Unit Descriptors for the Pearson BTEC Higher Nationals Applied Sciences Suite

Issue 1

For use with:

Pearson BTEC Higher National Certificate and Diploma in Applied Sciences for England

Pearson BTEC Higher National Certificate and Diploma in Applied Sciences

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1.0 Introduction

The unit descriptors included in this document are for use with the following qualifications:

- Pearson BTEC Level 4 Higher National Certificate in Applied Sciences: 610/7896/7
- Pearson BTEC Level 5 Higher National Diploma in Applied Sciences: 610/7897/9
- Pearson BTEC Level 4 Higher National Certificate in Applied Sciences for England: 610/7898/0
- Pearson BTEC Level 5 Higher National Diploma in Applied Sciences for England: 610/7899/2.

1.1 Qualifications indicated ‘for England’

Qualifications that are indicated as ‘for England’ are designed to align to the requirements of specific occupational standards that meet the Department for Education’s (DfE) current occupation criteria. Meeting the requirements of the occupational standards relates to:

- qualifications that are ‘quality marked’ as Higher Technical Qualifications (HTQs)
- the knowledge, skills and behaviours for identified occupations that are associated with relevant occupational standards.

1.2 Qualifications not indicated ‘for England’

Qualifications that are **not** indicated as ‘for England’ can be delivered at any centre, in the UK or overseas, subject to approvals from Pearson. These qualifications are not ‘quality marked’ as HTQs by DfE.

2.0 Programme structures

Programme structures define the unit combinations required for a given qualification. These are defined in *Section 6.0 Programme structures* within the relevant programme specification for the qualification.

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2.1 Programme structures overview

This infographic provides an ‘at a glance’ view of the pathway structures available in these qualifications. All units are 15 credits unless specified.

- HNC is made up of 120 credits (8 × 15 credit Level 4 units).
- HND is made up of 240 credits, of which 120 credits are at Level 5 (6 × 15, 1 × 30 credit Level 5 units) and 120 credits are at Level 4 (see previous point).
- At both Levels 4 and 5, specialist units can also be selected as optional units for the standard pathway, and for any of the specialist pathways.
- For the general pathway, the combination of units selected must not replicate the rules of combination of any of the other specialist pathways.

Figure 1: Student progression from HNC pathways to HND pathways.

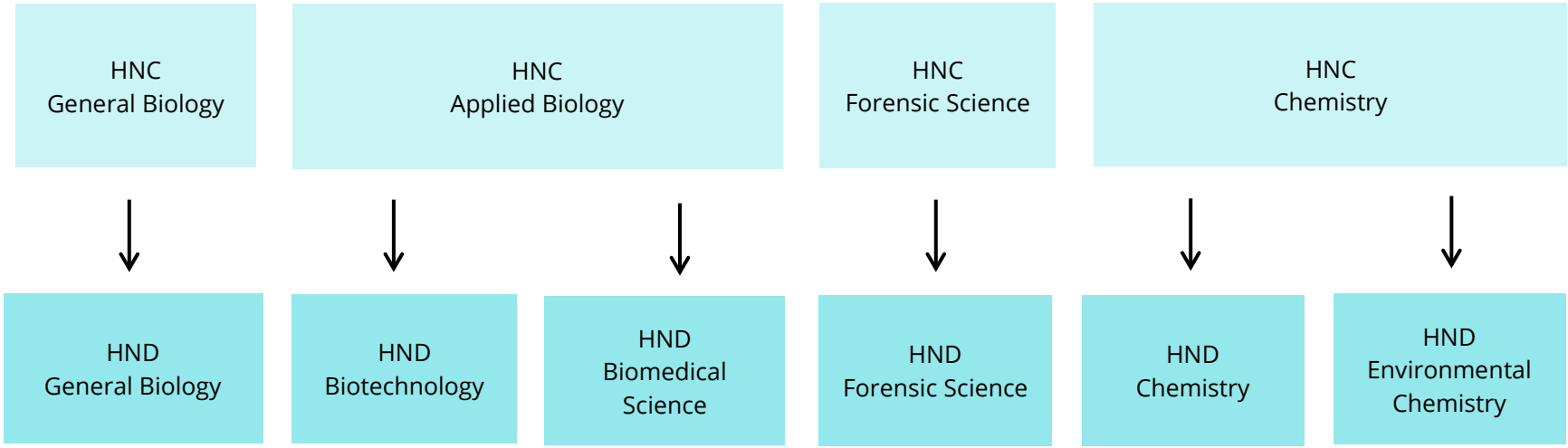


Table 1: HNC pathways showing core mandatory, specialist mandatory and space for optional or specialist units.

Level 4

UNIT TYPE	UNIT NUMBER	GENERAL BIOLOGY PATHWAY	UNIT TYPE	UNIT NUMBER	APPLIED BIOLOGY PATHWAY	UNIT TYPE	UNIT NUMBER	FORENSIC SCIENCE PATHWAY	UNIT TYPE	UNIT NUMBER	CHEMISTRY PATHWAY
Core Mandatory	**401**	Fundamentals of Biological Laboratory Protocols and Techniques	Core Mandatory	**401**	Fundamentals of Biological Laboratory Protocols and Techniques	Core Mandatory	**402**	Fundamentals of Forensic Laboratory Protocols and Techniques	Core Mandatory	**403**	Fundamentals of Chemical Laboratory Protocols and Techniques
Core Mandatory	**404**	Mathematics and Statistics for the Applied Sciences	Core Mandatory	**404**	Mathematics and Statistics for the Applied Sciences	Core Mandatory	**404**	Mathematics and Statistics for the Applied Sciences	Core Mandatory	**404**	Mathematics and Statistics for the Applied Sciences
Core Mandatory	**405**	Applied Experimental Methodology (Pearson-set)	Core Mandatory	**405**	Applied Experimental Methodology (Pearson-set)	Core Mandatory	**405**	Applied Experimental Methodology (Pearson-set)	Core Mandatory	**405**	Applied Experimental Methodology (Pearson-set)
Optional			Specialist Mandatory	**406**	Fundamentals of Cell and Molecular Biology	Specialist Mandatory	**407**	Fundamentals of Biochemistry	Specialist Mandatory	**411**	Inorganic Chemistry
Optional			Specialist Mandatory	**407**	Fundamentals of Biochemistry	Specialist Mandatory	**409**	Fundamentals of Forensic Science	Specialist Mandatory	**412**	Organic Chemistry
Optional			Specialist Mandatory	**408**	Human Anatomy and Physiology	Specialist Mandatory	**410**	Criminal Investigation	Specialist Mandatory	**413**	Physical Chemistry
Optional			Optional			Optional			Optional		
Optional			Optional			Optional			Optional		

Table 2: HND pathways showing core mandatory, specialist mandatory and space for optional or specialist units

Level 5

UNIT TYPE	UNIT NUMBER	GENERAL BIOLOGY PATHWAY	UNIT TYPE	UNIT NUMBER	BIOTECHNOLOGY PATHWAY	UNIT TYPE	UNIT NUMBER	BIOMEDICAL SCIENCE PATHWAY	UNIT TYPE	UNIT NUMBER	FORENSIC SCIENCE PATHWAY	UNIT TYPE	UNIT NUMBER	CHEMISTRY PATHWAY	UNIT TYPE	UNIT NUMBER	ENVIRONMENTAL CHEMISTRY PATHWAY
Core Mandatory	**501**	Personal and Professional Development for Scientists	Core Mandatory	**501**	Personal and Professional Development for Scientists	Core Mandatory	**501**	Personal and Professional Development for Scientists	Core Mandatory	**501**	Personal and Professional Development for Scientists	Core Mandatory	**501**	Personal and Professional Development for Scientists	Core Mandatory	**501**	Personal and Professional Development for Scientists
Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)	Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)	Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)	Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)	Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)	Core Mandatory	**502**	Applied Sciences Research Project (Pearson-set)
Optional			Specialist Mandatory	**503**	Applied Molecular Biology	Specialist Mandatory	**506**	Medical Microbiology	Specialist Mandatory	**509**	Forensic Evidence Collection at Crime Scenes	Specialist Mandatory	**512**	Solid State and Transition Metal Chemistry	Specialist Mandatory	**515**	Green Chemistry
Optional			Specialist Mandatory	**504**	Industrial Microbiology	Specialist Mandatory	**507**	Pathophysiology and Applied Diagnostics	Specialist Mandatory	**510**	Forensic Evidence Evaluation and Reporting	Specialist Mandatory	**513**	Aromatic and Carbonyl Compounds	Specialist Mandatory	**516**	Sources, Impact and Control of Pollution
Optional			Specialist Mandatory	**505**	Ethics and Biotechnology	Specialist Mandatory	**508**	Diagnostics for the Biomedical Sciences	Specialist Mandatory	**511**	Applied Forensic Science	Specialist Mandatory	**514**	Spectroscopy, Surface Chemistry and Equilibria	Specialist Mandatory	**517**	Environmental Monitoring and Analysis
Optional			Optional			Optional			Optional			Optional			Optional		
Optional			Optional			Optional			Optional			Optional			Optional		

Table 3: Level 4 and Level 5 Optional Units

UNIT NUMBER	L4 OPTIONAL UNITS
414	Introduction to Chemistry
415	Managing Scientific Projects
416	Work-based Learning
417	Principles of Ecology
418	Managing Environmental Resources
419	Bioinformatics
420	Cheminformatics
421	Volume Crime Scene Science
422	Forensic Anthropology and Pathology
423	Analytical Chemistry
424	Artificial Intelligence in Applied Science

UNIT NUMBER	L5 OPTIONAL UNITS
518	Calculus for the Applied Sciences
519	Science Laboratory Management
520	Stem Cell Biology
521	Infectious Disease Epidemiology and Control
522	Histology and Haematology
523	Principles of Pharmacology
524	Immunology
525	Genomics and Proteomics
526	Further Analytical Chemistry
527	Clinical Chemistry
528	Manage Forensic Investigations at Scenes
529	Conservation and Biodiversity
530	Plant Biotechnology
531	Soil Science and Geochemical Processes

3.0 The unit descriptor

The unit descriptor is how we define the individual units of study that make up a Higher National qualification. Students will complete the units included in the programme you offer at your centre.

You can use any of the unit descriptors listed in *Section 4 Unit descriptors*. We have described each part of the unit as follows.

Table 4: Description of each part of the unit

Unit title	A general statement of what the unit will cover.
Unit code	The Ofqual unit reference number.
Unit type	There are three unit types: • core (mandatory to all pathways) • specialist (mandatory to specific pathways) • optional (available to most pathways).
Unit level	All our Pearson BTEC Higher National units are at Levels 4 or 5.
Credit value	The credit value relates to the total qualification time (TQT) and unit learning hours (ULH). It is easy to calculate: • 1 credit = 10 ULH • 15 credits = 150 ULH. To complete a Higher National Certificate or Higher National Diploma, students must achieve all of the credits required. Refer to Section 7.5 Calculating the final qualification grade in the programme specification.
Introduction	Some general notes on the unit: • setting the scene • stating the purpose and aim, and • outlining the topics to be learned and skills gained through the unit.
Learning Outcomes	These clearly explain what students will be able to do after completing the unit. There are usually four Learning Outcomes for each unit.
Essential Content	This section covers the content that students can expect to study as they work towards achieving their Learning Outcomes.
Learning Outcomes and Assessment Criteria	Tutors can refer to this table when grading assignments. The table connects the unit's Learning Outcomes with the student's work. Assignments can be graded at 'Pass' (P), 'Merit' (M) and 'Distinction' (D), depending on the quality of the student's work.
Recommended Resources	This section lists the resources that students should use to support their study for the unit. It includes books, journals and online material. The programme tutor may also suggest resources, particularly for local information. It may also contain delivery requirements e.g. specific equipment, case study material, learning resources, depending on the subject.

Web resources – referencing

Some units have web resources as part of their recommended resources list. Hyperlinking to these resources directly can cause problems, as their locations and addresses may change. To avoid this problem we only link to the main page of the website and signpost students and tutors to the section where the resource can be found. Therefore, we have referenced web resources as follows:

[1] A link to the main page of the website

[2] The title of the site

[3] The section of the website where the resource can be found

[4] The type of resource it is, for example:

- research
- general reference
- tutorial
- training
- e-book
- report
- wiki
- article
- data set
- development tool
- discussion forum.

Example

[1] https://www.ncbi.nlm.nih.gov

[2] National Center for Biotechnology Information (NCBI)

[3] Biomedical and molecular bioscience resources

[4] (Research)

Students and tutors must use a referencing system to cite and reference resources in an academic format.

4.0 Unit descriptors

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit code: **L/652/3033**

Unit level: **4**

Credit value: **15**

Introduction

Biological laboratory techniques underpin a wide range of scientific and healthcare activities, from routine diagnostic testing to research and industrial analysis. Laboratories provide controlled environments in which biological materials can be handled, analysed and interpreted, and the reliability of results depends on consistent procedures, appropriate use of equipment and adherence to safety requirements. This unit introduces the key principles that support effective laboratory practice and prepares students for working within regulated scientific environments.

The aim of this unit is to develop students' understanding of core biological laboratory techniques alongside the regulatory frameworks and professional standards that govern their use. Students will explore how laboratory protocols, safety procedures and quality requirements contribute to accurate and reliable scientific outcomes. The unit also supports the development of practical skills and awareness of professional responsibilities, providing a foundation for further study or entry into laboratory-based roles.

The unit covers a range of essential topics that reflect real laboratory practice. Students will examine laboratory organisation, documentation systems and regulatory compliance, including the management of risk and safe working procedures. They will explore the preparation and handling of biological samples and the use of common laboratory techniques such as spectroscopy, chromatography and electrophoresis. The unit also introduces key principles of data generation, quality control and investigation workflows, allowing students to understand how valid scientific results are produced in routine laboratory settings.

On successful completion of this unit, students will be able to carry out basic laboratory techniques safely, apply standard procedures, and generate and handle reliable scientific data. These skills are directly relevant to employment and progression within the sector, supporting roles such as Laboratory Technician,

Biomedical Science Assistant, Quality Control Technician, Research Laboratory Assistant and Forensic Laboratory Technician, as well as further study in biological or applied science disciplines.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the principles of biological laboratory protocols and regulatory compliance

LO2 Explore the tools and techniques used in routine biological laboratory work

LO3 Review how the application of analytical biological techniques can generate valid data

LO4 Implement biological laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose.

Essential Content

LO1 **Explain the principles of biological laboratory protocols and regulatory compliance**

Biological laboratory protocols:

Standard operating procedures (SOPs): standard operating procedures e.g. laboratory SOPs, method instructions; procedure purpose e.g. quality assurance, task consistency; procedure structure e.g. scope sections, step sequences

Laboratory organisation: laboratory housekeeping e.g. clean workspaces, storage rules; work area organisation e.g. designated zones, labelled areas; equipment set-up e.g. pre-use checks, correct configuration

Sample checks: sample receipt checks e.g. label verification, condition inspection; sample preparation checks e.g. volume confirmation, contamination checks.

Regulatory compliance principles (laboratory context):

Laboratory responsibilities: laboratory rules e.g. access rules, conduct expectations; individual responsibility e.g. role compliance, task ownership; accountability e.g. supervisor sign-off, traceable actions

Documentation systems: controlled records e.g. version control, approval tracking; raw data recording e.g. primary observations, direct entries, source data; laboratory worksheets e.g. task sheets, procedural logs, digital lab books; digital data handling e.g. timestamps, electronic signatures, version control, audit trails

Incident management: deviations e.g. non-conformities, process anomalies; reporting procedures e.g. incident reporting, corrective processes, documented follow-up

Regulation examples: using relevant national or regional ethical, data protection, health and safety, and regulatory frameworks e.g. Control of Substances Hazardous to Health (COSHH) 2002, Good Laboratory Practice Regulations (GLP) 1999, Genetically Modified Organisms (Contained Use) (GMO(CU)) 2014; Management of Health and Safety at Work Regulations 1999; laboratory standards e.g. ISO/IEC 17025.

