overview of fire protection systems. The animation of the Boeing 767 fire protection system could support this (see resources).
- Ask the learners to work in small groups to research fire detection, containment and extinguishing systems and identify the components used and the function and operation of each system. The learners should then identify each system on an actual gas turbine engine.
- Further input will be required to describe the requirement for, and implementation of, ice protection systems. The animation of the Boeing 767 ice protection systems could support this (see resources).
- You could ask the learners to work in small groups to research ice protection systems, including detection methods, prevention and removal systems, and identify them on an actual gas turbine engine.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 50: Aircraft Gas turbine Engines*
- *Unit 53: Airframe Mechanical Systems*
- *Unit 54: Aircraft Electrical and Instrument Systems*
- *Unit 55: Aircraft First Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Gunston B – *The Development of Jet and Turbine Aero Engines 4th Edition* (Patrick Stephens Ltd, 2013) ISBN 97818522606183.
  This book provides a comprehensive overview of the development and types of gas turbine aero engines and includes a chapter on engine systems.
- Jeppesen and Atlantic Flight Training **–** *Powerplant JAA ATPL Training, 2nd Edition* (Jeppesen and Atlantic Flight Training, 2007) ISBN 9780884874928.
  This book contains several chapters on gas turbine engines and systems along with useful diagrams.
- Jeppesen and Atlantic Flight Training **–** *Airframes & Systems JAA ATPL Training***,** *2nd Edition* (Jeppesen and Atlantic Flight Training**,** 2007) ISBN 9780884874546.
  This book contains useful chapters on aircraft fuel systems, ice protection and fire protection systems along with good diagrams.
- Rolls Royce – *The Jet Engine, 5th Edition* (Wiley-Blackwell, 2015) ISBN 9781119065999.
  This book contains a readable account of all the major engine systems and provides coverage of the content for a large part this unit.
- FAA – *Aviation Maintenance Technician Handbook – Airframe, Volumes 1 and 2* (FAA [Online]).
  Available at: www.faa.gov/regulations_policies/handbooks_manuals/ (Accessed: 20 September 2015).
  These handbooks provide detailed chapters on airframes, including aircraft fuel systems, along with excellent illustrations.
- FAA – *Aviation Maintenance Technician Handbook – Powerplant, Volumes 1 and 2* (FAA [Online]).
  Available at: www.faa.gov/regulations_policies/handbooks_manuals/ (Accessed: 20 September 2015).
  These handbooks provide detailed chapters on power plants with excellent illustrations.

Videos

- www.youtube.com/watch?v=Sy-UtJG3uLU
  Turkish airlines aircraft engine fire.
- www.youtube.com/watch?v=2McBHnblSI4
  Provides an animated overview of the Boeing 767 fire protection system.
- www.youtube.com/watch?v=zQHxgq02CFY
  Provides an animated overview of the Boeing 767 ice protection system.
- www.youtube.com/watch?v=6l3F8G6syc0
  Emirates B777 engine fire on landing.

Websites

- www.animatedengines.com/jets.htm
  This website provides simple animations of the main types of gas turbine engine.
- www.grc.nasa.gov/www/K-12/airplane/ngnsim.htm
  This website, maintained by NASA, provides an engine simulator which may be used to investigate gas turbine engine performance. The simulator uses Java and may need some IT input to install.
- www.grc.nasa.gov/WWW/K-12/airplane/shortp.htm
  This is the Propulsion Index page of the NASA education website, which contains many useful aeronautical resources.

Unit 52: Airframe Construction and Repair

Delivery guidance

Approaching the unit

This unit should provide the learner with an understanding of the structural components that are used to build an airframe.

It would be most effective to deliver the unit learning aims in order. You will need to provide opportunities for the learners to examine how an airframe is constructed, perhaps starting with the major components (eg fuselage, wings and empennage). Further inspection of these components will reveal the detailed construction methods used.

You can use a range of delivery methods for this unit, such as:

- individual or group presentations on airframe construction, repair and the use of composite structures
- visits to engine manufacturers or maintenance organisations to examine actual airframes and identify the components discussed in class
- case studies covering the design and construction of current passenger aircraft eg Boeing 787, Airbus A340
- practical activities (learning aim C)
- videos.

Where group work is allowed, you must ensure that each learner produces their own evidence that is sufficient for assessment.

The main focus of the unit is the use and repair of composite structures in modern airframes. It will therefore be necessary to have a range of composite components available for inspection and the raw materials necessary for the repair of a composite structure.

A demonstration of the strength of composite structures could be used to inspire the learners with what can be achieved by careful design. A simple version of a honeycomb panel using paper and cardboard could be used to this end.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Delivery of this unit will benefit from links to the aviation industry, ideally local to your centre. You could contact the Training, Human Resources or Marketing Departments of aircraft manufacturers or aircraft maintenance organisations to investigate whether they would be able to provide a guest speaker or contribute to a technical workshop on a topic relevant to this unit (the topic chosen will depend on the availability of appropriately qualified staff within the organisation). You could engage them further by inviting them to contribute ideas for activities that could be used in the assessment and delivery of the unit.

Many smaller aircraft used in general aviation make use of composite materials so a local small airport would be a good place to start.

For learning aim A, you should introduce the topic by giving a brief history of aircraft design and development with an emphasis on materials used, leading to the current generation of passenger aircraft and the increasing use of composite materials, with a discussion of why composites are being increasingly used A guest speaker could be invited to provide insight into the use of composite materials in aircraft manufacture.

Each major airframe structure could then be examined (tutor led) and the learners required to research and report on the construction methods used for each. You will need to ensure that the learners are aware of the different assembly methods (eg riveting, bolting and bonding).

You will need to define airworthiness and introduce methods of identifying locations within the airframe. Access to an aircraft structural repair manual will be useful in explaining structural classifications. You should then require the learners to research zonal and station identification systems for a range of aircraft and ensure that they understand the need for them.

Further input will be required to introduce design concepts, corrosion protection and alignment checks. The learners should then be required to research and report on these areas individually or in groups. Reports could be in the form of a presentation to the group.

For learning aim B you should start delivery with health and safety and the safe working practices to be used when repairing airframe components. You should provide input covering adhesives, sealants and bonding methods which could be reinforced by a demonstration of their use (which can also be used to consolidate safe working practices). Defect types and inspection methods should be covered by practical activities after you have provided initial input.

You should then introduce repair procedures and provide opportunities for the learners to attempt a range of repairs (ensuring that they use safe working practices). This could be achieved by an employer-led technical workshop.

For learning aim C, you should provide a damaged airframe component and access to a range of information sources to enable the learner to plan the repair using approved procedures. You should require that the learner provide evidence for each of the three stages (planning, repair and inspection) of this learning aim with each stage needing to be ‘signed off’ before the learner is allowed to move on to the next. The component/repair should be challenging enough to engage all learners but achievable within the resources available to the centre.

Learning aim	Key content areas	Recommended assessment approach
A Examine the construction and protection methods used to ensure airworthiness of airframe structures	**A1** Construction and assembly of major airframe structures **A2** Structural considerations for airworthiness	A report covering the construction and assembly methods of major airframe structures, such as the fuselage and wings. Also, the structural concepts and corrosion protection methods to ensure airworthiness.
B Examine how inspection and repair methods are used in the maintenance of composite airframes and components	**B1** Adhesives and sealants **B2** Bonding methods **B3** Defect types and inspection **B4** Repair procedures **B5** Safe working practices when repairing airframe composites	A report covering the inspection and repair procedures used for the maintenance of aircraft composite structures and components.
C Carry out processes to inspect and repair safely an airframe composite structure or component that will help to ensure airworthiness	**C1** Inspection of airframe damage **C2** Structural repair manual **C3** Preparation procedures for the repair of airframe composite structures **C4** Airframe composite structure inspection and repair processes	A practical workshop task to safely undertake the inspection and repair of damage to a composite airframe structure. Evidence will include: finished repair, observation records/witness statements, annotated photographs and drawings and completed record of quality control measures needed to complete the repair process.

Assessment guidance

This unit is internally assessed through a number of independent tasks. Each task should cover at least one entire learning aim. There are three suggested assignments for this unit, each covering one of the learning aims. All learners must independently generate individual evidence that can be authenticated.

For learning aims A and B, evidence is likely to be in the form of written reports incorporating detailed research supported by a fully referenced bibliography.

For learning aim C, evidence will most likely be in the form of planning sheets and inspection records, observation records/witness statements (which must be supported by learner generated evidence in the form of annotated photographs, learner statements or logbook) and the completed repair to the given component. Learners must produce evidence that they have used the approved sources of information (eg SRM, MSDS or authorised repair drawings) in order to identify the required repair method, procedures, materials and safety precautions. It is important to make the learners aware of the legal responsibilities that aircraft engineers have with regard to any actions involving airworthiness. Repairs have to be carefully planned and follow authorised procedures in order to maintain aircraft safety. An example of the consequences of not following procedures could be given by discussing the crash of Japan Airlines Flight 123 (a Boeing 747 SR-100) in 1985, which resulted from an incorrect repair to the rear pressure bulkhead.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 52: Airframe Construction and Repair

Introduction

Introduce the unit to the learners through a group discussion explaining various aircraft roles and designs (eg passenger, freight, military, twin engine, four engine, increasing size). Highlight the trade-off between strength/weight of airframe and payload leading to the more widespread use of composite structures. Discuss the unit content, learning aims and assessment methods.

Learning aim A – Examine the construction and protection methods used to ensure airworthiness of airframe structures

- Provide learners with an overview of the construction and assembly of airframes, ensuring that they are able to identify the components and methods listed in topic A1.
- Ask learners to work in small groups to research the features of a different major airframe structure for each group and produce a presentation covering construction features, materials used, protection methods employed, etc. The groups should then deliver their presentations, which could be followed by a group Q & A session to develop/reinforce any points raised by the presentations.
- As a further activity, you could ask the learners to work in small groups to identify the structural classification of a range of airframe components using the relevant SRM. Using the appropriate zonal and station identification system they should identify the location of the given components.
- Additionally, you could ask the learners to investigate protection methods and design concepts used to ensure airworthiness and produce a report summarising their findings.
- Finally, you could ask the learners to work in groups to identify and describe the symmetry and alignment checks that would need to be performed following a heavy landing. They should summarise their findings in a presentation to the class.

Learning aim B – Examine how inspection and repair methods are used in the maintenance of composite airframes and components

- Provide learners with an overview of adhesives, sealants and bonding methods used in the repair of composite airframe components. Ensure that the learners understand the hazards associated with the various materials and the safety precautions and procedures to be used when handling them. It is important that the learners consult Material Safety Data Sheets.
- As a group, you could discuss the causes of typical defects and the inspection and repair methods used to restore airworthiness. Where possible, reinforce the discussion with a demonstration of various inspection and repair methods.
- As a further task, you should provide a series of practical activities that allow the learners to develop the skills required to perform a composite repair. This will be achieved by the learners performing a range of simple repairs, which should be conducted in three stages: inspection, preparation and repair. Before starting, ensure that all learners are familiar with the necessary safety precautions and procedures.

Learning aim C – Carry out processes to inspect and repair safely an airframe composite structure or components that will help to ensure airworthiness
• The delivery of the unit content should be carried out in the following three stages. • Inspection. Ask the learners to work individually or in groups depending on the availability of resources (but, during assessment, if groups are used ensure that the task will allow each learner to generate sufficient individual evidence to address the assessment criteria). The learners should inspect and classify the damage to given airframe components and produce a repair report. • Preparation. Direct the learners to consult the relevant information sources (eg SRM, approved repair drawings), and prepare a repair plan which includes consumables and hardware required, processes to be used and inspection checks to be made on completion. This document must be 'signed off' before the learner is allowed to progress to the next step. • Repair. You should then observe the learners performing the repair in order to generate an observation record, which can be used to provide formative feedback during the unit delivery (another can be used as part of the learner assessment evidence for this activity). Ask the learners to produce annotated photographs of their activities, with a written commentary of the process, and, finally, an inspection report to accompany the repaired component.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 2: Delivery of Engineering Processes Safely as a Team*
- *Unit 3: Engineering Product Design and Manufacture*
- *Unit 26: Mechanical Behaviour of Non-Metallic Materials*
- *Unit 47: Composites Manufacture and Repair Processes*
- *Unit 48: Aircraft Flight Principles and Practice*
- *Unit 49: Aircraft Workshop Methods and Practice*
- *Unit 55: Aircraft First Line Maintenance Operations*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- FAA, 2012 – *Aviation Maintenance Technician Handbook – Airframe, Volumes 1 and 2* (FAA [Online]). Available at: www.faa.gov/regulations_policies/handbooks_manuals (Accessed: 20 September 2015).
  These handbooks provide detailed chapters on airframes along with excellent illustrations. Volume 1, chapter 7 discusses advanced composite materials.
- CAA, 2013, CAP 562 – *Civil Aircraft Airworthiness Information and* Procedures (CAA [Online]). Available at: www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=list&type=subcat&id=5 (Accessed: 20 September 2015).
  Part 6 of this document contains many useful information sheets.
- Jeppesen and Atlantic Flight Training**–** *Airframes & Systems JAA ATPL Training, 2nd Edition* (Jeppesen and Atlantic Flight Training, 2007) ISBN 9780884874546.
  This book contains very useful information on aircraft structures and systems.

Journals

- Lewis A, 2014 – Making Composite Repairs to the 787, *Aero, Qtr 4* [Online]. Available at

www.boeing.com/commercial/aeromagazine/articles/2014_q4/pdf/AERO_2014q4.pdf (Accessed 2 September 2015).
This issue contains an article on Boeing 787 composite repairs.

Videos

- www.youtube.com/watch?v=J4DOwjfepBM
  A short video of the JAL 123 air crash.

Websites

- www.airbus.com/innovation/proven-concepts/in-manufacturing/
  This website contains information about the use of composite materials by Airbus Industries.

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Unit 53: Airframe Mechanical Systems

Delivery guidance

This unit is designed to introduce learners to the function, operation and maintenance of key systems typically found on modern aircraft. You should assume that from prior learning, or from current learning in other units associated with the course being delivered, that your learners understand the overall function of an aircraft. If from other units the learners have developed an understanding of how, aerodynamically, the elevator controls pitch manoeuvres, then this unit will instruct them on **how** those elevator motions are executed. Ideally, you should coordinate your delivery closely with the tutors of the other units to produce congruency. To return to the control surface analogy, when the learners are covering those portions concerning control surfaces in *Unit 48: Aircraft Flight Principles and Practice*, you should deliver the portions of this unit that discuss the operation of the devices.