Sustainability considerations within biological laboratory investigations:

Reagent use: controlled quantities e.g. measured volumes, regulated usage; measured use e.g. preparation control, accurate dispensing

Material efficiency: reduced consumption e.g. minimised usage, conservation practices; efficient use e.g. optimised quantities, planned utilisation, routine efficiency

Impact awareness: environmental effect e.g. ecological impact, operational footprint; resource impact e.g. material demand, consumption levels, waste output; device management e.g. asset life cycle, equipment lifespan, lifecycle planning, device disposal, recycling, procurement

Impact reduction: minimised emissions e.g. reduced releases, controlled outputs; reduced waste e.g. waste minimisation, segregation practices, compliant disposal.

Measurement accuracy and equipment function (principles):

Measurement quality: accuracy e.g. correct readings, reference comparisons; precision e.g. repeat measurements, consistency checks; measurement error e.g. random error, handling error

Equipment use: correct operation, method adherence; equipment checks e.g. functionality checks, condition checks

Calibration awareness: basic calibration awareness e.g. calibration schedules, reference standards; equipment limitations e.g. operating ranges, detection limits.

LO2 **Explore the tools and techniques used in routine biological laboratory work**

Biological sample types and characteristics:

Sample types: sample types e.g. tissue samples, microbial samples; sample matrices e.g. solid samples, liquid samples; sample stability e.g. temperature sensitivity, time limitations

Handling considerations: contamination susceptibility e.g. environmental exposure, handling contact; storage conditions e.g. refrigerated storage, room temperature storage; handling constraints e.g. fragility, limited volume

Transport conditions: transport requirements e.g. temperature-controlled transport, sealed containers; containment systems e.g. primary containers, secondary containment; transport documentation e.g. sample labels, transport records.

Biological laboratory tools and techniques:

Preparation techniques: aliquoting e.g. volume splitting, sub-sampling; dilution e.g. simple dilution, serial dilution; mixing e.g. manual mixing, vortex mixing

Processing techniques: separation e.g. phase separation, component isolation; centrifugation e.g. pellet formation, supernatant separation; staining e.g. basic stains, contrast stains

Controlled conditions: incubation e.g. timed incubation, temperature-controlled incubation; temperature control e.g. water baths, incubators

Liquid handling tools: pipettes e.g. micropipettes, adjustable pipettes; pipette tips e.g. sterile tips, disposable tips

Measurement and observation tools: balances e.g. digital balances, bench balances; microscopes e.g. light microscopes, basic compound microscopes; spectrophotometers e.g. visible light spectrophotometers, absorbance meters

Sample containment: glassware e.g. beakers, flasks; culture plates e.g. agar plates, multi-well plates

Aseptic practice: aseptic technique e.g. sterile handling, controlled movements; aseptic fields e.g. clean zones, sterile work areas

Contamination sources: contamination sources e.g. hands, surfaces; contamination routes e.g. air exposure, contact transfer; cross-contamination e.g. shared tools, reused consumables

Control measures: sterile consumables e.g. sterile tips, sterile containers; surface hygiene e.g. disinfected benches, wiped surfaces; hand hygiene e.g. hand washing, glove use

pH measurement methods: indicator methods e.g. pH paper, indicator dyes; electronic measurement e.g. digital pH meters, electrode probes

pH meter operation: electrode use e.g. glass electrodes, combination electrodes; measurement procedure e.g. sample immersion, stabilised readings; calibration checks e.g. buffer calibration, multi-point calibration

Volumetric glassware types: precision glassware e.g. volumetric flasks, burettes; transfer glassware e.g. pipettes, measuring cylinders; general glassware e.g. beakers, conical flasks

Volume measurement techniques: meniscus reading e.g. eye-level reading, bottom meniscus alignment; transfer techniques e.g. controlled pouring, pipette dispensing; rinsing methods e.g. pre-rinsing glassware, conditioning with solution.

Laboratory safety principles:

Hazard identification: chemical risks e.g. toxic substances, corrosive materials, volatile compounds, radioactive isotopes; biological risks e.g. infectious agents, biohazard materials, contamination sources, sharps risks

Risk assessment: control measures e.g. risk mitigation, hazard reduction, exposure prevention; safe working practices e.g. procedural compliance, authorised methods, standard procedures

Personal protection: personal protective equipment (PPE) e.g. lab coats, gloves; laboratory safety equipment e.g. fume cupboard, radiation shielding, safety shower

Waste handling: biological waste streams e.g. contaminated materials, disposal categories, hazardous waste; sharps disposal e.g. puncture-resistant containers, secure discarding, controlled handling.

LO3 **Review how the application of analytical biological techniques can generate valid data**

Core analytical technique principles (biological contexts):

Spectroscopy principles: light absorption e.g. energy uptake, wavelength interaction; light emission e.g. energy release, photon output; equipment and components: light sources e.g. lamps, LEDs; detectors e.g. photodiodes, sensors; cuvettes e.g. glass cells, sample holders; measurement practice: blanks e.g. baseline reference, zero calibration; concentration relationships e.g. signal intensity, proportional response

Chromatography principles: separation of mixtures e.g. compound separation, phase movement; mixture components e.g. analytes, sample constituents; separation process: sample introduction e.g. spotting, application points; sample movement e.g. solvent flow, migration distance; bands e.g. separated zones, visible spots; technique example: thin-layer chromatography (TLC) e.g. TLC plates, coated surfaces

Electrophoresis principles: separation by charge e.g. electric field movement, polarity effects; separation by size e.g. molecular separation, fragment distribution, mass-dependent differential migration; gel matrices e.g. agarose gels, polyacrylamide gels; operational stages: buffers e.g. running solutions, conductive media; sample loading e.g. wells, loading positions; staining e.g. visible dyes, DNA stains; result interpretation: visualisation e.g. band detection, imaging; molecular markers e.g. size standards, reference ladders; band patterns e.g. migration profiles, band arrangement.

Application of analytical biological techniques (overview concepts):

Analytical techniques: techniques e.g. laboratory tests, analytical methods; method purpose e.g. identification, measurement; measurement purpose e.g. concentration determination, comparison

Workflow considerations: sample preparation requirements e.g. dilution, filtration; workflow stages e.g. preparation, measurement; critical stages e.g. sample loading, result reading

Method suitability: suitability by sample type e.g. liquid samples, biological samples; method limitations e.g. sensitivity limits, interference effects

Generation of valid biological laboratory data:

Data quality: accuracy e.g. correct values, expected results; precision e.g. repeat measurements, consistency; repeat measurements e.g. duplicates, repeats

Controls and standards: calibration standards e.g. known standards, reference solutions; control samples e.g. comparison samples, check samples; positive controls e.g. expected outcome samples, known positives

Calibration processes: calibration procedures e.g. routine calibration, scheduled calibration; instrument adjustment e.g. zero adjustment, scale correction; calibration records e.g. calibration logs, documented checks

Performance verification: verification checks e.g. pre-use checks, performance checks; tolerance limits e.g. acceptable ranges, deviation limits; compliance requirements e.g. documented calibration, audit readiness

Error awareness: error sources e.g. handling errors, equipment variation; interference basics e.g. impurities, background signals

Impact on reliability: data quality e.g. result validity, measurement confidence; reliability e.g. interpretive strength, decision support.

LO4 **Implement biological laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose**

Applied regulatory-compliant investigation context:

Investigation purpose: defined purpose e.g. stated aim, investigation objective; scope definition e.g. investigation boundaries, activity limits

Regulatory alignment: SOPs alignment e.g. procedural compliance, method approval; risk assessment alignment e.g. identified hazards, documented controls

Technique selection: technique selection e.g. method selection, task alignment; safety requirements e.g. safe practice, regulatory compliance

Ethical and professional responsibilities: sample treatment e.g. secure handling, contamination avoidance; approved techniques e.g. validated methods, authorised processes; safety controls e.g. risk controls, protective measures.

Implementation of biological laboratory techniques:

Technique integration: multiple techniques e.g. combined methods, integrated methods; investigation workflow e.g. ordered steps, process flow; application consistency e.g. standardised methods, repeatable actions

Variable control: variable identification e.g. controlled variables, influencing factors; variable management e.g. condition control, consistency

Laboratory equipment use: equipment set-up e.g. instrument preparation, system configuration; operational checks e.g. performance checks, status verification

Contamination-control measures: controls e.g. clean environments, controlled procedures; waste handling e.g. waste segregation, disposal processes; laboratory waste e.g. hazardous materials, biohazards, contaminated waste, radioactive isotopes.

Quality and compliance:

Compliance monitoring: ongoing compliance e.g. procedure adherence, safety compliance; corrective action e.g. issue response, adjustment measures

Documentation maintenance: investigation records e.g. activity logs, procedural records; compliance evidence e.g. completed forms, recorded checks

Outcome evaluation: validity consideration e.g. result credibility, outcome trustworthiness; reliability consideration e.g. consistent outcomes, repeatability

Investigation limitations: technique limitations e.g. method constraints, equipment limits; application limitations e.g. operational constraints, procedural boundaries.

Data and evidence integrity:

Data handling: raw data e.g. instrument readings, observation notes; data recording e.g. tables, logged entries, timestamps, signatures; calculations e.g. basic calculations, checked values

Result verification: result checking e.g. range checks, repeat checks; repeat results e.g. duplicate runs, confirmation tests

Data storage: data storage e.g. lab folders, electronic files; data retention e.g. stored results, retained records; secure storage e.g. protected files, controlled access; data retrieval e.g. file access, record retrieval.

Presentation techniques:

Audience and purpose: audience identification e.g. assessor audience, peer audience; purpose of communication e.g. reporting purpose, assessment purpose, information sharing

Communication requirements: level of technical detail e.g. simplified language, subject terminology; stakeholder needs e.g. information needs, decision needs

Visual presentation: tables e.g. data tables, summary tables; figures e.g. diagrams, images; basic graph types e.g. bar charts, line graphs, scatter plots.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the principles of biological laboratory protocols and regulatory compliance</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the effectiveness of a range of identified tools and techniques used in routine biological laboratory work in relation to laboratory protocols and regulatory compliance principles.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the principles of biological laboratory protocols including equipment use.

P2 Discuss, using a selection of real-world examples, the principles of regulatory compliance and sustainability considerations within a biological laboratory context.</td><td>M1 Assess, using a selection of real-world examples, how biological laboratory protocols, regulatory compliance and sustainability considerations relate to biological laboratory activity.</td></tr>
<tr><td colspan="2">LO2 Explore the tools and techniques used in routine biological laboratory work</td></tr>
<tr><td>P3 Explore, using a selection of real-world examples, how tools and techniques are used in routine biological laboratory work.

P4 Review, using a selection of real-world examples, how biological samples are handled according to good laboratory safety principles.</td><td>M2 Analyse, using a selection of real-world examples, the effectiveness of selected tools and techniques used in routine biological laboratory work.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Review how the application of analytical biological techniques can generate valid data		**LO3 and LO4** **D2** Evaluate the effectiveness of the chosen biological laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation, considering how effectively they support the generation of valid data.
P5 Review, using a selection of practical examples, the principles of operation of analytical biological techniques. **P6** Explore, using a selection of practical examples, how the application of analytical biological techniques can be used to generate valid data.	**M3** Assess, using a selection of practical examples, the effectiveness of analytical biological techniques in the generation of valid data.	
LO4 Implement biological laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose		
P7 Create an experimental design for the regulatory-compliant scientific investigation for a defined purpose. **P8** Implement biological laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose. **P9** Present the outcomes of the regulatory-compliant biological laboratory investigation to an identified audience.	**M4** Assess the choice of the selected biological laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation.	

Recommended Resources

Textbooks

Cappuccino, J.G. and Welsh, C.T. (2021) *Microbiology: A Laboratory Manual*. 12th edn. Harlow: Pearson.

Hofmann, A. and Clokie, S. (eds.) (2018) *Wilson and Walker's Principles and Techniques of Biochemistry and Molecular Biology*. 8th edn. Cambridge: Cambridge University Press.

Jones, A., Reed, R. and Weyers, J. (2021) *Practical Skills in Biology*. 7th edn. Pearson. ISBN: 978-1292397078.

Plummer, D.T. (1987) *An Introduction to Practical Biochemistry*. London: McGraw-Hill.

Reed, R., *et al.* (2021) *Practical Skills in Biomolecular Science*. 6th edn. Pearson. ISBN: 978-1292397085.

Seidman, L.A., Moore, C.J. and Mowery, J. (2022) *Basic Laboratory Methods for Biotechnology: Textbook and Laboratory Reference*. 3rd edn. Boca Raton: CRC Press.

Websites

https://www.hse.gov.uk/biosafety/index.htm	Health and Safety Executive Biological agents and laboratory safety (General reference)
https://www.who.int/publications/i/item/9789240011311	World Health Organization Laboratory biosafety manual (General reference)
https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html	International Organization for Standardization ISO/IEC 17025 — Testing and calibration laboratories Standards/regulatory guidance (Research)
https://www.nist.gov/feature-stories/why-you-need-standards/calibrations-and-accreditations	National Institute of Standards and Technology Calibrations and Accreditations (Article)

https://www.thermofisher.com/uk/en/home/references/gibco-cell-culture-basics/aseptic-technique.html	ThermoFisher Scientific Aseptic Laboratory Techniques and Safety in Cell Culture (Resource)
https://www.addgene.org/protocols/	AddGene Addgene Protocols (Video Hub)
https://www.eppendorf.com/product-media/doc/en/72923/Eppendorf_Liquid-Handling_Poster_Manual-Pipettes_Pipetting-Techniques.pdf	Eppendorf Pipetting Techniques (Poster)
https://applications.emro.who.int/dsaf/dsa28.pdf	World Health Organization (WHO) Specimen collection and transport for microbiological investigation (PDF Download)
https://edu.rsc.org/download?ac=510955	Royal Society of Chemistry (RSC) Beer-Lambert Law (PDF Download)
https://www.nist.gov/programs-projects/spectrophotometry	National Institute of Standards and Technology Spectrophotometry (General reference)

Journals and articles

Bornstein-Forst, S.M. (2017) 'Establishing Good Laboratory Practice at Small Colleges and Universities', *Journal of Microbiology & Biology Education*, 18(1). Available at: https://doi.org/10.1128/jmbe.v18i1.1222.

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Stelz-Sullivan, E.J. *et al.* (2022) 'Enhancing STEM Education by Integrating Research and Teaching in Photochemistry: An Undergraduate Chemistry Laboratory in Spectroscopy and Photochemistry', *Education Sciences*, 12(10), 729. Available at: https://doi.org/10.3390/educsci12100729.

Tewari, S. *et al.* (2024) 'Measurement uncertainty in testing of biologicals for ISO/IEC 17025: practical approaches', *Accreditation and Quality Assurance*, 253–261. Available at: https://doi.org/10.1007/s00769-024-01589-8.

Links

This unit links to the following related units:

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 408: Human Anatomy and Physiology.

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit code: M/652/3034

Unit level: 4

Credit value: 15

Introduction

Forensic laboratories operate within highly regulated environments where scientific work must be accurate, reliable and fully traceable. The outcomes of forensic laboratory activity can have significant consequences within the criminal justice system, placing a strong emphasis on professional practice, quality systems and compliance with established standards. This unit introduces the principles and practices that underpin effective forensic laboratory work.

The aim of this unit is to develop students' understanding of core forensic laboratory protocols and the regulatory frameworks that govern laboratory operations. It is designed as an entry-level unit within the forensic pathway, providing a foundation comparable in scope and demand to other introductory laboratory units, while remaining firmly rooted in forensic practice. The unit supports students in developing an awareness of professional responsibilities, quality expectations and regulatory compliance within routine forensic laboratory settings.

The unit covers essential tools, techniques and working practices used in routine forensic laboratory work. Students will explore sample handling, measurement, equipment use and contamination-control procedures, alongside the application of selected analytical techniques used to generate valid forensic data. Emphasis is placed on good laboratory practice, sustainability considerations, adherence to standard operating procedures (SOPs), and the role of documentation and quality controls in maintaining evidential integrity, rather than on specialist analysis.

On successful completion of this unit, students will be able to work safely and effectively within a regulated forensic laboratory environment, applying appropriate techniques, quality controls and documentation practices to support a defined scientific investigation. This unit provides a foundation for progression within the forensic sector and supports entry into roles such as Forensic Laboratory Assistant, Evidence Handling Technician, Quality Support Technician, Forensic Laboratory Technician and Scientific Support Officer, as well as further study within forensic science pathways.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the principles of forensic laboratory protocols and regulatory compliance

LO2 Explore the tools and techniques used in routine forensic laboratory work

LO3 Review how the application of analytical forensic techniques can generate valid data

LO4 Implement forensic laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose.

Essential Content

LO1 **Explain the principles of forensic laboratory protocols and regulatory compliance**

Forensic laboratory protocols:

Standard operating procedures: laboratory SOPs e.g. written procedures, procedural documents; method instructions e.g. step instructions, task guidance; quality assurance e.g. process control, outcome accuracy, result reliability; structured format e.g. document scope, role allocation, sequential steps

Laboratory organisation: housekeeping practices e.g. cleanliness standards, workspace maintenance; designated work areas e.g. task-specific areas, separated zones, managed workflows; controlled access zones e.g. authorised entry, security restrictions

Sample checks: sample receipt verification e.g. intake logging, receipt confirmation, initial inspection; sample integrity e.g. identification markers, tamper indicators

Biohazard classification: biological risk levels e.g. low-risk biologicals, high-risk biohazards; infectious potential e.g. pathogen presence, contamination risk; regulatory classification e.g. biohazard categories.

Regulatory compliance principles (forensic laboratory context):

Laboratory responsibilities: laboratory rules e.g. behavioural standards, procedural expectations; individual roles e.g. assigned duties, responsibility allocation, accountability tracking

Documentation systems: controlled records e.g. version control, approval tracking; raw data recording e.g. primary observations, direct entries, source data; laboratory worksheets e.g. task sheets, procedural logs, digital lab books; digital data handling e.g. timestamps, electronic signatures, version control, audit trails

Incident management: deviations e.g. non-conformities, process anomalies; reporting procedures e.g. incident reporting, corrective processes, documented follow-up

Regulatory frameworks: using relevant national or regional ethical, data protection, health and safety, and regulatory frameworks e.g. Health and Safety at Work etc. Act 1974, Control of Substances Hazardous to Health Regulations (COSHH) 2002, Management of Health and Safety at Work Regulations 1999; laboratory standards e.g. ISO/IEC 17025, Forensic Science Regulator Codes of Practice, United Kingdom Accreditation Service (UKAS) requirements.

Sustainability considerations:

Reagent use: controlled quantities e.g. measured volumes, regulated usage; measured use e.g. preparation control, accurate dispensing

Material efficiency: reduced consumption e.g. minimised usage, conservation practices; efficient use e.g. optimised quantities, planned utilisation, routine efficiency

Impact awareness: environmental effect e.g. ecological impact, operational footprint; resource impact e.g. material demand, consumption levels, waste output; device management e.g. asset life cycle, equipment lifespan, life cycle planning, device disposal, recycling, procurement

Impact reduction: minimised emissions e.g. reduced releases, controlled outputs; reduced waste e.g. waste minimisation, segregation practices, compliant disposal.

Measurement accuracy, equipment function and calibration (principles):

Measurement principles: accuracy e.g. correctness of results, expected values; precision e.g. repeat consistency, reproducibility, stable outputs

Equipment use: laboratory equipment e.g. instrumentation types, analytical devices; condition checks e.g. functionality checks, maintenance review

Calibration awareness: calibration schedules e.g. planned intervals, service timelines, calibration records; equipment limitations e.g. performance constraints, operating boundaries.

LO2 **Explore the tools and techniques used in routine forensic laboratory work**

Forensic sample types and handling characteristics:

Forensic sample types: biological samples e.g. body fluid swabs, DNA extracts, tissue fragments; chemical samples e.g. seized powders, unknown substances, residue samples; physical samples e.g. fibres, particulate traces, debris fragments

Sample matrices: solids e.g. crystalline substances, powder residues, compact materials; liquids e.g. fluid specimens, solution-based evidence, solvent mixtures; mixed materials e.g. composite samples, heterogeneous materials, multi-phase evidence

Sample stability factors: environmental exposure e.g. temperature variation, moisture levels, light exposure; time delays e.g. storage duration, processing lag, delayed analysis; storage conditions e.g. refrigeration, sealed containment, controlled environments

Handling considerations: contamination susceptibility e.g. cross-transfer risk, airborne exposure, contact contamination; limited sample quantities e.g. small volumes, trace amounts, minimal samples; evidential integrity e.g. preservation requirements, continuity assurance, secure handling.

Forensic laboratory tools and techniques:

Core laboratory tools: measurement equipment e.g. balances, measurement tools; handling tools e.g. forceps, disposable tools; monitoring devices e.g. temperature monitors, pH monitors, environmental monitors

Routine techniques: weighing e.g. mass determination, quantitative measurement, balance readings; controlled transfer e.g. sample movement, contamination control, transfer precision; aliquoting e.g. portion division, measured splitting, sub-sampling; dilution e.g. concentration adjustment, solution preparation, controlled mixing; microscopy e.g. light microscopes, compound microscopes, basic imaging tools

Equipment use: equipment set-up e.g. power on, preparation steps, cleaning, equilibration; calibration status checks e.g. routine checks; safe shut-down procedures, equipment care.

Laboratory safety principles:

Hazard identification: chemical risks e.g. toxic substances, corrosive materials, volatile compounds, radioactive isotopes; biological risks e.g. infectious agents, biohazard materials, contamination sources

Risk assessment: control measures e.g. risk mitigation, hazard reduction, exposure prevention; safe working practices e.g. procedural compliance, authorised methods, standard procedures

Personal protective equipment: PPE e.g. gloves, lab coats, eye protection; forensic laboratory activities e.g. evidence processing, sample examination, laboratory handling

Waste handling: forensic waste streams e.g. contaminated materials, disposal categories, hazardous waste; sharps disposal e.g. puncture-resistant containers, secure discarding, controlled handling

Handling of body fluids:

Body fluid types: blood samples e.g. blood stains, liquid blood; saliva samples e.g. oral swabs, surface residues; other biological fluids e.g. semen samples, urine samples

Safe handling practices: controlled manipulation e.g. minimal handling, restricted exposure; transfer procedures e.g. secure transfer, sealed movement; exposure minimisation e.g. reduced contact, barrier methods

Sample labelling: identification labels e.g. sample identifiers, barcode systems; hazard labels e.g. biohazard symbols, warning labels; traceability records e.g. documentation links, chain of custody

Storage conditions: controlled storage e.g. refrigerated storage, secure containment; segregation requirements e.g. separation from non-biological samples, designated storage areas.

LO3 **Review how the application of analytical forensic techniques can generate valid data**

Analytical technique principles (forensic contexts):

Spectroscopy principles: light absorption e.g. energy uptake, wavelength interaction; light emission e.g. energy release, photon output; equipment and components: light sources e.g. lamps, LEDs; detectors e.g. photodiodes, sensors; cuvettes e.g. glass cells, sample holders; measurement practice: blanks e.g. baseline reference, zero calibration; concentration relationships e.g. signal intensity, proportional response

Electrophoresis principles: separation by charge e.g. electric field movement, polarity effects; separation by size e.g. molecular separation, fragment distribution, mass-dependent differential migration; gel matrices e.g. agarose gels, polyacrylamide gels

Operational stages: buffers e.g. running solutions, conductive media; sample loading e.g. wells, loading positions; staining e.g. visible dyes, DNA stains

Result interpretation: visualisation e.g. band detection, imaging; molecular markers e.g. size standards, reference ladders; band patterns e.g. migration profiles, band arrangement

Chromatography principles: separation of mixtures e.g. compound separation, phase movement; mixture components e.g. analytes, sample constituents; separation process: sample introduction e.g. spotting, application points; sample movement e.g. solvent flow, migration distance; bands e.g. separated zones, visible spots; technique example: thin-layer chromatography (TLC) e.g. TLC plates, coated surfaces

Mass spectrometry principles: mass-to-charge analysis; ion separation e.g. *m*/*z* ratios, ion mass values; charged particles e.g. ionised molecules, fragment ions; mass spectra e.g. spectral patterns, peak profiles; ionisation methods: electron ionisation e.g. electron ionisation sources, fragmentation patterns; soft ionisation e.g. electrospray ionisation, chemical ionisation; sample ionisation e.g. gas-phase ions, liquid-phase ions

Combined techniques: gas chromatography–mass spectrometry (GC–MS): volatile compound separation and detection e.g. gas-phase separation, retention time analysis, fragmentation pattern identification; liquid chromatography–mass spectrometry (LC–MS): non-volatile compound separation and detection e.g. liquid–phase separation, polar compound analysis, molecular ion detection.

Application of analytical forensic techniques (overview concepts):

Purpose of analytical techniques: identification e.g. substance recognition, material classification; comparison e.g. sample matching, reference comparison; measurement e.g. quantitative values, analytical outputs

Routine forensic workflows: sample preparation e.g. extraction, initial treatment; sequencing of tests e.g. ordered analysis, workflow stages; critical control points e.g. process checks, validation stages

Technique suitability: sample type e.g. biological material, chemical evidence; sample condition e.g. degraded material, contamination effects; sample quantity e.g. trace amounts, limited samples.

Generation of valid forensic laboratory data:

Valid data concepts: accuracy e.g. correct values, expected results; precision e.g. repeat agreement, consistent outputs; consistency e.g. stable results, uniform outputs

Quality controls: calibration standards e.g. known values, reference standards; control samples e.g. positive controls, negative controls; reference materials e.g. certified materials, benchmark samples

Sources of error: sample handling e.g. preparation errors, transfer issues; equipment variation e.g. instrument drift, calibration fluctuation; environmental interference e.g. temperature effects, humidity impact

Impact on reliability: data quality e.g. result validity, measurement confidence; evidential reliability e.g. interpretive strength, decision support.

LO4 **Implement forensic laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose**

Applied regulatory-compliant investigation context:

Investigation purpose: defined purpose e.g. stated aim, investigation objective; scope definition e.g. investigation boundaries, activity limits

Regulatory alignment: SOP alignment e.g. procedural compliance, method approval; risk assessment alignment e.g. identified hazards, documented controls

Technique selection: e.g. method selection, task alignment; safety requirements e.g. safe practice, regulatory compliance

Ethical and professional responsibilities: evidential materials e.g. secure handling, contamination avoidance; approved techniques e.g. validated methods, authorised processes; safety controls e.g. risk controls, protective measures.

Implementation of forensic laboratory techniques:

Technique integration: multiple techniques e.g. combined methods, integrated methods; investigation workflow e.g. ordered steps, process flow; application consistency e.g. standardised methods, repeatable actions

Variable control: variable identification e.g. controlled variables, influencing factors; variable management e.g. condition control, consistency

Laboratory equipment use: equipment set-up e.g. instrument preparation, system configuration; operational checks e.g. performance checks, status verification

Contamination-control measures: controls e.g. clean environments, controlled procedures; waste handling e.g. waste segregation, disposal processes; forensic waste e.g. hazardous materials, biohazards, contaminated waste.

Quality and compliance:

Compliance monitoring: ongoing compliance e.g. procedure adherence, safety compliance; corrective action e.g. issue response, adjustment measures

Documentation maintenance: investigation records e.g. activity logs, procedural records; compliance evidence e.g. completed forms, recorded checks

Outcome evaluation: validity consideration e.g. result credibility, outcome trustworthiness; reliability considerations e.g. consistent outcomes, repeatability

Investigation limitations: technique limitations e.g. method constraints, equipment limits; application limitations e.g. operational constraints, procedural boundaries.

Data and evidence integrity:

Data handling: raw data e.g. instrument readings, observation notes; data recording e.g. tables, logged entries; calculations e.g. basic calculations, checked values

Result verification: result checking e.g. range checks, repeat checks; repeat results e.g. duplicate runs, confirmation tests

Data storage: e.g. lab folders, electronic files; data retention e.g. stored results, retained records; secure storage e.g. protected files, controlled access; data retrieval e.g. file access, record retrieval.

Presentation techniques:

Audience and purpose: audience identification e.g. assessor audience, peer audience; purpose of communication e.g. reporting purpose, assessment purpose, information sharing

Communication requirements: level of technical detail e.g. simplified language, subject terminology; stakeholder needs e.g. information needs, decision needs

Visual presentation: tables e.g. data tables, summary tables; figures e.g. diagrams, images; basic graph types e.g. bar charts, line graphs, scatter plots.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the principles of forensic laboratory protocols and regulatory compliance</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the effectiveness of a range of identified tools and techniques used in routine forensic laboratory work in relation to laboratory protocols and regulatory compliance principles.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the principles of forensic laboratory protocols including equipment use.

P2 Discuss, using a selection of real-world examples, the principles of regulatory compliance and sustainability considerations within a forensic laboratory context.</td><td>M1 Assess, using a selection of real-world examples, how forensic laboratory protocols, regulatory compliance and sustainability considerations relate to forensic laboratory activity.</td></tr>
<tr><td colspan="2">LO2 Explore the tools and techniques used in routine forensic laboratory work</td></tr>
<tr><td>P3 Explore, using a selection of real-world examples, how tools and techniques are used in routine forensic laboratory work.

P4 Review, using a selection of real-world examples, how forensic samples are handled according to good laboratory safety principles.</td><td>M2 Analyse, using a selection of real-world examples, the effectiveness of selected tools and techniques used in routine forensic laboratory work.</td></tr>
</table>

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO3 Review how the application of analytical forensic techniques can generate valid data</td><td rowspan="5">LO3 and LO4

D2 Evaluate the effectiveness of the chosen forensic laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation, considering how effectively they support the generation of valid data.</td></tr>
<tr><td>P5 Review, using a selection of practical examples, the principles of operation of analytical forensic techniques.

P6 Explore, using a selection of practical examples, how the application of analytical forensic techniques can be used to generate valid data.</td><td>M3 Assess, using a selection of practical examples, the effectiveness of analytical forensic techniques in the generation of valid data.</td></tr>
<tr><td colspan="2">LO4 Implement forensic laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose</td></tr>
<tr><td>P7 Create an experimental design for the regulatory-compliant scientific investigation for a defined purpose.

P8 Implement forensic laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose.

P9 Present the outcomes of the regulatory-compliant forensic laboratory investigation to an identified audience.</td><td>M4 Assess the choice of the selected forensic laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation.</td></tr>
</table>

Recommended Resources

Textbooks

Bell, S. (2025) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 6th edn. Boca Raton: CRC Press.

Bell, S. (2022) *Forensic Chemistry*. 3rd edn. Boca Raton: CRC Press.

Harris, H.A. and Lee, H.C. (2019) *Introduction to Forensic Science and Criminalistics*. 2nd edn. Boca Raton: CRC Press.

Houck, M.M. and Siegel, J.A. (2015) *Fundamentals of Forensic Science*. 3rd edn. London: Academic Press.

James, S.H., Nordby, J.J. and Bell, S. (2019) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 5th edn. Boca Raton: CRC Press.

McCartney, C. (2012) *Forensic Evidence and Criminal Justice*. London: Routledge.