Given the need to examine and understand the function and operation of the devices and systems concerned, it would be advisable to acquire as many example devices for display or demonstration as you possibly can. Schematics and cutaway drawings have limited impact as learning aids. The opportunity to handle, dismantle and operate real devices will ensure superior retention through active and experiential learning. Moreover, if this unit is being delivered as part of a training programme or apprenticeship concerning aircraft maintenance, the manipulation of these devices will constitute development of direct employment skills and experience.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Approaching the unit

You should begin by developing the learners' broad understanding of the range and complexity of aircraft systems. You might begin with a categorised view of aircraft systems, including manoeuvre control, landing systems, environmental control, fuel systems etc. This approach is supported by the layout of the unit specification. You may, however, wish to adopt a different strategy. Begin by developing knowledge of the operation of mechanisms according to type, for example hydraulics, mechanical linkages, pneumatics etc. Then proceed to the systems and devices that utilise these methods.

All of the systems and their devices detailed in the specification are not simply designed for functionality. They are also subject to the strictures and demands of certification requirements. While the specification does not call for any learning regarding this topic, the impact on the design and operation of aircraft systems as a function of certification is of primary importance. This is also true in the maintenance of airworthiness. You should link the requirements to the devices wherever possible. Safe and continuous operation is a key parameter.

Ideally, you will have access to an aircraft which features all the specified devices and can be stripped, inspected and re-assembled over the course of the unit. Each learning aim might begin with a broad treatment of the system in question, the types of devices commonly in use, the manner of their operation, and the mode of inspection. This could then be followed by direct treatment of the example aircraft, stressing that device type differs for other aircraft even if the function remains the same. When manipulating the device on the aircraft you should refer the learners to the maintenance manual for that aircraft and the FAA (EASA) requirements. In addition to contextualising the activities, this exercise will habitualise the learners to common industrial practice and standards. With regards to the familiarisation with normal working practices and standards in the aircraft industry, you should make efforts to secure a visit from a professional in the context of aircraft inspection and maintenance. Note that if you are using a real aircraft in a hanger environment, you will require an appropriate power source to charge the systems on board the airframe. Suitable support trestles to leave the undercarriage free for test will also be required, though not strictly necessary.

If access to a live airframe is not possible, then a full suite of example devices must suffice. If possible have these devices mounted on representative rigs that simulate the operation. For example, a hydraulic actuator might be fitted within a representative wing section with aileron. The treatment of the devices will be the same as with the complete airframe.

Development of the fundamental theories that support each system would best be approached through demonstration rigs. Educational pneumatic, hydraulic and electronics rigs are readily available. Such learning aims may well be common to other units and you should liaise with the other tutors to establish where concurrent teaching or common assessment might take place.

Delivering the learning aims

As suggested earlier, you should begin with a broad overview of an aircraft system's technology, purpose and typical execution. Draw attention to the variety of devices that might be encountered and how the choice in device will be dictated by aircraft size, operating altitude, manoeuvrability, operating environment, weight concerns etc. You should link the other aspects of aircraft science at this stage. Assess the learners' knowledge of flight mechanics, airframe design and construction, thermodynamics, aerodynamics and solid mechanics. Clearly you are not responsible for delivering the tutoring/learning for these subjects, nor do the learners require an in depth understanding of them, but the rudimentaries are essential. The learner must first comprehend the purpose of the systems if they are to appreciate the function.

The learning aims open with a treatment of the fundamentals of hydraulics. The focus is predominantly on the components and their control. Hydraulic design and operation can certainly be demonstrated from a purely parametric standpoint (black box), but learner comprehension of these parameters will be improved if they simultaneously understand the theoretical principles (what is in the black box). Both theory and operation can be developed brilliantly with an appropriate demonstration rig. Ensure that the rig chosen for this purpose includes all the major components. Hose lines, differing control valves, indicators, a variety of actuator types etc. With such a rig at your disposal, you could develop a number of discrete exercises designed to develop learner competence with hydraulic equipment. Each exercise would start with an outline of theory and application of parameters, followed by a tutor led demonstration, followed by a set task in which the learner is directed to achieve some given outcome with the apparatus available to them. Connect each outcome to application of the real devices as found on the aircraft. Importantly, you should invite the learners to consider the ramifications of loss of function in any part of the system they have been investigating. This would also be a suitable point to start introducing fault-finding techniques. Note that this is not strictly included in the specification so should not be laboured.

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The second part of learning aim A deals with landing gear. The hydraulic actuation of typical landing gear can be explicitly linked to the learning developed on the demonstration rig. Introduce the specific devices and invite the learners to examine the operation and parameters from the perspective of what they learned previously. If you have access to an aircraft or at least a landing gear assembly, introduce the maintenance manual for that specific system. Ensure the learners understand how to reference the document to extract the specific data, especially the directives concerning the inspection and test of the undercarriage. Lessons might take the form of access-inspect-repair processes that reflect the real world processes. This will allow the simultaneous development of knowledge with industrial protocols. You may also wish to introduce a standard recording format as typically used in order to familiarise learners and develop directly pertinent industrial experience. Given the range of devices stipulated in the learning aims, it seems unlikely that you will have examples of all of them. At the very least, you should have one device type per application and support the missing device types through images and drawings with supporting explanation.

The final part of learning aim A is concerned with flight control systems. It would be sensible to commence this portion by defining why a mechanical system might be adopted in preference to a hydraulic one, or vice versa, depending on the aircraft in question. Invite the learners to explore this question in the light of supported learning. For an aircraft of such a size and such a typical operation, what are the advantages and disadvantages to each system? If we combine these systems, are there any potential advantages? If you have access to an aircraft it is likely that it will not be overly large and will likely be somewhat aged. Therefore it is likely that it will have examples of both systems on the airframe. Direct the learners to witness the effects of cockpit controls on surface movements, track how these control inputs are transmitted to the surfaces and record their findings. This can be performed for all surfaces. Ensure that the learners appreciate the purpose of these surfaces and the ramifications of loss of function. Support this learning by indicating alternative solutions that might be present on different aircraft. Without access to an aircraft, you will need to rely heavily on images and drawings to support teaching. However, you should at least have a rig that can simulate control input to surface movement, even if only a model. This rig should have all the likely mechanical system components. Simulation of hydraulic actuation could be achieved via the hydraulic rig mentioned previously, providing you have access to supplementary controls such as a control column and some means of translating electrical signals to hydraulic component activation. This would also allow the demonstration of electro-hydraulic signal transmission as a mechanism.

Learning aim B is concerned primarily with environmental control systems. If the aircraft you have access to was designed and hence equipped for high altitude flight then you will have access to all the devices and systems noted in the specification. If not, then a large quantity of the devices will require a purely theoretical approach. Ensure, this being the case, that you have an adequate pre-prepared supply of supporting images and drawings to utilise in support of this learning. If this approach is adopted, you should make efforts to secure a visit, if possible, to a maintenance centre where some aircraft is presently undergoing a C or preferably, D check. This would allow the learners to view the devices in an exposed state and, importantly, witness the procedures for the inspection and testing of these systems. Note that such a visit could also be used to witness the MRO (maintenance, repair and operation) of all other systems of interest in this unit. The final part of this learning aim concerns protection systems and their operation. Note that this segment is focused on how these devices are used by the crew and passengers. You could arrange a visit to any active civilian airport where cabin crew could be asked to indicate the devices onboard, their location, their operation and the conditions under which they might be used.

Learning aim C opens with an exploration of fuel systems and the composition of the fuel itself. If the learners have, or are, pursuing learning in thermodynamics, you should link that learning to the treatment of combustible substances. This will make a good scaffold for dealing specifically with AVGAS and its treatment. Proceed to additives and their purpose. Fuel systems can be demonstrated directly on an example aircraft or schematically supported by examples of the various devices such as pumps and valves.

Treatment of the anti-icing and de-icing systems should begin with the causes and dangers of icing on aircraft. You should link to *Unit 48: Aircraft Flight Principles and Practice* at this point to support the foundation theories. How and why is ice formed? Why is it a problem? Clearly draw the distinctions between pre-emptive and reactive systems. Why is one approach selected over the other? You can then proceed to the specific systems themselves and their operation.

The final part of the learning aim is concerned with the detection, suppression and extinguishing of fire. You should commence with an exploration of the potential sources of ignition and of the relative flammability and toxicity of the materials and substances that comprise the airframe. Detection systems can be explored through the example aircraft as simulation of ignition sources is easily achieved. Create structured exercises where specific alarms are activated and have the learners identify the location and source. The operation of the specific devices might be pursued through an examination of example devices subjected to the differing environmental conditions which activate them, ie thermal, chemical, infrared etc. Fire suppression systems can then be examined. You should distinguish clearly between those systems which require operator intervention and those which are automatic.

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Learning aim	Key content areas	Recommended assessment approach
A Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight	**A1** Hydraulic-power systems and components **A2** Landing-gear systems and components **A3** Mechanically and hydraulically powered flight control systems	A report based on inspections of systems and research, covering the function and operation of aircraft-hydraulic power, landing-gear and flight-control systems as well as components and their contribution to safe flight.
B Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew	**B1** Cabin environmental control systems and components **B2** Cabin protection systems	A report covering the, operation of cabin environmental control and protection systems as well as components and their contribution to the protection of passengers and crew.
C Examine how the operation of airframe fuel, ice- and fire- protection systems contribute to safe flight	**C1** Airframe fuel systems and components **C2** Anti-icing and de-icing systems **C3** Fire detection and extinguishing systems and components	A report covering the operation of airframe fuel, ice- and fire- protection systems as well as components and their contribution to safe flight.

Assessment guidance

The assessment criteria for learning aim A calls explicitly for the inspection, recording of findings, analysis and reporting of three systems. Namely, at least one of each of the following:

- hydraulic power system
- landing gear system
- flight control system.

Note that this will require access to an aircraft. If an aircraft is not available, as per the suggested activities detailed throughout this document, you will be obliged to arrange a visit to a location where some particular aircraft is available on which you can carry out the necessary inspections. The unit specification recommends as an example, ‘Inspection of a hydraulic supply system will be used to determine the identity, layout and function of the system and its power source(s), oil-storage components, fluid plumbing, control valves and feeds to the hydraulic services’. Note that neither the assessment criteria nor the example guidance require that the learner identify faults or for that matter quantify the status of the system. The objective is to identify the system components and then to explain their operation. The landing system and the flight control system chosen are subject to the same requirements. You should direct the learners to document all details during their inspection. You may wish to direct them to photograph the systems for the purposes of insertion into any report. Video recording or witness statements of the activities can constitute an aspect of the evidence for completion of assessment criteria A.P1. However, A.P2, A.M1, and A.D1 require the generation and submission of findings. This might be done through presentation, but it is recommended for the sake of robust assessment, as well as evidence, that you direct learners to generate a written report.

The assessment criteria for learning aim B do not explicitly require any access to an aircraft. The learners might simply be directed to report on the function and operation of the stipulated systems. However, if you have access to an aircraft, either on or off site, you may wish to make the assessment specific to that aircraft. The learners might generate a report where they identify the systems on the aircraft, document their type and operation and explain how they maintain the comfort and protection of the crew and passengers. You might create an assessment opportunity for 'analysis' by positing a scenario in which there is a system or sub-system failure and inviting the learner to explore and report on the ramifications. For 'evaluation' you might extend the task to include an exploration of alternative solutions to the system in hand and why these might be superior or inferior.

The assessment criteria for learning aim C follow precisely the same format as for learning aim B. The only difference being in the systems under investigation. With this similarity in mind, the suggestions proposed for learning aim B are equally valid for learning aim C.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 53: Airframe Mechanical Systems

Introduction

The most likely objective for any learner pursuing this unit is either in manufacture/assembly or maintenance of aircraft. With this in mind, familiarisation with the devices and systems involved within a realistic environment cannot be underestimated. Most of the systems could be investigated in isolation from the aircraft, but experiencing these in the ultimate context will give the best possible learning environment. Direct experience of working on a real aircraft will not only facilitate effective learning, but will also constitute invaluable and relevant industrial experience. In short, directly applicable skills and experience in the aerospace sector.

Where possible, have ready a wide range of example devices that can be handled, dismantled, inspected and explored. Let the learners develop knowledge through direct experience of handling these components. The operation and theory of these devices can then be readily developed.

Learning aim A – Investigate how the operation of hydraulic-power, landing-gear and flying-control systems contribute to safe flight

Hydraulic power systems and components.

- Hydraulic transmission.
  - Begin by establishing any previous or concurrent learning regarding hydraulics with the learner cohort. Where this learning is not present you will need to start by developing the fundamental principles of force and pressure in fluids.
  - Fluid types, properties and requirements can be covered theoretically, but take care to establish the typical types as used in airframe hydraulic systems, in particular any system the learners will use, be it on a real aircraft or the demonstration rig.
- Hydraulic power-supply systems and components.
  - Power source function and layout. From the theoretical framework developed previously, you can now begin to introduce the practical applications, starting with pumps. Focus on the pump type(s) you have to hand but ensure the learners are aware of the different types that might be encountered and how these operate.
  - Identification, function and layout of fluid storage, control, conditioning and actuation components. This requirement will definitely profit from the use of a demonstration rig outfitted with a broad range of differing components. This will allow the operation of such devices to be explored in a comfortable and simplified environment prior to examining real devices in the context of an actual aircraft. In a real environment the devices may not immediately betray their function by appearance and may be heavily embedded within the airframe, making inspection difficult.
  - Operation of hydraulic power supply systems. This portion of the learning aim would definitely benefit from access to a live aircraft as the alternative will involve static images and verbal explanations, which will make a poor substitute.

Landing gear systems and components.

- Identification, function and layout of landing gear and retardation components.
    - This could be explored through images and explanations, but since the assessment will ultimately require access to an aircraft, it would be sensible to ensure the learners have access, at the very least, to an isolated undercarriage assembly. The function and operation of the components could be explored through separate exercises. For example, the hydraulic actuators via the hydraulics rig.
    - Ensure that regardless of what undercarriage type you have acquired, the learners are made aware of the full range of devices that might be employed.
- Function and operation of extension/retraction system.
    - This portion would ideally be delivered through the operation and examination of a real system in use. If you have access to an aircraft, this will of course require that the airframe can be supported to free the undercarriage. Note that there is a requirement to understand and interpret the indicators present in the cockpit.

Mechanically and hydraulically powered flight control systems.

- Function and operation of mechanical flight control systems and identification, function and layout of system components.
    - Begin by ensuring that the learners understand the purpose of flight controls and how these affect flight.
    - As suggested in the delivery guidance, you might want to utilise the systems present on an example aircraft. The learners could be invited to witness the effect of cockpit control input on flight control surfaces, and then investigate how these motions were transmitted.
    - Appropriate models of mechanical systems could be used to simulate such systems either as substitutions for the above or as supplementary support to the above.
- Function and operation of hydraulically powered flying control systems and identification, function and layout of system components.
    - The requirements here are the same as for the previous section but involving specifically hydraulic devices.
    - Following previous suggestions, you should note that since the learners will be assessed on their ability to identify and explain these system components, it is essential that they have an opportunity to familiarise themselves with such items prior to assessment. This implies that they will require access to an aircraft, or at the very least, isolated segments of an aircraft that contain representative components.