Mozayani, A. and Noziglia, C. (2010) *The Forensic Laboratory Handbook: Procedures and Practice*. 2nd edn. Totowa, NJ: Humana Press.

Nic Daéid, N. and White, P.C. (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. London: Royal Society of Chemistry.

Robertson, J., Roux, C. and Wiggins, K.G. (2017) *Forensic Examination of Fibres*. 3rd edn. Boca Raton: CRC Press.

Websites

https://www.labmanager.com/comprehensive-guide-to-iso-iec-17025-accreditation-prep-for-forensic-labs-34639	Lab Manager Comprehensive Guide to ISO/IEC 17025 Accreditation (Article)
https://www.qse-academy.com/iso-17025-documentation-package/	QSE Academy ISO/IEC 17025:2017 Documentation Kit (General reference)
https://www.numberanalytics.com/blog/contamination-control-forensic-labs	Number Analytics Contamination Control in Forensic Laboratories (Blog)

https://www.labmanager.com/biohazardous-and-toxin-sample-handling-protocols-for-laboratory-safety-34637	Lab Manager Biohazardous and Toxin Sample Handling Protocols (Article)
https://www.simplyforensic.com/the-ultimate-guide-to-forensic-chromatography-techniques-types-and-applications/	Simply Forensic Guide to Forensic Chromatography (General resource)
https://www.azooptics.com/Article.aspx?ArticleID=2456	AZoOptics Spectroscopy Techniques Used in Forensic Science (Article)
https://nij.ojp.gov/nij-hosted-online-training-courses/law-101-legal-guide-forensic-expert/pretrial/pretrial-motions/chain-custody	National Institute of Justice Chain of Custody Guidance (General reference)
https://www.labmanager.com/evidence-chain-of-custody-best-practices-building-trust-and-traceability-across-scientific-and-forensic-labs-34564	Lab Manager Evidence Chain of Custody Best Practices (Guide)
https://www.excedr.com/blog/lab-equipment-list-for-forensic-analysis	Excedr Laboratory Equipment List for Forensic Analysis (Article)
https://www.aeanet.org/what-tools-do-forensic-scientists-use/	AEANET Tools Used by Forensic Scientists (Article)

Journals and articles

Bornstein-Forst, S.M. (2017) 'Establishing Good Laboratory Practice at Small Colleges and Universities', *Journal of Microbiology & Biology Education*, 18(1). Available at: https://doi.org/10.1128/jmbe.v18i1.1222.

D'Anna, T., *et al.* (2023) 'The Chain of Custody in the Era of Modern Forensics: From the Classic Procedures for Gathering Evidence to the New Challenges Related to Digital Data', *Healthcare*, 11(5), 634. Available at: https://doi.org/10.3390/healthcare11050634.

Giappichini, G., *et al.* (2022) 'Quality assurance in forensic biology inspection: A validation study', *International Journal of Forensic Sciences*, 7(1). Available at: https://doi.org/10.23880/ijfsc-16000250.

Hughes, N. and Ziemak, E. (2021) 'Toward a cost-benefit analysis of quality programmes in digital forensic laboratories in the United States', *WIREs Forensic Science*, 3(4). Available at: https://doi.org/10.1002/wfs2.1422.

Jones, N.S. and Forry, E.P. (2023) *Demystifying Accreditation: A Framework for Accreditation of Forensic Units*. NIST Grant/Contractor Report GCR 23-043. Available at: https://doi.org/10.6028/NIST.GCR.23-043.

Neuteboom, W., *et al.* (2024) 'Quality Management in forensic science: A closer inspection', *Forensic Science International*, 358, 111779. Available at: https://doi.org/10.1016/j.forsciint.2023.111779.

Overill, R.E. and Collie, J. (2021) 'Quantitative evaluation of the results of digital forensic investigations: A review of progress', *Forensic Sciences Research*, 6(1), pp. 13–18. Available at: https://doi.org/10.1080/20961790.2020.1837429.

Sandhu, P.K., *et al.* (2017) 'Effectiveness of Laboratory Practices to Reduce Specimen Labeling Errors at the Time of Specimen Collection in Healthcare Settings: A Laboratory Medicine Best Practices (LMBP) Systematic Review', *Journal of Applied Laboratory Medicine*, 2(2), pp. 244–258. Available at: https://doi.org/10.1373/jalm.2017.023762.

Tewari, S., *et al.* (2024) 'Measurement uncertainty in testing of biologicals for ISO/IEC 17025: Practical approaches', *Accreditation and Quality Assurance*, 29, pp. 1–11. Available at: https://doi.org/10.1007/s00769-024-01589-8.

Links

This unit links to the following related units:

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 407: Fundamentals of Biochemistry

Unit 409: Fundamentals of Forensic Science

Unit 410: Criminal Investigation.

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit code: R/652/3035

Unit level: 4

Credit value: 15

Introduction

Chemical laboratories play a central role across a wide range of applied science sectors, including industrial, environmental, forensic, pharmaceutical and research settings. In these settings, laboratory activity must be carried out with precision, consistency and a strong awareness of safety and regulatory requirements. Developing confidence in the use of laboratory techniques and understanding how controlled procedures lead to reliable outcomes is essential for anyone progressing into scientific or technical roles. This unit introduces the core practices that support effective laboratory work within real-world chemical environments.

The aim of this unit is to provide students with a clear and practical understanding of fundamental chemical laboratory techniques and the principles that govern their use. It focuses on developing competence in following established procedures, using laboratory equipment correctly, and working in a safe and organised manner. The unit also highlights the importance of regulatory frameworks, accurate record keeping and responsible working practices as central aspects of professional laboratory activity.

The unit covers a range of essential topics that form the foundation of routine chemical laboratory work. Students will explore standard laboratory protocols, including workflow organisation, housekeeping and documentation systems, alongside relevant health and safety and regulatory requirements. Students will investigate the core analytical techniques used to generate chemical data, including spectroscopy, chromatography, titration and electrochemical methods. They will explore the fundamental principles behind measurement, calibration and detection, and examine how factors such as accuracy, precision, sensitivity and method suitability influence results.

On successful completion of this unit, students will be able to carry out chemical laboratory tasks in a safe, organised and compliant manner, applying appropriate techniques to produce dependable results. They will be able to select and use laboratory equipment effectively, follow established procedures and present findings

clearly. These skills support progression within applied science and prepare students for entry-level laboratory roles such as Laboratory Technician, Quality Control Technician, Analytical Science Assistant, Pharmaceutical Production Technician and Environmental Laboratory Assistant.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the principles of chemical laboratory protocols and regulatory compliance

LO2 Explore the tools and techniques used in routine chemical laboratory work

LO3 Review how the application of analytical chemistry techniques can generate valid data

LO4 Implement chemical laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose.

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Essential Content

LO1 **Explain the principles of chemical laboratory protocols and regulatory compliance**

Chemical laboratory protocols:

Standard operating procedures (SOPs): purpose e.g. defined intent, procedural rationale; scope e.g. activity boundaries, application limits; authorisation e.g. managerial approval, sign-off responsibility; version control e.g. document numbering, revision tracking

Laboratory workflow organisation: e.g. task sequencing, activity planning; clean-to-dirty sequencing e.g. contamination control, process order; activity segregation e.g. incompatible activities, spatial separation

Housekeeping expectations: workspace organisation e.g. bench layout, equipment placement; routine cleaning schedules e.g. daily cleaning, scheduled cleaning; cross-contamination prevention e.g. surface control, material separation.

Regulatory compliance principles (chemical laboratory context):

Laboratory responsibilities: laboratory rules e.g. behavioural standards, procedural expectations; individual roles e.g. assigned duties, responsibility allocation, accountability tracking

Documentation systems: controlled records e.g. version control, approval tracking; raw data recording e.g. primary observations, direct entries, source data; laboratory worksheets e.g. task sheets, procedural logs, digital lab books; digital data handling e.g. timestamps, electronic signatures, version control, audit trails

Incident management: deviations e.g. non-conformities, process anomalies; reporting procedures e.g. incident reporting, corrective processes, documented follow-up

Chemical waste management: waste classification e.g. hazard classes, waste types; waste containment e.g. sealed containers, secondary containment; disposal routes e.g. authorised disposal, collection systems

Regulatory frameworks: health and safety legislation e.g. Health and Safety at Work etc. Act 1974, Control of Substances Hazardous to Health Regulations (COSHH) 2002, Management of Health and Safety at Work Regulations 1999; laboratory standards e.g. ISO/IEC 17025 (using relevant national or regional ethical, data protection, health and safety, and regulatory frameworks).

Sustainability considerations:

Reagent use: controlled quantities e.g. measured volumes, regulated usage; measured use e.g. preparation control, accurate dispensing

Material efficiency: reduced consumption e.g. minimised usage, conservation practices; efficient use e.g. optimised quantities, planned utilisation, routine efficiency

Impact awareness: environmental effect e.g. ecological impact, operational footprint; resource impact e.g. material demand, consumption levels, waste output; device management e.g. asset life cycle, equipment lifespan, life cycle planning, device disposal, recycling, procurement

Impact reduction: minimised emissions e.g. reduced releases, controlled outputs; reduced waste e.g. waste minimisation, segregation practices, compliant disposal.

Measurement accuracy, equipment function and calibration (principles):

Measurement principles: accuracy e.g. correctness of results, expected values; precision e.g. repeat consistency, reproducibility, stable outputs

Equipment use: laboratory equipment e.g. instrumentation types, analytical devices; condition checks e.g. functionality checks, maintenance review

Calibration awareness: calibration schedules e.g. planned intervals, service timelines, calibration records; equipment limitations e.g. performance constraints, operating boundaries.

LO2 **Explore the tools and techniques used in routine chemical laboratory work**

Chemical sample types and handling characteristics:

Physical sample types: solids e.g. powders, crystals, pellets; liquids e.g. aqueous solutions, organic solvents, emulsions; gases e.g. compressed gases, vapours, volatile compounds; particulates e.g. suspended solids, aerosols, fine particulates

Handling requirements: contamination control e.g. clean transfer, surface control; temperature control e.g. refrigeration, controlled heating, ambient stability; degradation sensitivity e.g. light sensitivity, oxidation risk, moisture sensitivity

Storage requirements: storage conditions e.g. temperature control, humidity control, light exclusion; container selection e.g. sealed containers, inert materials, compatible storage vessels; segregation e.g. incompatible substances, hazard class separation; labelling requirements e.g. chemical identification, hazard labelling, date marking

Transport conditions: sample transport e.g. secure containers, sealed transport, spill prevention; environmental control e.g. temperature regulation, vibration minimisation, light protection; handling during transport e.g. secure positioning, impact prevention, containment integrity.

Chemical laboratory tools and techniques:

Balances and weighing: analytical balances e.g. mass measurement, precision weighing; top pan balances e.g. routine weighing, sample weighing; mass recording e.g. value recording, unit notation

Volumetric glassware and measurement: pipettes e.g. liquid transfer, volume delivery; burettes e.g. titration delivery, controlled release; volumetric flasks e.g. solution preparation, fixed volume preparation; volume reading e.g. meniscus alignment, eye-level reading

Basic meters and measurement: pH meters e.g. acidity measurement, alkalinity measurement; simple probes e.g. parameter monitoring, routine measurement; meter operation e.g. instrument activation, probe immersion; reading stabilisation e.g. response stabilisation, consistent values

Solution handling: solution transfer e.g. pouring technique, pipetting technique; solution mixing e.g. homogenisation, complete dissolution

Equipment preparation and readiness: cleanliness e.g. contamination prevention, residue removal; suitability for purpose e.g. correct capacity, task matching; environmental considerations e.g. temperature control, vibration avoidance

Equipment checking and calibration: visual checks e.g. damage identification, defect recognition; zeroing procedures e.g. balance zeroing, baseline setting; verification checks e.g. reference checks, control checks; calibration status e.g. calibration labels, calibration records; tolerance limits e.g. acceptable variation, allowable range.

Laboratory safety principles:

Hazard identification: chemical risks e.g. toxic substances, corrosive materials, volatile compounds, flammable substances, oxidising agents

Risk management frameworks: COSHH principles e.g. exposure control, substance assessment; hazard identification e.g. hazard recognition, danger identification; risk assessment processes e.g. hazard evaluation, risk scoring

Personal protection: personal protective equipment (PPE) selection e.g. glove choice, eye protection; PPE correct use e.g. proper fitting, correct wearing; PPE limitations e.g. protection boundaries, material limits; laboratory safety equipment e.g. fume cupboard, safety shower, fire extinguishers

Waste handling: chemical waste streams e.g. contaminated materials, disposal categories, hazardous waste

Chemical handling practices: safe handling e.g. careful transfer, exposure avoidance, spill prevention, exposure control; chemical storage e.g. storage conditions, containment areas; chemical labelling e.g. hazard labels, identification labels.

LO3 **Review how the application of analytical chemistry techniques can generate valid data**

Core analytical technique principles (chemistry contexts):

Spectroscopy principles: quantification e.g. absorbance reading, concentration calculation; measurement range e.g. linear range, instrument scale; sensitivity e.g. absorbance sensitivity, signal response; selectivity e.g. wavelength selection, analyte targeting; detection limits e.g. minimum concentration, instrument detection

Chromatography principles: concentration e.g. sample concentration, solution concentration; calibration e.g. calibration curves, standard solutions; standardisation e.g. reference standards, calibration standards; detection limits e.g. minimum detection, signal threshold

Mass spectrometry principles: mass-to-charge analysis: ion separation e.g. *m*/*z* ratios, ion mass values; charged particles e.g. ionised molecules, fragment ions; mass spectra e.g. spectral patterns, peak profiles; ionisation methods: electron ionisation e.g. electron ionisation sources, fragmentation patterns; soft ionisation e.g. electrospray ionisation, chemical ionisation; sample ionisation e.g. gas-phase ions, liquid-phase ions

Combined techniques: gas chromatography–mass spectrometry (GC–MS): volatile compound separation and detection e.g. gas-phase separation, retention time analysis, fragmentation pattern identification; liquid chromatography–mass spectrometry (LC–MS): non-volatile compound separation and detection e.g. liquid-phase separation, polar compound analysis, molecular ion detection

Titration principles: quantification e.g. concentration calculation, endpoint determination; concentration e.g. analyte concentration, titrant concentration; standardisation e.g. standard solutions, primary standards; calibration e.g. burette calibration, volume checks

Electrochemical methods: sensitivity e.g. electrode sensitivity, pH response; selectivity e.g. ion selectivity, analyte detection; response time e.g. electrode response, reading stabilisation; instrument stability e.g. meter stability, probe stability.

Application of analytical chemistry techniques (overview concepts):

Analytical techniques: e.g. laboratory tests, analytical methods; method purpose e.g. identification, measurement; measurement purpose e.g. concentration determination, comparison

Workflow considerations: sampling and preparation techniques: sampling e.g. grab sampling, composite sampling; sample preparation e.g. drying, grinding; solution preparation e.g. dissolution, mixing; dilution e.g. serial dilution, volumetric dilution; separation techniques: filtration e.g. gravity filtration, vacuum filtration; separation e.g. phase separation, solid–liquid separation; titration e.g. acid–base titration, redox titration; measurement and detection techniques: measurement e.g. volume measurement, mass measurement; detection e.g. endpoint detection, colour change; observation e.g. colour observation, precipitation observation

Method suitability: suitability by sample type e.g. liquid samples, solid samples, gaseous samples; method limitations e.g. sensitivity limits, interference effects.

Generation of valid chemistry laboratory data:

Data quality definitions: accuracy e.g. closeness to true value, measurement correctness; precision e.g. repeatability, consistent results; repeatability e.g. repeated measurements, consistent outcomes; reliability e.g. dependable results, reproducible data

Sources of error: equipment error e.g. instrument limitations, calibration issues; technique error e.g. handling mistakes, procedural deviation; environmental factors e.g. temperature effects, vibration effects; operator factors e.g. user variation, handling skill

Data quality impact: incorrect technique application e.g. measurement bias, result distortion; data validity e.g. trustworthy data, usable results.