Learning aim B – Examine how the operation of cabin environmental control and protection systems contribute to the protection of passengers and crew

Cabin environmental control systems and components.

- Pneumatic-supply systems.
    - Pneumatics can again be explored through the use of a suitable demonstration rig. However, the focus here is on the application within the airframe systems. From this perspective, the systems can again be explored from a purely hypothetical standpoint, but access to real systems would be preferable in order to contextualise their operation.

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- Identification, function and layout of supply system components. Reference to example items might be made here, but again, examining the systems and their components in situ would be preferable.

- Cabin air-conditioning and pressurisation systems and components.
  - As suggested in the delivery guidance and in the assessment guidance, this segment might be conducted by visiting an MRO facility where some commercial aircraft is under C or D check. With the system and its components exposed, the learners can be guided through the system and its operation.
  - The above activity should be supported by directed learning on return to your institution.

Cabin protection systems.

- Function and operation of aircraft oxygen systems.
- Identification, function and layout of cabin and crew equipment.
  - Both of the above segments could be pursued with a visit to an active commercial aircraft. A member of cabin crew could be approached to guide the learners around the aircraft, directing their attention to the devices, how they are operated, and under what conditions they are operated.

Learning aim C – Examine how the operation of airframe fuel, ice- and fire-protection systems contribute to safe flight

Airframe fuel systems and components.

- Fuel types and properties.
  - Assess the learners for previous or current learning regarding thermodynamics and the behaviour and properties of combustible substances. Link this learning to the present segment.
  - Indicate the importance of the parameters involved and guide the learners to explore the significance of these in light of the aircraft operation, in particular with regards to safety.
- Type and function of fuel additives, including ice and corrosion inhibitors, antioxidants, anti-static agents.
  - This segment could only, realistically, be conducted theoretically. The emphasis is on developing learner comprehension on why these additives are necessary.
- Fuel system component identification and function.
  - Direct viewing of such devices on an aircraft will be hampered by access restriction. You should acquire as many of the representative devices as possible for examination off aircraft. Ensure that these devices and their functions are placed in context regarding the overall system.
- Fuel-tank layout, eg wing inboard and outboard tanks, fuselage tanks, ventral tanks, longitudinal balance fuel system and trim tanks.
  - This can be achieved by direct examination of an aircraft, but should be supported by adequate schematic representations to fully develop an understanding of the complexity of such systems. Link to the concepts of trim and balance as encountered in *Unit 48: Aircraft Flight Principles and Practice*.
- Fuel system operation.
  - This follows logically from the previous section and again, direct inspection should be supported by schematic interpretation. Put each of the processes into context. Why might it be necessary to jettison fuel?

Aircraft anti-icing and de-icing systems.

- Ice formation, rim ice, glaze ice and Hoare frost, effects of ice and snow.
  - Again link to *Unit 48: Aircraft Flight Principles and Practice.* What are the ramifications of ice accretion?
- Ice detection, eg probes, vanes, electronically activated, mass activated.
  - If not present on an accessible aircraft, these will have to be explored purely theoretically.
- Function and operation of pre-emptive anti-icing systems.
  - You should begin by stressing why an anti-icing system would need to be pre-emptive as opposed to reactive. Link directly to the relative importance or criticality of the systems in which anti-icing is applied.
  - Proceed to the demonstration or explanation of how these operate.
- Function and operation of reactive de-icing systems.
  - As before, demonstrate or explain how these operate.

Fire detection and extinguishing systems and components.

- Fire detection.
  - Fire-detection zones, including engines, APU, jet pipes, cargo compartment, toilets. Commence this segment by inviting the learners to consider why each of these zones requires fire detection, and then proceed by examining the potential dangers posed by ignition in any of these zones. Examine the likely sources of ignition.
  - Function and operation of fire/overheat detector systems. These systems will realistically be examined theoretically; however, if you have access to example devices, these can be energised and subjected to simulated conditions which will activate them for the purposes of examining operation.
  - Function and operation of smoke-, carbon monoxide- and flame-detection systems. This segment can be pursued in exactly the same manner as the previous one.
  - Nature of flight-deck and cabin-fire warnings, including location indicators, red lights, claxons, overheat indicators. Without access to an aircraft, this can be examined through a simulated cockpit display schematically or otherwise.
- Fire extinguishing.
  - Commence with an examination of the differing classes of fire and the relevant suppressing techniques.
  - Proceed by examining the fire suppression systems, both user applied and automatic. Link the devices to the retarding chemical they contain and therefore the previous segment.

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Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 50: Aircraft Gas Turbine Engines*
- *Unit 51: Aircraft Propulsion Systems*
- *Unit 55: Aircraft Electrical and Instrument Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Moir I & Seabridge A – *Aircraft Systems – Mechanical, electrical, and avionics subsystems integration, 3rd edition* (Wiley-Blackwell, 2008) ISBN 9780470059968.
  This textbook covers all the systems detailed in this unit in great depth and detail. This makes a great resource for teaching but should be considered with care before being recommended as a resource for learners at level 3. The complexity that many of the chapters reach is, fundamentally, beyond what the learners require or are expected to manage.
- Langton R et al – *Aircraft Fuel Systems, 1st Edition* (John Wiley and Sons Ltd, 2009) ISBN 9780470057087.
  Given the relative complexity of fuel systems, it is worth having a reference text to explain the manifold issues and devices involved. This text is exhaustive on the topic and should be treated with the same caution as the above text if you are considering making it available to the learners.

Unit 54: Aircraft Electrical and Instrument Systems

Delivery guidance

Approaching the unit

This unit builds on the engineering principles investigated in the mandatory *Unit 1: Engineering Principles*. It gives an in-depth understanding of aircraft electrical power generation and distribution systems, building on the concepts learnt in *Unit 1: Engineering Principles*. The unit content is structured so that learners are able to understand, develop and apply practical skills to the construction and operating principles of a range of modern electrical components and instruments associated with aircraft electrical and instrument systems. To stimulate enquiry and investigation, your learners should combine theoretical studies with significant amounts of simulation and practical applications. One of the key elements of this unit is to encourage your learners to examine the importance of electrical power generation and distribution within an aircraft engineering environment as compared to a general engineering environment, by emphasising the importance of working to high tolerances, tool control and awareness of surrounding areas.

Throughout the delivery of this unit you should relate all teaching to actual engineering situations and make it clear to your learners that what they are learning is applied, as opposed to pure science. The first learning aim examines how electrical power generation and distribution systems support the safe operation of aircraft. There is scope here to do a useful amount of theory and practical investigation using simple equipment, for example basic DC generators with field coils and stators. You can then move on to examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight. Again, there is scope here to utilise practical learning through LJ Create boards for example. The third learning aim explores how air data and gyroscopic instruments and systems contribute to maintaining safe flight. There is again obvious scope here for practical exercises, with basic gyroscopic instruments (for example, a navigational computer) as well as in-depth teaching of the theory of aircraft air data systems (for example, pitot static system).

To complete this unit your learners will need access to aircraft flight instrumental systems, display information, air data systems etc.

You can use a range of delivery methods in this unit such as:

- formal teaching
- individual and small group investigation
- structured workshops
- laboratory and practical investigation
- computer simulation
- case studies.

Learners would benefit from access to data related to complex modern aircraft operation, as well as an example of a static aircraft electrical and instrument system.

This unit could be delivered using a largely practical approach. Learners should have access to aircraft electrical systems or static simulations in order to carry out tests and check performance. These systems can be demonstrated using purpose-built rigs and simulations. However, it is expected that learners will investigate real electrical systems on aircraft in order to fulfil the practical assessment evidence required for assessment.