LO4 **Implement chemical laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose**

Applied regulatory-compliant investigation context:

Investigation purpose: defined purpose e.g. stated aim, investigation objective; scope definition e.g. investigation boundaries, activity limits

Regulatory alignment: SOP alignment e.g. procedural compliance, method approval; risk assessment alignment e.g. identified hazards, documented controls

Technique selection: e.g. appropriate methods, task suitability; safety requirements e.g. safe practice, regulatory compliance

Ethical and professional responsibilities: sample treatment e.g. secure handling, contamination avoidance; approved techniques e.g. validated methods, authorised processes; safety controls e.g. risk controls, protective measures.

Implementation of chemical laboratory techniques:

Technique integration: multiple techniques e.g. combined methods, sequential techniques; investigation workflow e.g. ordered steps, process flow

Variable control: variable identification e.g. controlled variables, influencing factors; variable management e.g. condition control, consistency

Safe operation: chemical handling e.g. controlled transfer, exposure avoidance; equipment handling e.g. correct use, damage prevention

Laboratory equipment use: equipment set-up e.g. instrument preparation, system configuration; operational checks e.g. performance checks, status verification

Technique application consistency: application consistency e.g. standardised methods, repeatable actions; operational control e.g. controlled procedures, stable operation.

Quality and compliance:

Compliance monitoring: ongoing compliance e.g. procedure adherence, safety compliance; corrective action e.g. issue response, adjustment measures

Documentation maintenance: investigation records e.g. activity logs, procedural records; compliance evidence e.g. completed forms, recorded checks

Outcome evaluation: validity consideration e.g. result credibility, outcome trustworthiness; reliability consideration e.g. consistent outcomes, repeatability

Investigation limitations: technique limitations e.g. method constraints, equipment limits; application limitations e.g. operational constraints, procedural boundaries.

Data and evidence integrity:

Data handling: raw data e.g. instrument readings, observation notes; data recording e.g. tables, logged entries; calculations e.g. basic calculations, checked values

Result verification: result checking e.g. range checks, repeat checks; repeat results e.g. duplicate runs, confirmation tests

Data storage: e.g. lab folders, electronic files; data retention e.g. stored results, retained records; secure storage e.g. protected files, controlled access; data retrieval e.g. file access, record retrieval.

Presentation techniques:

Audience and purpose: audience identification e.g. assessor audience, peer audience; purpose of communication e.g. reporting purpose, assessment purpose, information sharing

Communication requirements: level of technical detail e.g. simplified language, subject terminology; stakeholder needs e.g. information needs, decision needs

Visual presentation: tables e.g. data tables, summary tables; figures e.g. diagrams, images; basic graph types e.g. bar charts, line graphs, scatter plots.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the principles of chemical laboratory protocols and regulatory compliance</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the effectiveness of a range of identified tools and techniques used in routine chemical laboratory work in relation to laboratory protocols and regulatory compliance principles.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the principles of chemical laboratory protocols including equipment use.

P2 Discuss, using a selection of real-world examples, the principles of regulatory compliance and sustainability considerations within a chemical laboratory context.</td><td>M1 Assess, using a selection of real-world examples, how chemical laboratory protocols, regulatory compliance and sustainability considerations relate to chemical laboratory activity.</td></tr>
<tr><td colspan="2">LO2 Explore the tools and techniques used in routine chemical laboratory work</td></tr>
<tr><td>P3 Explore, using a selection of real-world examples, how tools and techniques are used in routine chemical laboratory work.

P4 Review, using a selection of real-world examples, how chemical samples are handled according to good laboratory safety principles.</td><td>M2 Analyse, using a selection of real-world examples, the effectiveness of selected tools and techniques used in routine chemical laboratory work.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Review how the application of analytical chemistry techniques can generate valid data		**LO3 and LO4** **D2** Evaluate the effectiveness of the chosen chemical laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation, considering how effectively they support the generation of valid data.
P5 Review, using a selection of practical examples, the principles of operation of analytical chemistry techniques. **P6** Explore, using a selection of practical examples, how the application of analytical chemistry techniques can be used to generate valid data.	**M3** Assess, using a selection of practical examples, the effectiveness of analytical chemistry techniques in the generation of valid data.	
LO4 Implement chemical laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose		
P7 Create an experimental design for the regulatory-compliant scientific investigation for a defined purpose. **P8** Implement chemical laboratory tools and techniques to carry out a regulatory-compliant scientific investigation for a defined purpose. **P9** Present the outcomes of the regulatory-compliant chemical laboratory investigation to an identified audience.	**M4** Assess the choice of the selected chemical laboratory tools and techniques used to carry out a regulatory-compliant scientific investigation.	

Recommended Resources

Textbooks

Ault, A. and Jones, R. (2021) *Chemical Laboratory Techniques*. 3rd edn. London: Pearson Education.

Bradley, D. and Smith, J. (2022) *Laboratory Safety and Compliance in Chemistry*. 2nd edn. Oxford: Oxford University Press.

Dey, P. (2022) *Basic and Advanced Laboratory Techniques*. 2nd edn. Singapore: Springer.

Harris, D.C. (2020) *Quantitative Chemical Analysis*. 10th edn. New York: W.H. Freeman.

Miller, J.N. and Miller, J.C. (2021) *Statistics and Chemometrics for Analytical Chemistry*. 7th edn. Harlow: Pearson.

Mohrig, J.R., *et al.* (2022) *Laboratory Techniques in Organic Chemistry*. 4th edn. New York: W.H. Freeman.

Rouessac, F. and Rouessac, A. (2020) *Chemical Analysis: Modern Instrumentation Methods*. 3rd edn. Chichester: Wiley.

Slowinski, E.J., Wolsey, W.C. and Rossi, R.C. (2021) *Chemical Principles in the Laboratory*. 12th edn. Boston: Cengage Learning.

Skoog, D.A., Holler, F.J. and Crouch, S.R. (2020) *Principles of Instrumental Analysis*. 7th edn. Boston: Cengage Learning.

Zhang, W. and Cue, B.W. (2021) *Green Techniques for Organic Synthesis and Medicinal Chemistry*. 2nd edn. Hoboken: Wiley.

Websites

https://www.hse.gov.uk/coshh/	Health and Safety Executive (UK) COSHH regulations and guidance for controlling hazardous substances in chemistry laboratories (General reference)
https://mygreenlab.org/how-to-green-your-lab/	MyGreenLab Sustainability in labs (General reference)

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https://warwick.ac.uk/fac/sci/eng/local/hands/labsafety/guide_to_good_lab_practice_v4.pdf	University of Warwick Good laboratory practice, housekeeping, workflow organisation and contamination prevention in chemistry labs (PDF download)
https://chemtl.york.ac.uk/home	University of York Chemistry Teaching Laboratories (General reference)
https://readchemistry.com/2019/01/07/calibrating-volumetric-glassware-in-the-laboratory/	Read Chemistry Calibration principles and procedures for volumetric equipment used in teaching laboratories (Article)
https://www.physicsclassroom.com/Chemistry-Tutorial/Measurement-and-Units/Evaluating-Results	The Physics Classroom Accuracy, precision and repeatability applied to chemistry laboratory data (Tutorial)
https://chem-textbook.ucalgary.ca/version2/review-of-background-topics/measurements-and-data/uncertainty-accuracy-and-precision/sources-of-error/	University of Calgary Sources of uncertainty and experimental error in laboratory measurements (General reference)
https://sciencenotes.org/error-in-science/	Science Notes and Projects Systematic and random errors in chemistry laboratory experiments with practical examples (General reference)
https://www.acs.org/content/dam/acsorg/about/governance/committees/chemicalsafety/publications/safety-in-academic-chemistry-laboratories-students.pdf	American Chemical Society Regulatory-compliant chemistry laboratory investigations, risk assessment and safe execution (PDF download)
https://www.rsc.org/policy-and-campaigning/sustainability/sustainable-laboratories	Royal Society of Chemistry Sustainable laboratories (General reference)

Journals and articles

Budelier, M.M. and Hubbard, J.A. (2023) 'The regulatory landscape of laboratory developed tests: Past, present, and future perspectives', *Journal of Mass Spectrometry and Advanced Clinical Laboratory*, 28, pp. 67–69. Available at: https://doi.org/10.1016/j.jmsacl.2023.02.008.

Chaudhry, A.S., Inata, Y. and Nakagami-Yamaguchi, E. (2023) 'Quality analysis of the clinical laboratory literature and its effectiveness on laboratory quality improvement: a systematic review', *Journal of Clinical Biochemistry and Nutrition*, 73(2), pp. 108–115. Available at: https://doi.org/10.3164/jcbn.23-22.

Graden, K.C., *et al*. (2021) 'A High-Level Overview of the Regulations Surrounding a Clinical Laboratory and Upcoming Regulatory Challenges for Laboratory Developed Tests', *Laboratory Medicine*, 52(4), pp. 315–328. Available at: https://doi.org/10.1093/labmed/lmaa086.

Goldsack, J.C., *et al*. (2020) 'Verification, analytical validation, and clinical validation (V3): The foundation of determining fit-for-purpose for Biometric Monitoring Technologies (BioMeTs)', *npj Digital Medicine*, 3, Article 55. Available at: https://doi.org/10.1038/s41746-020-0260-4.

Konnick, E.Q. (2020) 'The regulatory landscape of precision oncology laboratory medicine in the United States – Perspective on the past 5 years and considerations for future regulation', *Practical Laboratory Medicine*, 21, e00172. Available at: https://doi.org/10.1016/j.plabm.2020.e00172.

Sonntag, O. and Loh, T.P. (2023) 'Calibration – an under-appreciated component in the analytical process of laboratories', *Advances in Laboratory Medicine*, 5(2), pp. 148–152. Available at: https://doi.org/10.1515/almed-2023-0127.

Links

This unit links to the following related units:

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 411: Inorganic Chemistry

Unit 412: Organic Chemistry

Unit 413: Physical Chemistry.

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit code: T/652/3036

Unit level: 4

Credit value: 15

Introduction

Mathematics and statistics play a central role across the applied sciences, underpinning how data is collected, analysed and used to support scientific decision-making. From laboratory measurements to experimental investigations, these tools allow scientists and technicians to describe relationships, identify patterns and draw meaningful conclusions from real-world data. This unit introduces students to the core mathematical and statistical concepts that support accurate and reliable scientific practice.

The aim of this unit is to develop students' confidence and competence in applying mathematical and statistical techniques within applied science contexts. Students will build essential skills in numerical handling, algebra, graphical interpretation and statistical reasoning, enabling them to approach scientific problems in a structured and methodical way.

The unit covers key mathematical techniques such as measurement, units, algebraic manipulation and graphing, alongside fundamental statistical methodologies including data types, sampling, probability and descriptive statistics. Students will also explore how these techniques are selected and applied to real scenarios, with an emphasis on interpreting results, recognising limitations and communicating findings clearly.

On successful completion of this unit, students will be able to apply mathematical and statistical methods to support scientific investigations and data-driven decisions. These skills are directly relevant to entry-level and junior roles within science-based sectors, including Laboratory Technician, Science Technician, Quality Control Assistant, Data Technician and Research Support Assistant, and provide a strong foundation for progression to further study in applied science and data-focused units.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explore the mathematical techniques required by the applied sciences

LO2 Discuss the different statistical methodologies used by the applied sciences

LO3 Explain the range of statistical techniques used by the applied sciences

LO4 Apply a range of mathematical and statistical techniques to an identified applied sciences dataset to obtain useful insights.

Essential Content

LO1 **Explore the mathematical techniques required by the applied sciences**

Number, units and measurement:

Units and scale systems: SI base units and derived units e.g. mass, length, time; force and energy units; unit symbols and conventions e.g. standard SI notation, correct symbol casing; conversion between SI prefixes e.g. milli-, micro- and nano.

Numerical representation: prefixes and powers of ten e.g. kilo-milli scaling, scientific measurement notation; scientific notation e.g. standard form writing, calculator scientific display; calculator and spreadsheet notation e.g. scientific calculator modes, spreadsheet exponential formats

Measurement accuracy: significant figures and decimal places e.g. reporting experimental results, calculator rounding behaviour; rounding rules e.g. standard rounding conventions, truncation effects; measurement resolution and instrument readability e.g. scale divisions, digital resolution limits, analogue readability

Standard error: sampling variability e.g. repeated sample variation, mean spread; calculation methods e.g. standard deviation ÷ $\sqrt{n}$, spreadsheet functions; estimate precision e.g. reliability of mean, comparison of datasets

Mathematical error types: absolute error e.g. measured vs true value difference, instrument deviation; relative error e.g. proportional error values, fractional difference; percentage error e.g. % calculation, cross-measurement comparison.

Algebra and functions (applied science contexts):

Formula handling: rearrangement of formulae e.g. subject change in physics equations, chemistry concentration equations; substitution e.g. replacing variables with measured values, parameter insertion; isolating variables e.g. solving for experimental unknowns, rate calculations

Relationships between variables: linear forms e.g. straight-line relationships, proportional trends; gradients and intercept meanings e.g. rate of change interpretation, baseline values; proportionality relationships e.g. direct proportional change, inverse relationships, scaling effects

Growth and decay patterns: exponential growth and decay forms e.g. half-life models, simple population growth, cooling curves.

Graphs and modelling (non-calculus):

Graph construction and reading: graph conventions e.g. titles and axis labels, unit labelling; axes, units and scale choice e.g. linear scale selection, appropriate units; plotting from data e.g. scatter plots, line graphs; reading values e.g. interpolation, approximate value extraction

Interpreting trends: gradient interpretation e.g. speed from distance-time graphs, reaction rate comparison; intercept interpretation e.g. starting value identification, baseline conditions

Selecting graph types: selection of appropriate plotting approach e.g. line graphs for trends, bar charts for categories, log scales for wide-range data.

LO2 **Discuss the different statistical methodologies used by the applied sciences**

Population, sample and representativeness:

Population and sample concepts: target population identification e.g. study group definition, investigation scope; sample selection e.g. choosing specimens, selecting participants

Representativeness considerations: coverage of key characteristics e.g. age groups, material types; relevance to investigation aim e.g. matching samples to research question

Sampling approaches: simple random sampling e.g. random number selection, unbiased choice; stratified sampling e.g. grouping by characteristic, proportional selection; convenience sampling e.g. readily available samples, time-limited collection.

Data types and implications for methodology:

Data types: categorical data e.g. classification groups, outcome categories; numerical data e.g. measured values, counted results; discrete and continuous data e.g. whole-number counts, measured quantities

Measurement scales: nominal scales e.g. named categories, labels; ordinal scales e.g. ranked outcomes, ordered groups; interval and ratio scales e.g. temperature measurements, mass and length measurements

Implications for analysis: suitable summary methods e.g. frequency counts, averages; appropriate chart selection e.g. bar charts, line graphs.

Study design approaches and bias reduction:

Study design types: surveys e.g. questionnaires, observation checklists; experiments e.g. controlled testing, variable manipulation; observational studies e.g. field observations, recorded behaviours

Sources of bias: selection bias e.g. non-representative samples, volunteer bias; measurement bias e.g. instrument error, observer variation

Bias reduction concepts: consistent procedures e.g. standardised methods, repeatable steps; fair selection methods e.g. random choice, balanced grouping; control of conditions e.g. same equipment, same environment.