You can involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

Learning aim A focuses on the electrical power generation and distribution systems, and their respective components, in order to support the safe operation of aircraft. Practical activities involving the design, construction, checking and testing of electrical systems and components should form the majority of delivery. It is anticipated that the majority of learning can take place using electrical training and simulation boards and/or utilising specific software if applicable. Although demonstrations will be useful, it is important that learners develop the ability to independently test and check electrical power generation systems as well as associated components.

You should give your learners the opportunity to observe real aircraft power generation and distribution systems in operation. They should be allowed to construct, activate, check and fault-find all of the systems and categorise them appropriately. Visits to local aircraft maintenance facilities, or aircraft engine maintenance facilities, could be used to help learners understand the use of electrical power generation when checking the performance of distribution systems for the safe operation of aircraft.

You will need to supervise your learners closely when working in workshops or on aircraft, ensuring that appropriate risk assessments and health and safety procedures are in place.

In a similar manner to power generation systems, the opportunity to observe and activate components within a distribution system (ie lights, motors etc) should be facilitated, whether using an actual aircraft or purpose built training rig. In the section on general systems, examples of electrical systems are identified.

For learners to be able to check the performance of an aircraft's power generation and distribution system, it is important that they have access to the manufacturer's specifications in order to perform appropriate calculations. This may require assessors to simulate faults in the systems. If learners will be accessing the same aircraft, it would be useful to have variety of different faults to ensure enough valid evidence can be generated.

Learning aim B requires learners to examine how electrical actuation, loading and control and warning systems contribute to maintaining safe flight. As well as gaining a thorough understanding in these areas, learners will undertake practical investigations of these system elements using bench-work activities that allow them to identify clearly the structure, construction and purpose of component parts and disassemble, assemble and test components. In order to facilitate these activities there needs to be safe removal of the components from aircraft and safe replacement as well as testing. These activities should be undertaken under close supervision with a focus on using appropriate personal protective equipment (PPE) and ensuring that suitable risk assessments and health and safety procedures are in place. For learners to carry out performance tests will require them to be competent with tools and measuring equipment such as test meters and analysers.

The opportunity to work with individuals during the delivery of this practical work can be actively facilitated to underpin learning. In particular, it can be used to reinforce working practices and skills, help learners to deal with problems with the use of tools or equipment or support them when they need to work with others more effectively in order to achieve the task.

Learning aim C requires learners to understand how air data and gyroscopic instruments and systems contribute to maintaining safe flight. Again, as well as gaining a thorough understanding in these areas, learners will undertake practical investigations of these system components. They will use practical tasks on an aircraft or simulated rigs to allow them to identify clearly the structure, purpose, importance, construction and relevance of component parts including the disassembly, assembly and testing of components. In order to facilitate these activities there needs to be safe removal and testing of components from aircraft and safe replacement and 'entire' system testing. These activities should be undertaken under close supervision with a focus on using appropriate personal protective equipment (PPE) and ensuring that suitable risk assessments and health and safety procedures are in place. For learners to carry out performance tests will require them to be competent in using tools and measuring equipment such as test meters and analysers.

The opportunity to work with individuals during the delivery of this practical work can be actively utilised to underpin learning. In particular, it can be used to reinforce working practices and skills, help learners to deal with problems with the use of tools or equipment or support them when they need to work with others more effectively in order to achieve the task.

Learning aim	Key content areas	Recommended assessment approach
A Examine how electrical power generation and distribution systems support the safe operation of aircraft	**A1** Aircraft electrical power generation **A2** Aircraft electrical power distribution	A report covering the operation, including construction, principles, control and protection of aircraft generators and power distribution component and systems
B Examine how electrical actuation, loading, control and warning systems contribute to maintaining safe flight	**B1** Electrical motors and actuators **B2** Electrical loading systems **B3** Electrical control and warning systems	A report covering the function, layout, operation and aircraft application or electrical motors, actuators, loading, control and warning systems.
C Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight	**C1** Air data instruments and systems **C2** Gyroscopic principles and instruments	A series of practical tasks to explore safely the function, construction and operating principles of air data instruments and systems and gyroscopic instruments. Evidence will include observation records/witness statements, annotated photographs and/or drawings and procedural details.

Assessment guidance

This unit is internally assessed and you should use three assignments that are carried out under controlled conditions, with combinations of assessment criteria as listed in the unit specification. It is important to adhere to these combinations because of the way that assessment criteria are funnelled in order to achieve a thematic approach.

Your learners must independent generate hard copy evidence presented as a portfolio. For most learners, hand written/drawn evidence will be the most time efficient method of presentation. The use of still photographs should be encouraged when carrying out practical activities. For all three learning aims, learner evidence will be based on fixed tasks. Assessor signed observation records must contain comments about how each learner approached practical tasks, set up equipment, carried out the task and processed the findings. Where experimentation is involved on rigs previously set up you will need to plan how each learner can access the equipment without overcrowding.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 54: Aircraft Electrical and Instrument Systems

Introduction

Begin by introducing this unit to your learners through a group discussion about what they think an aircraft electrical and instrument system entails. It is also worth getting your learners to think about the differences between domestic or automobile electrical and instrument systems and those of an aircraft.

You could support the brain storming activity with a whole-group presentation that will familiarise learners with the requirements of the learning aims and how to approach each one effectively. An overview of aircraft electrical and instrument systems linked to practical demonstrations of the operation of each system using a demonstration aircraft, videos and simulation rigs could be used to show the purpose of different electrical and instrument systems and associated components.

The intention of this unit is that when your learners are carrying out experimental work, they are given an overall objective to be achieved but the way that they approach the task(s) is up to them. Some will need guidance, others may not (differentiation within the group). For each learning aim the thematic nature of the assessment criteria gives scope for your learners to show initiative and the experiments to become true investigative activities.

Where appropriate do use simulation packages to support your formal teaching and learner investigation but not at the expense of denying them a proper hands–on experience with experimental apparatus and a functioning aircraft appropriate to this level and qualification. Most of what you will be teaching is applied but set in realistic engineering contexts.

Learning aim A – Examine how electrical power generation and distribution systems support the safe operation of aircraft

You could start with whole-class teaching, including:

- an overview of the fundamental construction and operation of Direct Current (DC) generators
- an overview of the fundamental construction and operation of Alternating Current (AC) single-phase and multiphase brushed and brushless generators
- the differences between DC and AC generation and the importance of both on an aircraft
- the methods of converting AC to DC and DC to AC where required
- a health and safety briefing regarding working practices in the aircraft maintenance industry and associated workshop.

Using paired or small-group activities:

- Researching individual systems or components to determine operation and whether they are statutory or non-statutory. For example where protection control is required, what determines the requirements and how does this operate.
- Each pair/group could feed back to the whole class on the use of the electrical power generation and distribution systems supporting the operation of an aircraft.

In whole-group teaching you could then:

- present an overview of auxiliary electrical systems and components using artefacts, video clips and animations.

Individual activity:

- Use of interactive software packages investigating electrical systems and incorporating self-assessment exercises.
- Practical skills – constructing a simple generator and circuit and powering a component to light a filament for example.

Learning aim B – Examine how electrical actuation, loading, control and warning systems contribute to maintain safe flight

You could start with whole-class teaching, including:

- an overview of the fundamental operation, including construction, principles and application of DC and AC motors:
  - You could demonstrate the practical application of DC brush types, AC single and three-phase motors.
- an overview of the fundamental construction and operation of aircraft electrical actuators
- an overview of the function and operation of airframe loading systems to include lighting, high load components like anti-icing and de-icing etc
- the methods of and function of the electrical control warning systems
- a health and safety briefing regarding working practices in the aircraft maintenance industry and associated workshops relevant to the specifics of safety warning systems and the hazards and conformities you must be aware of when working around them.