Probability concepts and distributions (planning analysis):

Probability language: likelihood description e.g. chance statements, outcome expectation; chance interpretation e.g. possible vs unlikely events

Uncertainty and variation: expected variation e.g. natural differences in results, repeat measurement variation; outcome uncertainty e.g. unpredictable results, confidence in findings

Use of probability in planning: anticipating variability e.g. planning repeats, allowance for spread; judging rare outcomes e.g. unusual event awareness, low-frequency results.

LO3 **Explain the range of statistical techniques used by the applied sciences**

Descriptive statistics and data presentation:

Measures of central tendency: mean e.g. average measurement value, overall result indicator; median e.g. middle value identification, skew-resistant summary; mode e.g. most frequent value, common outcome identification

Measures of spread: range e.g. minimum–maximum comparison, variability span; interquartile range e.g. middle spread of data, variability comparison; standard deviation e.g. spread around the mean, consistency of results

Graphical summaries: bar charts e.g. category comparison, frequency display; histograms e.g. distribution shape, spread of values; scatter plots e.g. relationship display, pattern identification.

Relationships between variables and modelling (introductory):

Association concepts: relationship awareness e.g. linked variables, comparative change; direction of association e.g. positive trends, negative trends

Correlation awareness: strength indication e.g. weak relationships, strong relationships; interpretation limits e.g. association not causation, contextual influence

Best-fit line concepts: linear trend lines e.g. overall pattern indication, approximate prediction; extrapolation caution e.g. limits of data range, reliability awareness.

Hypothesis testing concepts:

Hypotheses: null hypothesis (H_0) e.g. no difference, no relationship; alternative hypothesis (H_1) e.g. difference present, relationship present

Hypothesis types: directional hypothesis e.g. greater than, less than; non-directional hypothesis e.g. difference without direction, general variation

Testing outcomes: hypothesis decision e.g. reject null hypothesis, fail to reject null hypothesis; result interpretation e.g. evidence of effect, no evidence of effect

Significance: statistical significance e.g. *p*-value threshold, strength of evidence; decision thresholds e.g. 0.05 level, comparison of values

Error types: type I error e.g. false positive, incorrect rejection; type II error e.g. false negative, failure to reject a false null hypothesis.

Non-parametric and assumption-aware technique selection:

Assumption awareness: normality concept e.g. symmetrical distributions, typical spread; independence awareness e.g. unrelated measurements, separate observations

Non-parametric technique awareness: rank-based comparison e.g. ordered data comparison, non-normal data handling; suitability contexts e.g. small samples, skewed data

Limitations and constraints: sample size sensitivity e.g. small dataset reliability, large variation effects; measurement scale constraints e.g. categorical data limits, ordinal ranking limits.

LO4 **Apply a range of mathematical and statistical techniques to an identified applied sciences dataset to obtain useful insights**

Dataset preparation and quality checks:

Data structure: records and variables e.g. rows as observations, columns as measurements; consistent units and coding e.g. same measurement units, clear category labels

Data quality checks: missing values e.g. incomplete records, absent measurements; duplicates e.g. repeated entries, copied records; outliers e.g. unusual values, extreme results

Data organisation: basic formatting e.g. tidy tables, consistent layouts; documentation of decisions e.g. notes on changes, reasons for exclusions.

Core analytical techniques and software outputs:

Summary calculations: measures of central tendency e.g. mean, median; measures of spread e.g. range, interquartile range, standard deviation

Relationship analysis: trend identification e.g. increasing or decreasing patterns, linear trends; comparison of groups e.g. differences between categories, simple comparisons, *t*-test, chi-square test

Use of software outputs: reading results e.g. table summaries, graph outputs; interpreting values e.g. typical results, noticeable differences; automated or AI-supported outputs e.g. suggested patterns, anomaly flags, with human verification.

Assumption checks and quick diagnostic approaches:

Visual checks: distribution inspection e.g. histograms, box plots; pattern recognition e.g. symmetry, skew

Data limitations: sample size constraints e.g. small datasets, limited repeats; measurement issues e.g. instrument precision, recording errors

Responding to issues: simple adjustments e.g. cautious interpretation, alternative summaries; stating limitations e.g. data quality notes, reliability concerns.

Presentation of findings and meaning:

Graphical presentation: appropriate charts e.g. bar charts, line graphs, scatter plots; clear labelling e.g. titles, units, legends

Interpreting results: linking findings to the scenario e.g. answering the question, relating to context; identifying key outcomes e.g. main trends, notable differences

Communicating conclusions: clear summaries e.g. plain-language explanations, short conclusions; awareness of limits e.g. assumptions made, confidence in results.

Real-world examples:

A range of real-world mathematical and statistical software: spreadsheet and general analysis tools e.g. Microsoft Excel for data tables, summary statistics, graphing; Google Sheets for collaborative data analysis, chart generation, data cleaning

Statistical analysis software: e.g. SPSS for descriptive statistics, hypothesis testing, regression analysis; R for statistical modelling, scripting-based analysis, data visualisation; Minitab for statistical testing, quality-control analysis

Data visualisation tools: e.g. Tableau for dashboards, interactive visualisations, trend analysis; Power BI for data dashboards, reporting outputs, interactive charts

Scientific and specialist tools: e.g. GraphPad Prism for biological data analysis, statistical testing, scientific graphing; OriginLab for scientific graphing, curve fitting, data modelling.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explore the mathematical techniques required by the applied sciences</td><td rowspan="5">LO1, LO2 and LO3

D1 Evaluate, using a selection of real-world examples, the effectiveness of mathematical techniques, statistical methodologies and statistical techniques used in applied science contexts.</td></tr>
<tr><td>P1 Explore, using a selection of real-world examples, the numerical and algebraic mathematical techniques required by the applied sciences.

P2 Explain, using a selection of real-world examples, the non-calculus graphical techniques required by the applied sciences.</td><td>M1 Analyse, using a selection of real-world examples, the numerical, algebraic and graphical techniques required by the applied sciences.</td></tr>
<tr><td colspan="2">LO2 Discuss the different statistical methodologies used by the applied sciences</td></tr>
<tr><td>P3 Discuss, using a selection of real-world examples, the use of different statistical methodologies in applied science investigations, including populations, samples, data types and probability concepts.

P4 Explore, using a selection of real-world examples, how sampling approaches and sources of bias can impact the approaches to the design of a study.</td><td>M2 Assess, using a selection of real-world examples, the suitability of different statistical methodologies for a study considering sampling approach, data types, probabilities and potential sources of bias.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Explain the range of statistical techniques used by the applied sciences		
P5 Explain, using a selection of real-world examples, the use of descriptive statistical techniques to summarise and present data in applied science contexts. **P6** Explore, using a selection of real-world examples, how basic graphical and relational techniques are used to identify patterns and relationships between variables in applied science data.	**M3** Analyse, using a selection of real-world examples, how the selection and interpretation of statistical techniques can impact the conclusions drawn from applied science data.	
LO4 Apply a range of mathematical and statistical techniques to an identified applied sciences dataset to obtain useful insights		**LO4** **D2** Justify the quality and reliability of the insights obtained from the identified dataset, considering the choice of mathematical and statistical techniques.
P7 Apply a range of mathematical and statistical techniques to an identified applied sciences dataset to obtain useful insights. **P8** Present the insights obtained from the application of selected mathematical and statistical techniques to an identified target audience to obtain feedback.	**M4** Evaluate, using audience feedback, the quality and reliability of the insights obtained from the identified dataset, considering the choice of mathematical and statistical techniques.	

Recommended Resources

Textbooks

Fein, E.C., *et al*. (2022) *Statistics for Research Students.* Toowoomba: University of Southern Queensland.

McClave, J.T. and Sincich, T. (2020) *Statistics*. 13th edn. Harlow: Pearson.

Meister, M., Lee, K.H. and Portugues, R. (2025) *Mathematics in Biology*. Cambridge, MA: The MIT Press.

Raffoul, Y.N. (2023) *Applied Mathematics for Scientists and Engineers*. New York: Chapman and Hall/CRC.

Samuels, M.L., Witmer, J.A. and Schaffner, A.A. (2021) *Statistics for the Life Sciences.* 5th edn. Harlow: Pearson.

Tan, S.T. (2022) *Applied Mathematics for the Managerial, Life, and Social Sciences.* 7th edn. Boston: Cengage Learning.

Vu, J. and Harrington, D. (2020) *Introductory Statistics for the Life and Biomedical Sciences*. Boston: OpenIntro.

Websites

https://www.nist.gov/pml/owm/si-learning-hub	NIST - SI Learning Hub Explanations of SI units, prefixes and unit conventions used in applied science (General reference)
https://www.mathcentre.ac.uk/	Mathematics learning support (General reference)
https://www.scribbr.co.uk/bias-in-research/sampling-bias-explained/	Scribbr Sampling bias explained with practical examples and avoidance strategies (Article)
https://serc.carleton.edu/mathyouneed/geomajors/intro-stats/index.html	Carleton College Using mean, median and spread in applied science contexts (Tutorial)
https://openstax.org/details/books/introductory-statistics-2e	OpenStax Introductory statistics (General reference)

https://www.cancer.gov/about-nci/organization/cbiit/training/learn/clean	Cancer.gov Cleaning data: the basics (General reference)
https://www.geeksforgeeks.org/data-visualization/scatter-diagram-correlation/	GeeksforGeeks Scatter diagrams and basic correlation explained with clear visuals (Tutorial)
https://www.elsevier.com/connect/5-key-practices-for-data-presentation-in-research	Elsevier Best practices for presenting scientific data clearly and accurately (Article)

Journals and articles

Abdi, S.J. (2023) 'A Comprehensive Guide for Selecting Appropriate Statistical Tests: Understanding When to Use Parametric and Nonparametric Tests', *Open Journal of Statistics*, 13(4), pp. 464–474. Available at: https://doi.org/10.4236/ojs.2023.134023.

Banda, G. and Patson, T.F. (2021) 'Parametric and Nonparametric Tests: A Brief Review', *International Journal of Statistical Distributions and Applications*, 7(3), pp. 78–82. Available at: https://doi.org/10.11648/j.ijsd.20210703.12.

Chicco, D., Oneto, L. and Tavazzi, E. (2022) 'Eleven quick tips for data cleaning and feature engineering', *PLOS Computational Biology*, 18(12), e1010718. Available at: https://doi.org/10.1371/journal.pcbi.1010718.

Hunter, P. (2021) 'Technical bias and the reproducibility crisis', *EMBO Reports*, 22, Article EMBR202052327. Available at: https://doi.org/10.15252/embr.202052327.

Kafadar, K. (2021) 'EDITORIAL: Statistical significance, *P*-values, and replicability', *The Annals of Applied Statistics*, 15(3), pp. 1081–1083. Available at: https://doi.org/10.1214/21-AOAS1500.

O'Leary, T.J. (2021) 'Rigor, Reproducibility, and the *P* Value', *The American Journal of Pathology*, 191(5), pp. 805–808. Available at: https://doi.org/10.1016/j.ajpath.2021.03.001.

Sharifnia, A.M., *et al.* (2025) 'A Primer of Data Cleaning in Quantitative Research: Handling Missing Values and Outliers', *Journal of Advanced Nursing*. Available at: https://doi.org/10.1111/jan.16908.

Vrbin, C.M. (2022) 'Parametric or nonparametric statistical tests: Considerations when choosing the most appropriate option for your data', *Cytopathology*, 33(6). Available at: https://doi.org/10.1111/cyt.13174.

Zhu, G., *et al*. (2024) 'A review of common statistical methods for dealing with multiple pollutant mixtures and multiple exposures', *Frontiers in Public Health*, 12, 1377685. Available at: https://doi.org/10.3389/fpubh.2024.1377685.

Links

This unit links to the following related units:

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 423: Analytical Chemistry

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 517: Environmental Monitoring and Analysis

Unit 518: Calculus for the Applied Sciences

Unit 519: Science Laboratory Management

Unit 521: Infectious Disease Epidemiology and Control

Unit 526: Further Analytical Chemistry

Unit 527: Clinical Chemistry.

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit code: Y/652/3037

Unit level: 4

Credit value: 15

Introduction

This unit is assessed through a Pearson-set assignment. The project brief will be set by the centre, based on a theme provided by Pearson (this will change annually). The theme and chosen project within the theme will enable students to explore and examine a relevant and topical aspect of applied science in the context of a professional environment.

Experimental design is central to applied scientific practice and supports the production of reliable and meaningful data. This unit introduces students to the principles and methods used to plan, conduct and present laboratory-based investigations. By exploring different experimental approaches, students will develop the ability to design and justify investigations appropriate to applied science contexts.

The aim of this unit is to develop students' knowledge of the principles that underpin effective experimental design and to build their confidence in applying these principles when planning and carrying out investigations. Through an exploration of methodological choices and experimental optimisation, students will learn how to design investigations that are robust, reproducible and fit for purpose.

On successful completion of this unit, students will be able to plan and justify experimental approaches, develop coherent experimental investigations, and communicate results clearly to an identified audience. These skills support progression into roles such as Laboratory Technician, Quality Control Technician, Scientific Technician, Research Assistant and Laboratory Analyst, as well as progression to further study in applied science disciplines.

***Please refer to the accompanying Pearson-set Assignment Guide and the Theme Release document for further support and guidance on the delivery of the Pearson-set unit.**

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core principles of experimental design

LO2 Discuss the methodological choices used to select and optimise experimental methods in applied laboratory contexts

LO3 Develop a series of laboratory-based experiments to investigate an identified scientific scenario

LO4 Deliver a presentation on the results of the experimental investigation to a technical and non-technical audience.

Essential Content

LO1 **Explain the core principles of experimental design**

Core principles of experimental design:

Experimental purpose and structure: experimental purpose e.g. investigation aim, study objective; investigable questions e.g. testable questions, focused research questions; hypothesis e.g. null hypothesis, alternative hypothesis, predicted outcome

Variables and controls: independent variables e.g. input factor, test condition; dependent variables e.g. measured outcome, response variable; controlled variables e.g. fixed conditions, constant factors; controls e.g. positive controls, negative controls

Experimental robustness: replication e.g. repeat measurements, replicate samples; avoidance of bias e.g. operator bias reduction, selection bias reduction; documentation of design decisions e.g. method records, planning notes.

Reliability and validity in experiments:

Measurement quality: reliability e.g. repeatability, consistency; validity e.g. measurement relevance, method appropriateness; accuracy e.g. closeness to true value, measurement correctness

Error and variability: sources of error e.g. measurement error, handling error, systematic error, calibration bias, method bias; random error e.g. reading variation, environmental fluctuation

Measurement limitations: instrument limitations e.g. detection limit, calibration range; method limitations e.g. procedural constraints, sensitivity limits; acceptance criteria e.g. tolerance limits, quality thresholds.

Iterative experimental development:

Experimental evaluation: unexpected results e.g. anomalous data, outlier values; failed outcomes e.g. no reaction, invalid results; identification of errors e.g. procedural faults, equipment faults

Improvement processes: basic troubleshooting e.g. method checks, equipment checks; problem solving e.g. issue identification, corrective actions

Development: modification of experimental approach e.g. parameter adjustment, method revision; planning next steps e.g. follow-up tests, repeat trials; process improvement e.g. method refinement, efficiency changes; implementation support e.g. team adoption, updated procedure.

LO2 **Discuss the methodological choices used to select and optimise experimental methods in applied laboratory contexts**

Experimental method selection choices:

Scientific method choice: experimental methods e.g. controlled experiments, comparative tests; investigative approach e.g. quantitative methods, qualitative methods; method suitability e.g. fitness for purpose, method alignment

Alignment with aims and data needs: experimental aims e.g. investigation goals, outcome focus; data requirements e.g. measurable outcomes, observable changes; variable suitability e.g. measurable variables, controllable factors

Practical considerations: feasibility e.g. practical viability, operational realism; resource constraints e.g. equipment access, material availability; time constraints e.g. schedule limits, duration limits.