Using paired or small-group activities:

- Researching individual systems and components to determine operation and whether they are essential or non-essential for automatic or manual load shedding purposes.
- Each pair/group could create a simple presentation or perform a practical task to feed back to the whole class on the use of the electrical motors and actuators, electrical loading systems or electrical control and warning systems.

In whole-group teaching you could then:

- Present an overview of electrical actuation, loading, control and warning systems including components using artefacts, video clips and animations.

Individual activity:

- Use of interactive software packages investigating electrical systems and incorporating self-assessment exercises.
- Use practical skills through software packages or performing tests on the aircraft systems.

Learning aim C – Explore how air data and gyroscopic instruments and systems contribute to maintaining safe flight

- Using a formal presentation you could start by giving an overview of air data and gyroscopic instruments that contribute to maintaining safe flight, opening this out into a whole class discussion.
- Demonstrate how to analyse a range of gyroscopic principles in association with different instruments.

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- Demonstrate how to interpret air data instruments and associated systems.
- Learners work independently or in small groups to investigate the systems.
- Your learners could present an overview bringing the groups together to discuss each element of the system they have researched.
- Practical demonstration and practical application using an aircraft to gain access to the various systems would be advantageous to gain hands-on experience having learnt the theory.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 1: Engineering Principles*
- *Unit 15: Electrical Machines*
- *Unit 16: Three Phase Electrical Systems*
- *Unit 48: Aircraft Flight Principles and Practice*
- *Unit 49: Aircraft Workshop Methods and Practice*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Pallett EHJ – *Aircraft Electrical Systems, Third Edition* (Longman, 1988) ISBN 9780582988194.
  A good general guide.

Websites

- www.pilotfriend.com/training/flight_training/tech/elec.htm
  Pilot Friend - Basic overview of an aircraft electrical system.

Unit 55: Aircraft First Line Maintenance Operations

Delivery guidance

Approaching the unit

This unit has been designed to give learners an understanding of the practical application of safety precautions, procedures, planning and quality processes associated with first-line maintenance operations. When delivering the unit content a real or realistic maintenance-training environment should be used wherever possible.

Delivery should ensure that the theory relating to safety procedures and documentation is taught before the practical aspects of the unit. Safety issues and precautions associated with aircraft ground handling and first-line maintenance activities should be delivered right at the start. Emphasis should be placed on the maintenance safety precautions directly associated with the specialisation of the learner and group being taught, as well as the mandatory safety precautions associated with aircraft ground handling.

When delivering the theory aspects of learning aim B, the associated documentation and recording procedures could also be taught. This will enable learners to become familiar with maintenance manuals, planning and quality processes associated with first-line maintenance. This can link to learning aim D by covering the documents for recording work such as job cards and technical logs and the status of the parts and consumables that might be required to complete associated handling and maintenance procedures.

In order to put the maintenance documentation into context, it would be useful to first teach the parts of learning aim B relating to aspects of maintenance planning and quality control that affect the execution of maintenance. In this way, the need for and identification of the different types of first-line maintenance and check cycles could be taught and their relationship to the actual work cards, technical logs and log books associated with the job recording system could be explained at this stage. Learners would then have sufficient underpinning knowledge to start on the practical activities for learning aim C. The range of practical activities listed in the content would best be undertaken in a real maintenance first-line operations environment. However they could equally be carried out in a realistic training environment, so long as the centre has the necessary physical resources and equipment.

Centres may be involved in partnerships with airline operators, third party maintenance organisations, a Part 147 approved organisation, Part 145 approved organisations or Armed Services establishments where the required practical work can be undertaken. In all such environments, there are the further opportunities for learners to familiarise themselves with the associated reference and recoding documentation directly applicable to their specialisation.

Throughout delivery of the unit, emphasis needs to be placed on all associated safety issues and the mandatory documentation that needs to be followed and completed. For this reason you should note that these two vitally important elements make up the majority of the assessment criteria.

You can use a range of delivery methods in this unit such as:

- formal teaching
- individual and small group investigation
- structured workshops/practical simulation
- laboratory/practical investigation
- computer simulation /real-time tasks
- case studies.

This unit could be delivered using a largely practical approach with partnerships with airline operators, third party maintenance organisations, Part 147 approved organisations, Part 145 approved organisations or Armed Services establishments where the required practical work can be undertaken. In all such environments, the learner will need to have access to an aircraft, either static or in real-time, in order to carry out the practical elements of learning aim C.

You can also involve local employers in the delivery of this unit if there are local opportunities to do so.

Delivering the learning aims

For learning aim A, learners must develop an understanding of the reasons for aircraft handling precautions. This means that they must have knowledge of the safety zones when aircraft engines are running and understand the dangers associated with intake pulling forces and the implications of foreign object debris (FOD) ingestion. They will also need to understand the dangers associated with engine exhaust efflux when the aircraft is turning into or away from the parking area. Learners also need to understand the electro-static hazards associated with radio transmission and the reasons for earthing and bonding the aircraft. The use of fire extinguisher equipment should also be explained, including carbon dioxide, dry powder and foam.

Learning aim B focuses on the planning, quality and administrative processes that you must be able to demonstrate to your learners. You could state the purpose and describe a typical check cycle or aircraft turn-around cycle that also includes planning provision for an additional maintenance requirement, such as the embodiment of a modification like data upload or the satisfaction of, or deferral of, a special technical instruction or service bulletin. You will need to define and explain the need for quarantine and bonded stores, within a typical maintenance environment such as a line station. Tasks should be included that require explanation of the role and functions of a civil or military quality department and the functions and role of inspection and check systems and how life-limited components and equipment are controlled. When describing the control of life-limited items, learners will need to understand the appropriate maintenance actions necessary for continued airworthiness and integrity of the aircraft structure and systems.

Learning aim C focuses on the practical elements of maintenance during first-line maintenance operations and safety surrounding the tasks. You will need to give learners an opportunity to carry out two given general maintenance activities, and one other maintenance activity, as well as two given specialist activities. For the specialist activities, all actions must be recorded in accordance with laid down standards, using the correct documentation. The most appropriate method for gathering evidence might be through use of expert witness statements and/or observation records. Annotated photographs could also supplement these statements or records. Tasks should be assessed not only in terms of practical competence but also to ensure all technical procedures, safety precautions and related documentation have been adhered to as appropriate, including the knowledge behind why a task is being performed and the implications surrounding each task, the effects on components, systems, personnel etc. Assessment evidence could be obtained from a written report that explains the need and nature of two of the general/specialist maintenance activities carried out.

Learning aim D focuses on self-evaluation of the tasks performed and the knowledge learned throughout the unit. You must support the learner with guidance for self-evaluation of what went well and what did not go so well, emphasising the importance of safety and implications of both. Learners should focus on reflective learning and analysis of their own performance. Assessment evidence could possibly be in the form of a written statement with justification.