Strengths and limitations of methodological choices:

Method strengths: reliability benefits e.g. consistent results, repeatable outcomes; validity benefits e.g. relevant measurements, appropriate methods

Method limitations: procedural weaknesses e.g. complex steps, operator dependence; scope limits e.g. narrow application, limited sensitivity

Impact on data quality: susceptibility to error e.g. measurement sensitivity, handling risks; bias risks e.g. selection bias, operator bias; reproducibility considerations e.g. repeatability across trials, consistency across operators.

Experimental method optimisation choices:

Optimisation purpose: method refinement e.g. procedural adjustment, step modification; improvement objectives e.g. improved accuracy, reduced variability; practical outcomes e.g. clearer results, reduced errors

Method adjustments: single-factor adjustment e.g. variable change, condition change; procedural modification e.g. step reordering, process simplification; parameter adjustment e.g. range adjustment, setting change

Decision criteria: result comparison e.g. improved accuracy, reduced error; feasibility considerations e.g. time constraints, resource availability; comparison methods e.g. baseline comparison, previous results comparison.

Strengths and limitations of optimisation choices:

Optimisation strengths: reliability improvement e.g. consistent results, repeatable outcomes; clarity improvement e.g. clearer trends, reduced ambiguity

Optimisation limitations: scope limits e.g. partial improvement, limited impact; change risks e.g. unintended effects, new errors.

LO3 **Develop a series of laboratory-based experiments to investigate an identified scientific scenario**

Scientific scenario definition and scope:

Scenario definition: scenario context e.g. investigation setting, application context; aims e.g. investigation aims, intended outcomes; objectives e.g. specific targets, measurable goals; innovation impact e.g. process improvement, efficiency gains, applied outcomes

Hypotheses in experimental series design: hypothesis formulation e.g. null hypothesis, alternative hypothesis; hypothesis operationalisation e.g. variable linkage, measurable outcomes; hypothesis testing structure e.g. controlled comparison, baseline comparison

Experimental framing: investigable questions e.g. testable questions, focused questions; variable identification e.g. independent variables, dependent variables; control strategies e.g. control variables, reference conditions

Constraints and criteria: assumptions and constraints e.g. practical limits, boundary limits; success criteria e.g. performance thresholds, outcome requirements; ethical and safety considerations e.g. risk awareness, ethical compliance.

Experimental series structure and control:

Experimental sequencing: logical sequencing e.g. ordered steps, staged progression; baseline measurements e.g. initial readings, reference values; progression between experiments e.g. stepwise development, incremental change

Control and decision points: control of variables e.g. constant conditions, controlled factors; decision points e.g. go-no-go points, evaluation stages; contingency planning e.g. backup plans, alternative actions

Documentation and traceability: version control across experiments e.g. protocol versions, method tracking; laboratory worksheets e.g. task sheets, procedural logs.

Preparation and use of laboratory equipment:

Equipment readiness: equipment selection e.g. suitable instruments, task-appropriate tools; equipment set-up e.g. configuration steps, assembly stages; calibration e.g. calibration checks, reference standards

Operational control: instrument checks e.g. performance checks, functionality checks; reagent preparation e.g. solution preparation, concentration preparation; contamination control e.g. clean handling, separation measures

Safe operation and maintenance: safe operation e.g. correct use, risk control; cleaning procedures e.g. cleaning routines, decontamination steps; routine maintenance e.g. maintenance schedules, basic servicing.

Data collection planning and integrity:

Data planning: measurement planning e.g. measurement strategy, sampling plan; observation and recording conventions e.g. standard notation, recording formats; units and calibration considerations e.g. measurement units, calibration references

Data integrity: data capture formats e.g. tables, electronic records; raw data integrity e.g. unaltered data, original records; completeness and traceability e.g. full datasets, audit trails

Data readiness: readiness for basic statistical summaries e.g. mean values, ranges; use of digital tools e.g. data modelling tools, data visualisation tools, AI-supported outputs with human verification.

LO4 **Deliver a presentation on the results of the experimental investigation to a technical and non-technical audience**

Audience and purpose of communication:

Audience and purpose: audience identification e.g. assessor audience, peer audience; purpose of communication e.g. reporting purpose, assessment purpose, information sharing

Communication requirements: level of technical detail e.g. simplified language, subject terminology; stakeholder needs e.g. information needs, decision needs

Ethical communication: ethical communication e.g. honest reporting, responsible claims; transparency e.g. clear methods, open explanation; acknowledgement of limitations e.g. data limitations, method limitations.

Results presentation conventions:

Selection and structure: selection of results e.g. relevant findings, key outcomes; ordering of information e.g. logical order, result sequence

Visual presentation: tables e.g. data tables, summary tables; figures e.g. diagrams, images; basic graph types e.g. bar charts, line graphs, scatter plots

Clarity and labelling: axis labelling e.g. labelled axes, variable names; units e.g. measurement units, standard units; legends e.g. symbol keys, colour keys; captions e.g. figure captions, table captions; visual clarity e.g. readable layout, clear formatting

Interpretation and coherence of presented results:

Result interpretation: description of trends e.g. increasing trends, decreasing trends; simple comparisons e.g. group comparison, value comparison

Linkage and conclusions: linkage to experimental aims e.g. aim alignment, objective alignment; cautious conclusions e.g. evidence-based conclusions, limited claims

Narrative coherence: consistency between methods and results e.g. method alignment, result relevance; clear narrative flow e.g. logical progression, structured explanation.

Scientific responsibility, sustainability and professional practice:

Professional integrity: integrity e.g. honest reporting, data honesty; ethical considerations e.g. consent, risk awareness; transparency e.g. clear methods, open reporting

Data responsibility: responsible data recording e.g. lab notebooks, electronic records; acknowledgement of limitations e.g. method constraints, data uncertainty

Professional practice and sustainability: safe use of resources e.g. equipment handling, chemical safety; minimisation of waste e.g. reagent reduction, efficient use; adherence to professional standards e.g. laboratory codes, workplace procedures.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core principles of experimental design</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the impact of experimental design principles, method selection and optimisation choices on the development of effective experimental design.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the core principles of experimental design and iterative development.

P2 Discuss, using a selection of real-world examples, the concepts of reliability and validity in scientific experiments.</td><td>M1 Analyse, using a selection of real-world examples, how the core principles of experimental design can impact experimental reliability and validity.</td></tr>
<tr><td colspan="2">LO2 Discuss the methodological choices used to select and optimise experimental methods in applied laboratory contexts</td></tr>
<tr><td>P3 Discuss, using a selection of real-world examples, the methodological choices used to select and optimise experimental methods in applied laboratory contexts.

P4 Review, using a selection of real-world examples, the strengths and limitations of the methodological choices used to optimise experimental methods in applied laboratory contexts.</td><td>M2 Assess, using a selection of real-world examples, the implications of different methodological choices for experimental selection and optimisation.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Develop a series of laboratory-based experiments to investigate an identified scientific scenario		**LO3**
P5 Plan a series of laboratory-based experiments to investigate an identified scientific scenario that demonstrates appropriate preparation and use of relevant laboratory equipment. **P6** Implement a series of laboratory-based experiments to investigate an identified scientific scenario to generate appropriate data. **P7** Review the data gathered from the laboratory-based experiments with a range of identified stakeholders to inform decisions.	**M3** Analyse, using the data collected and stakeholder feedback, the effectiveness of the selected laboratory-based experiments in addressing the hypotheses of the identified scientific scenario.	**D2** Justify, using the data collected and stakeholder feedback, the decisions made in the development of the experimental series identifying strengths and areas for improvement.
LO4 Deliver a presentation on the results of the experimental investigation to a technical and non-technical audience		**LO4**
P8 Deliver a presentation to a technical and non-technical audience that communicates the results of the experimental investigation and the methods used, demonstrating awareness of scientific responsibility, sustainability and professional practice. **P9** Review audience feedback to identify strengths and areas for improvement in the presentation and the experimental investigation.	**M4** Optimise the presentation using feedback from the identified audience.	**D3** Evaluate the effectiveness of the presentation in response to audience feedback.

Recommended Resources

Textbooks

Antony, J. (2023) *Design of Experiments for Engineers and Scientists*. 3rd edn. Amsterdam: Elsevier.

Glass, D.J. (2014) *Experimental Design for Biologists*. 2nd edn. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press.

Haaland, P.D. (2020) *Experimental Design in Biotechnology*. Boca Raton: CRC Press.

Harvey, D. (2016) *Analytical Chemistry 2.1*. DePauw University (Open Textbook).

Kubic, T. and Petraco, N. (2005) *Forensic Science Laboratory Manual and Workbook*. 2nd edn. Boca Raton: CRC Press.

Lazic, S.E. (2016) *Experimental Design for Laboratory Biologists: Maximising Information and Improving Reproducibility*. Cambridge: Cambridge University Press.

Manahan, S.E. (2022) *Environmental Chemistry*. 11th edn. Boca Raton: CRC Press.

Mozayani, A. and Noziglia, C. (eds.) (2011) *The Forensic Laboratory Handbook: Procedures and Practice*. New York: Springer.

Murphy, R.A. (2022) *Environmental Chemistry in the Lab*. Boca Raton: CRC Press.

Websites

https://writing.colostate.edu/guides/pdfs/guide66.pdf	Colorado State University Reliability and validity in research measurement (PDF download)
https://explorable.com/validity-and-reliability	Explorable Reliability, validity and replication in experimental design (Article)
https://www.labmanager.com/introduction-to-analytical-method-development-and-validation-33922	Lab Manager Introduction to analytical method development and optimisation (Article)
https://www.epa.gov/sites/default/files/2015-05/documents/402-b-04-001a-06-final.pdf	US Environmental Protection Agency Selection and application of analytical methods (PDF download)

https://www.stemcell.com/efficient-research/planning-experiments	STEMCELL Technologies Planning and managing laboratory experiments (Article)
https://online.stat.psu.edu/stat503/lesson/1	Pennsylvania State University Steps for planning and conducting experiments (General reference)
https://www.giss.nasa.gov/edu/icp/education/presentation/	NASA Presenting scientific research to different audiences (Resource)

Journals and articles

Dudda, L., *et al*. (2025) 'Open science interventions to improve reproducibility and replicability of research: A scoping review', *Royal Society Open Science*, 12(4), 242057. https://doi.org/10.1098/rsos.242057.

Hanisch, R.J., Gilmore, I.S. and Plant, A.L. (2019) 'Improving Reproducibility in Research: The Role of Measurement Science', *Journal of Research of the National Institute of Standards and Technology*, 124, Article 124024. https://doi.org/10.6028/jres.124.024.

Ioannidis, J.P.A. (2005) 'Why Most Published Research Findings Are False', *PLOS Medicine*, 2(8), e124. https://doi.org/10.1371/journal.pmed.0020124.

McEwen, L.R. and Martinsen, D.P. (2017) 'The Rise of Primary Research Data', *Chemistry International*, 39(3), pp. 3–4. https://doi.org/10.1515/ci-2017-0302.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 409: Fundamentals of Forensic Science

Unit 411: Inorganic Chemistry

Unit 412: Organic Chemistry

Unit 413: Physical Chemistry

Unit 415: Managing Scientific Projects

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 519: Science Laboratory Management.

Unit 406: Fundamentals of Cell and Molecular Biology

Unit code: A/652/3038

Unit level: 4

Credit value: 15

Introduction

Cell and molecular biology underpin the functioning of all living organisms, from single-cell microorganisms to complex biological systems. Knowledge of how cells are structured, function, communicate and are organised into systems, is relevant to a wide range of applied science disciplines, including biomedical sciences, biotechnology, forensic science, environmental science and life sciences. Skills required to investigate cellular and molecular levels are key within laboratory-based biomedical and life sciences research. Professionals working in these fields are required to understand how cells are structured, how they function, and how molecular processes such as gene expression, metabolism and signalling within and between cells, govern normal and disrupted biological systems. This unit positions cell and molecular biology within an applied science context, reflecting the foundational knowledge and skills expected of technicians, technologists and scientists working in laboratory, clinical, research and industrial environments. As biology increasingly relies on computational tools, databases and data-driven approaches, digital literacy, alongside core scientific knowledge, is essential.

The purpose of this unit is to develop students' understanding of the fundamental principles within cellular structure and function, molecular mechanisms of genetic information flow and the biochemical processes that support metabolism and communication within and between cells. Students will explore how these processes interact to maintain cellular or systemic homeostasis and how disruption can lead to altered function. The unit supports progression by providing essential knowledge that underpins more specialised study and practical application including knowledge of basic investigation techniques used across applied science pathways.

Students will examine the structural organisation of prokaryotic and eukaryotic cells and the roles of major cellular components. They will explore the molecular mechanisms governing genetic information flow, including DNA replication, transcription, translation and regulatory control. The unit also reviews key biochemical processes involved in cell metabolism and communication, highlighting the integration of metabolic pathways and signalling mechanisms in maintaining normal cellular function. Students will then apply this knowledge by investigating

the practical applications of cell and molecular biology techniques through theoretical case studies or practical laboratory-based investigation, culminating in the presentation of their findings to an identified audience.

On completion of this unit, students will be able to explain core cellular and molecular concepts, analyse relationships between structure and function, and evaluate the effects of disrupted biological processes. They will also develop skills in collecting, analysing and interpreting biological data; applying theoretical knowledge to practical contexts; and communicating scientific information clearly and appropriately. These capabilities support progression into laboratory-based employment, technical and scientific roles, and further academic study within applied biological, biomedical and biotechnological disciplines where a secure understanding of cell and molecular biology and the techniques used within this field is essential. Moving between bench and computer is a key skill for life science professionals and large datasets and complex bioinformatics analytic tools consume information derived from traditional experimental approaches. The combination of knowledge and skills gained within this unit prepares students for entry into biomedical and clinical research, pharmaceutical and biotechnology industries, clinical diagnostics, microbiology and public health, forensic science, bioinformatics, regulatory affairs, scientific communication and teaching.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles of cell structure and function

LO2 Describe the molecular mechanisms governing the flow of genetic information

LO3 Review the biochemical processes supporting cell metabolism and communication

LO4 Present, using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in cell and molecular biology, to an intended audience.

Essential Content

LO1 **Explain the fundamental principles of cell structure and function**

Cell types and cellular organisation:

Prokaryotic and eukaryotic cells: core structural differences e.g. presence or absence of membrane-bound organelles, cell size, surface area to volume ratio; functional differences e.g. exchange, metabolism, cellular efficiency

Cellular specialisation and differentiation: epithelial cells e.g. transport, barriers; neurones e.g. signal transmission; muscle cells e.g. contraction; plant cells e.g. chloroplasts for photosynthesis, cell walls for support

Microbiology related to cell types and organisation: e.g. single-celled organisms as models for cellular structure and function.

Cell membranes, dynamics and transport:

Cell membranes: structure e.g. phospholipid bilayer, integral and peripheral proteins, cholesterol, carbohydrates

Transport: transport mechanisms e.g. diffusion, osmosis, facilitated diffusion, active transport, endocytosis, exocytosis; energy requirements and concentration gradients; fluid mosaic model

Cell membrane receptors: cellular regulation and communication e.g. receptor-mediated responses to external signals.

Major cellular components and their roles:

Major components: nucleus, nucleolus, cytoplasm, cytosol, ribosomes, rough and smooth endoplasmic reticulum, Golgi apparatus, vesicles, mitochondria, lysosomes, peroxisomes; roles in cellular organisation, metabolism and protein processing

Structural support systems: cytoskeletal elements, centrosomes; cell shape, transport, division; cell surface, intercellular structures e.g. cell walls, tight junctions, desmosomes, plasmodesmata; cell integrity, adhesion, communication.