Learning aim	Key content areas	Recommended assessment approach
A Examine aircraft safe maintenance operations in a first-line engineering environment	**A1** Safety procedures for aircraft first-line maintenance operations **A2** Types of aircraft first-line maintenance operations	A report focusing on operational maintenance procedures and the function, use and compliance with planning, administrative and safety procedures and quality processes necessary to restore the aircraft to a serviceable condition in a first-line engineering environment.
B Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations	**B1** Maintenance planning and quality processes **B2** Administrative procedures for aircraft maintenance	
C Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition	**C1** Preparation for aircraft first-line maintenance operations **C2** Aircraft general first-line maintenance operations **C3** Aircraft specialist first-line maintenance operations	A series of practical tasks to complete aircraft maintenance operations, safely. Evidence will include: a record of the procedures followed, observation records and correctly completed servicing documents, with witness signatures against each completed task.
D Review aircraft first-line maintenance operations and reflect on personal performance	**D1** Lessons learned from aircraft first-line maintenance operations **D2** Personal performance while carrying out aircraft first-line maintenance operations	The evidence will focus on what went well and what did not go so well when carrying out aircraft first-line maintenance operations and a conclusion of improvements that could be made. The portfolio of evidence generated while exploring and reviewing aircraft maintenance operations and reflecting on own performance.

Assessment guidance

This unit is internally assessed and you could use three assignments that are carried out under controlled conditions, with combinations of assessment criteria as listed in the unit specification. It is important to stick to these combinations because of the way that assessment criteria are funnelled in order to achieve a thematic approach.

Your learners must independently generate hard copy evidence presented as a portfolio. For most learners hand written/drawn evidence will be the most time efficient method of presentation. The use of still photographs should be encouraged when carrying out practical activities. For all four learning aims, learner evidence will be based on fixed tasks. Assessor signed observation records must contain comments about how each learner approached practical tasks, set up equipment, carried out the task and processed the findings. Where experimentation is involved on rigs previously set up you will need to plan how each learner can access the equipment without overcrowding.

Getting started

This gives you a starting place for one way of delivering the unit, based around the recommended assessment approach in the specification.

Unit 55: Aircraft First Line Maintenance Operations
Introduction Begin by introducing the unit to your learners through a group discussion about what they believe are the differences between military, general aviation and civil airline organisations, considering the way they operate their aircraft and the variety of roles that these aircraft undertake. Emphasise that aircraft need to be maintained to be airworthy and, in doing so, suitably qualified aircraft maintenance technicians need to ensure the continued serviceability of the aircraft in a specific operating environment. You could support the brain storming activity with a whole-group presentation to familiarise learners with the overall aspect of continuing airworthiness and meaning behind the term. The intention of this unit is that when your learners are carrying out tasks on an aircraft safety is always paramount, learners having examined the all-important safety measures that are foremost in all aspects of aircraft maintenance operations. The theme of continuing airworthiness continues in the role and function of the administrative procedures and quality processes that underpin the need for documentation within maintenance operations plays. You could support the learners by visiting organisations to gain an overview of the role of an aircraft engineer as well as more specifically letting the learners gain knowledge surrounding the role of an aircraft maintenance technician. Reflective learning throughout the unit would encourage the learner try to take on the mind-set of an aircraft engineer.
Learning aim A – Examine aircraft safe maintenance operations in a first-line engineering environment
• You could start with whole-class teaching to include: ○ an introduction to unit content, the scheme of work and assessment strategy ○ in an aircraft maintenance environment, explaining and familiarising learners with aircraft engine running zones, radio-transmission electro-static hazards and safety zones, earthing, bonding and personal protection ○ explaining and familiarising learners with general safety procedures and precautions and specialist safety precautions applicable to the group ○ using small group activities you could get the learners to investigate and familiarise themselves with the precautions associated with the safe use of equipment ○ a visit to an aircraft flight line station to observe the maintenance operations that take place on within a civil and military environment ○ an individual activity to research the different types of aircraft that are maintained in a first-line operational environment including the differences between certain aircraft types and the different types of first-line maintenance categories ○ a multiple-choice quiz in line with the Civil Aviation Authority standards or getting learners to present on a safety topic on handling and maintenance safety.

Learning aim B – Examine the planning, quality processes and administrative procedures associated with aircraft first-line maintenance operations
• You could start with whole class teaching to include: ○ in an aircraft maintenance environment, explaining maintenance planning as associated with the military or civil group being taught ○ revising and consolidating previous learning on use of documentation ○ explaining the function of military or civil quality departments/activities such as aircraft maintenance quality assurance and control, quality inspection, scheduled and unscheduled maintenance, duplicate/independent inspections, authorisations and control of life-limited items ○ a visit to an aircraft maintenance, overhaul or repair facility to see their planning, stores and quality departments and aircraft handling/maintenance activities at first hand.
Learning aim C – Carry out aircraft first-line maintenance operations that safely restore aircraft to a serviceable condition
• Group activity. ○ Visit an aircraft maintenance, overhaul or repair facility to see their planning, stores and quality departments and aircraft handling/maintenance activities at first hand. ○ Aircraft first-line maintenance environment to demonstrate and explain (with appropriate manuals and documentation) practices and procedures associated with first-line maintenance. ○ Explain the inspection procedures applied, for example after a lightning strike, tyre burst, heavy landing, bird strike or flight through turbulence. • Practical application. ○ A series of practical tasks to complete aircraft maintenance operations, safely. Evidence to include a record of the procedures, followed by observation records and correctly completed servicing documents with witness signatures against each completed task. Tasks as appropriate to the maintenance/line station being visited.
Learning aim D – Review aircraft first-line maintenance operations and reflect on personal performance
• Individual report writing. ○ Focus on what went well and what did not go so well when carrying out the practical tasks on aircraft first-line maintenance operations and the consequences of the 'what did not go so well' scenarios. ○ Conclusion of improvements and analysis of self-belief as well as whether the learner thinks that they would make a good line engineer, operations, mechanic, avionic, planner etc. ○ A summative account of the whole unit in terms of job prospects for the individual learner.

Details of links to other BTEC units and qualifications, and to other relevant units/qualifications

Pearson BTEC Level 3 Nationals in Engineering (NQF):

- *Unit 49: Aircraft Workshop Methods and Practice*
- *Unit 53: Airframe Mechanical Systems*
- *Unit 54: Aircraft Electrical and Instrument Systems*

Resources

In addition to the resources listed below, publishers are likely to produce Pearson-endorsed textbooks that support this unit of the BTEC Nationals in Engineering. Check the Pearson website (http://qualifications.pearson.com/en/support/published-resources.html) for more information as titles achieve endorsement.

Textbooks

- Federal Aviation Administration, U S Department of Transportation, Flight Standards Service – *Aviation Maintenance Technician Handbook: General (2008 Revision, Incorporating 2011 Addendum)* (Books Express Publishing, 2012) ISBN 9781782660873.
  A useful resource.
- De Florio, F – *Airworthiness: An Introduction to Aircraft Certification* (Elsevier Limited, 2011) ISBN 9780080968025.
  A useful resource.

Videos

- www.youtube.com/watch?v=bNvwz8r_300
  WA Career Centre – BAE Systems Aircraft Maintenance technician, looking at the journey of an apprentice.
- www.youtube.com/watch?v=pvoeMRC6ZB8
  British Airways Maintenance – a look at an Airbus A319 Maintenance Check of what is involved.
- www.youtube.com/watch?v=rraLC4zTBtQ
  Federal Aviation Administration – overview of how to do aircraft maintenance.

Websites

- www.raf.mod.uk/recruitment/roles/roles-finder/technical-and-engineering/aircraft-technician-mechanical
  Royal Air Force – gives an overview of the Aircraft Technician (Mechanical) who is responsible for flight turnarounds in the military.
- www.ba-mro.com/baemro/aircraftMaintenance.shtml
  British Airways - gives an overview of civil aircraft maintenance and the type of work involved.

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