LO2 **Describe the molecular mechanisms governing the flow of genetic information**

Organisation of genetic information:

Structure: DNA nucleotide structure e.g. complementary base pairing, double-helix, antiparallel strands; DNA stability and replication

Gene organisation: coding regions, regulatory regions, control of gene expression; prokaryotic and eukaryotic genetic organisation; prokaryotes e.g. circular DNA, operons; eukaryotes e.g. linear chromosomes, regulatory sequences.

DNA replication:

Semi-conservative replication: replication origins, replication forks, leading strands, lagging strands, primer requirement, Okazaki fragments, DNA polymerase enzymes

Replication fidelity: proofreading mechanisms, causes of error; consequences of errors; conceptual differences between prokaryotic and eukaryotic replication e.g. single versus multiple origins, replication speed, complexity.

Transcription and RNA processing:

Transcription: initiation, elongation, termination; RNA polymerase, promoters, transcription factors

RNA types: mRNA, tRNA, rRNA e.g. their functions in gene expression; RNA processing in eukaryotic cells e.g. 5' capping, splicing, polyadenylation

Effects on RNA stability and translation efficiency: prokaryotes e.g. simultaneous transcription and translation; eukaryotes e.g. separate transcription and translation.

Translation and protein production:

Genetic code principles: codons, ribosome structure, ribosome function, tRNA roles, peptide bond formation; translation stages

Protein production: initiation, elongation, termination; post-translational modification e.g. phosphorylation, glycosylation; protein targeting principles e.g. direction of proteins to secretion pathways by signal peptides.

LO3 **Review the biochemical processes supporting cell metabolism and communication**

Cell metabolism and bioenergetics:

Cell metabolism: catabolism, anabolism, energy coupling, ATP, oxidation–reduction (redox) reactions

Electron carriers: transfer of energy e.g. NAD and FAD; metabolic activity and cellular function e.g. biosynthesis, active transport and cell division.

Enzymes and metabolic regulation:

Enzyme properties: specificity, active sites, structure-function relationships

Factors affecting enzyme activity: temperature, pH, substrate concentration, optimum conditions, denaturation

Enzyme inhibition: competitive, non-competitive; effects on reaction rate; regulation of metabolic pathways e.g. feedback inhibition, rate-limiting steps, regulation of key enzymes within glycolysis.

Core metabolic pathways and compartmentalisation:

Major metabolic pathways: glycolysis, aerobic respiration, fermentation e.g. purpose, energy yield; photosynthesis; metabolic breadth, comparison between autotrophic and heterotrophic metabolism

Biomolecule interconversion between carbohydrates, lipids and proteins: cellular compartmentalisation of metabolic processes within eukaryotic cells e.g. cytosolic versus mitochondrial reactions.

Cell communication and signalling processes:

Cell communication modes: autocrine, paracrine, endocrine, direct contact signalling

Categories of signalling molecules: peptide, steroid, small molecules

Receptor types: cell-surface, intracellular; differences in action mechanisms; signal transduction

Signalling processes: second messengers, phosphorylation cascades, signal amplification, signal termination, desensitisation e.g. receptor down-regulation.

Integration and disruption of metabolic and communication pathways:

Metabolic and communication pathways: cellular homeostasis, feedback mechanisms, maintenance of internal balance e.g. integration of signalling and metabolism

Coordination: signalling pathways in response to internal or external signals e.g. glucose uptake, biosynthetic activity

Sources of disruption: genetic changes, enzyme inhibition, receptor malfunction; effects on ATP production, metabolite balance, signalling accuracy, cellular function.

LO4 **Present**, **using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in cell and molecular biology, to an intended audience**

Application of cell and molecular biology techniques:

Purpose principles and applications: real-world case studies e.g. common cell and molecular biology techniques, laboratory investigation, theoretical analysis

Techniques: microscopy and staining, centrifugation, cell fractionation, nucleic acid extraction and quantification, polymerase chain reaction (PCR), gel electrophoresis, immunodetection techniques, spectroscopy-based measurement, cell counting, viability assessment

Data types and application contexts: diagnostics, biotechnology, biomedical research, quality testing.

Technique selection, limitations and sources of error:

Technique selection: investigative question, sample type, sensitivity, specificity, data output

Limitations and sources of error: contamination during nucleic acid extraction, non-specific antibody binding in immunodetection, limitations of resolution in microscopy, variability during sample preparation; controls, standards, replicates e.g. reliability, validity

Digital approaches to sample processing: digital microscopy, AI image processing and interpretation, reference databases, digitised and automated workflows.

Data types, interpretation and presentation:

Data types: qualitative and quantitative data e.g. generated by cell and molecular biology techniques

Results interpretation: interpretation in relation to the investigative question; patterns, anomalies, uncertainty

Data presentation conventions: tables, graphs, annotated images, flow diagrams, labelled figures, appropriate units, correct terminology e.g. gel electrophoresis band patterns, enzyme activity graphs, microscopy images; data integrity risks; digital tools e.g. data gathering, recording, analysis, presentation of large datasets.

Scientific communication, audience awareness and inclusion:

Communication: inclusive practices; adaptation for audiences with different levels of prior knowledge

Presentation structure: background, purpose, technique choice, rationale, findings, interpretation, limitations; scientific language, visual design, referencing e.g. clear figure labelling, no unnecessary jargon, appropriate visual aids

Ethical scientific communication: transparency, accuracy, avoidance of overclaiming and cultural bias in data selection, interpretation, presentation.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental principles of cell structure and function</td><td rowspan="9">LO1, LO2 and LO3

D1 Evaluate the impact of disruption to cellular structures, molecular mechanisms and biochemical pathways on cellular and systemic function.</td></tr>
<tr><td>P1 Describe key differences between prokaryotic and eukaryotic cells, including organisation and implications for function.

P2 Explain how membranes, transport mechanisms and major cellular components support cell function.</td><td>M1 Analyse the relationship between cell structure and function in different cell types.</td></tr>
<tr><td colspan="2">LO2 Describe the molecular mechanisms governing the flow of genetic information</td></tr>
<tr><td>P3 Outline how genetic information is organised in prokaryotic and eukaryotic cells.

P4 Describe the main stages of DNA replication.

P5 Outline the process of protein synthesis.</td><td>M2 Analyse how molecular mechanisms regulate genetic information flow under different cellular conditions.</td></tr>
<tr><td colspan="2">LO3 Review the biochemical processes supporting cell metabolism and communication</td></tr>
<tr><td>P6 Summarise key biochemical processes involved in cell metabolism.

P7 Describe biochemical processes involved in cell communication.</td><td>M3 Analyse the integration of metabolic pathways and cell communication in maintaining cellular homeostasis.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Present, using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in cell and molecular biology, to an intended audience		**LO4**
P8 Outline the practical applications of selected cell and molecular biology techniques through a real-world case study or laboratory-based investigation. **P9** Deliver a presentation on the results of the investigation into the practical applications of the selected cell and molecular biology techniques to an intended audience.	**M4** Assess the practical applications of selected cell and molecular biology techniques in a real-world case study or laboratory-based investigation.	**D2** Evaluate the effectiveness of the selected techniques in a real-world case study or laboratory-based investigation.

Recommended Resources

Textbooks

Alberts, B., *et al.* (2023) *Essential Cell Biology*. 6th edn. New York: W. W. Norton & Company.

Alberts, B., *et al.* (2022) *Molecular Biology of the Cell*. 7th edn. New York: W. W. Norton & Company.

Allison, L. A. (2021) *Fundamental Molecular Biology*. 3rd edn. Hoboken, NJ: Wiley-Blackwell.

Bergtrom, G. (2022) *Cell and Molecular Biology 5e: What We Know and How We Found Out*. Milwaukee, WI: University of Wisconsin-Milwaukee Libraries. Available at: https://minds.wisc.edu/communities/c843753f-9ba7-45b9-a385-4b6a82fafbd1/subcoms-cols.

Goodman, S. R. (ed.) (2020) *Goodman's Medical Cell Biology*. 4th edn. London: Academic Press.

Lodish, H., *et al*. (2021) *Molecular Cell Biology*. 9th edn. New York: W. H. Freeman.

Pollard, T. D., *et al*. (2023) *Cell Biology*. 4th edn. Philadelphia, PA: Elsevier.

Websites

https://open.oregonstate.education/cellbiology/	Fundamentals of Cell Biology - Open-access textbook covering cell structure, membranes, gene expression, metabolism and signalling (General reference)
https://bio.libretexts.org	Biology LibreTexts - Cell and molecular biology concepts, microscopy, genetics and metabolism resources (General reference)
https://www.ncbi.nlm.nih.gov	National Center for Biotechnology Information - Molecular biology, genetics and protein resources (General reference)

https://www.thermofisher.com/uk/en/home/technical-resources/learning-centers.html	Thermo Fisher Scientific - Cell and molecular biology techniques and applications (General reference)
https://www.cellsignal.com/learn-and-support/videos-and-webinars	Cell Signaling Technology - Cell signalling pathways and molecular mechanisms (General reference)

Journals and articles

Bacigalupa, Z.A., Landis, M.D. and Rathmell, J.C. (2024) 'Nutrient inputs and social metabolic control of T cell fate', *Cell Metabolism*, 36(1), pp. 10–20. Available at: https://www.cell.com/cell-metabolism/fulltext/S1550-4131(23)00460-6.

Newton, K., *et al*. (2024) 'A guide to cell death pathways', *Nature Reviews Molecular Cell Biology*, 25(5), pp. 379–395. Available at: https://doi.org/10.1038/s41580-023-00689-6.

Picard, M. and Shirihai, O.S. (2022) 'Mitochondrial signal transduction', *Cell Metabolism*, 34(11), pp. 1620–1653. Available at: https://doi.org/10.1016/j.cmet.2022.10.008.

Su, M., *et al*. (2024) 'Cell-cell communication: new insights and clinical implications', *Signal Transduction and Targeted Therapy*, 9, 196. Available at: https://doi.org/10.1038/s41392-024-01888-z.

Tábara, L.-C., Segawa, M. and Prudent, J. (2025) 'Molecular mechanisms of mitochondrial dynamics', *Nature Reviews Molecular Cell Biology*, 26(2), pp. 123–146. Available at: https://doi.org/10.1038/s41580-024-00785-1.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 407: Fundamentals of Biochemistry

Unit 419: Bioinformatics

Unit 503: Applied Molecular Biology

Unit 520: Stem Cell Biology

Unit 524: Immunology

Unit 525: Genomics and Proteomics.

Unit 407: Fundamentals of Biochemistry

Unit code: D/652/3039

Unit level: 4

Credit value: 15

Introduction

Biochemistry is central to the applied sciences because it explains biological systems in terms of molecular structure, chemical interactions, reaction mechanisms and energy transfer. In laboratory research, clinical diagnostics, biotechnology, pharmaceuticals and environmental science, biochemical knowledge underpins the identification, analysis and interpretation of biological materials and processes. This unit provides students with a foundation in the principles and applications of biochemistry that supports progression to further study and laboratory-based practice in the applied sciences.

The unit introduces the organic chemistry that underpins the structure and function of biological macromolecules, including carbohydrates, proteins, lipids and nucleic acids. Students will examine how functional groups, bonding, polarity and intermolecular interactions determine biomolecular properties and behaviour, and how these principles relate to biological function. The unit also develops understanding of analytical techniques used to investigate biological molecules in applied biochemical contexts.

Students will then explore enzyme catalysis, kinetics and regulation, and examine how metabolic pathways involved in respiration and photosynthesis support cellular bioenergetics. They will consider energy transfer, redox processes and the integration of metabolic pathways in meeting cellular energy demands. Throughout the unit, students will apply biochemical knowledge to laboratory investigation, data handling and scientific communication.

This unit supports progression to further study in subjects such as biochemistry, molecular biology, biomedical science, biotechnology, pharmaceutical science and bioinformatics. It also helps to prepare students for laboratory-based and technical roles where biochemical knowledge, practical competence and clear scientific communication are required, including progression towards work in laboratory operations, biomedical support, quality control, biotechnology and research support environments.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss how the fundamentals of organic chemistry determine the structure and function of macromolecules

LO2 Explain enzymatic characteristics in biochemical reactions

LO3 Explore metabolic pathways and their roles in bioenergetics

LO4 Present, using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in biochemistry, to an intended audience.

Essential Content

LO1 **Discuss how the fundamentals of organic chemistry determine the structure and function of macromolecules**

Carbohydrates: functional groups, bonding and analytical characterisation:

Monosaccharides: hydroxyl and carbonyl functional groups; aldose, ketose; ring formation, hemiacetal, hemiketal; anomers, alpha, beta e.g. glucose, fructose, ribose

Glycosidic bonding: condensation, hydrolysis; linkage types, structure-property relationships; alpha-1,4, alpha-1,6, beta-1,4 linkages; storage polysaccharides, structural polysaccharides e.g. starch, glycogen, cellulose

Chemical properties: polarity, hydrogen bonding, solubility; reducing sugars, oxidation potential, reducing end behaviour e.g. glucose, maltose

Carbohydrate analysis: reducing sugar tests, colorimetric assays, Benedict's test, DNS assay; chromatographic separation, paper chromatography, TLC; spectrophotometry, assay readout e.g. glucose testing, sugar separation.

Proteins: amino acid chemistry, structural interactions, and biochemical analysis:

Amino acids: amino/ammonium, carboxyl/carboxylate; side-chain functional groups, hydroxyl, thiol, amide, carboxylate, amino, aromatic ring, methyl; zwitterions, isoelectric point, charge, reactivity, interactions e.g. serine, cysteine, lysine, phenylalanine

Peptide bonds: amide bond chemistry; condensation, hydrolysis; backbone polarity; resonance, restricted rotation e.g. dipeptides, polypeptides

Structural interactions: hydrogen bonds, ionic interactions, hydrophobic interactions, van der Waals forces, disulfide bonding; thiol oxidation, structural stabilisation e.g. disulfide bridges in insulin and antibodies

Levels of protein structure: primary, secondary, tertiary, quaternary; peptide bonds, hydrogen bonds, ionic bonds, hydrophobic interactions, van der Waals forces, disulfide bridges; structure-function relationships e.g. globular proteins, fibrous proteins, insulin, antibodies, haemoglobin, collagen, keratin, sickle cell haemoglobin

Protein analysis: colorimetric protein assays, Biuret, Bradford; electrophoresis, SDS-PAGE, agarose gel electrophoresis, native PAGE; chromatography, ion-exchange, size-exclusion, affinity; spectrophotometry, absorbance at 280 nm; clinical protein analysis e.g. serum proteins, enzyme purification, abnormal proteins, blood markers, kidney function, liver function.

Lipids: hydrophobicity, amphipathic behaviour, membrane chemistry and analytical approaches:

Fatty acids and phospholipids: hydrocarbon chains; unsaturation, *cis*, *trans*; carboxyl/carboxylate, ester linkages; amphipathic structures e.g. phospholipids

Ester chemistry: triacylglycerols, phospholipids; condensation, hydrolysis; saponification e.g. triglycerides

Membrane chemistry: intermolecular forces, hydrophobic effect, bilayer formation; saturation, chain length, sterol content; membrane fluidity, permeability; cholesterol e.g. phospholipid bilayers

Lipid analysis: solvent extraction, Folch, Bligh and Dyer; chromatography, thin-layer chromatography (TLC); colorimetric and indicator tests, emulsion test, Sudan staining; spectroscopic and analytical profiling, gas chromatography (GC), gas chromatography–mass spectrometry (GC–MS) e.g. lipid extraction, lipid separation.

Nucleic acids: nucleotide chemistry, polymer structure and characterisation techniques:

Nucleotides: base functional groups, hydrogen bonding; aromaticity, base stacking; ribose, deoxyribose, hydroxyl differences, stability e.g. ATP, DNA nucleotides, RNA nucleotides

Phosphate groups and linkages: phosphoester, phosphodiester; condensation, hydrolysis; charge density, interactions with water and ions e.g. DNA backbone, ATP

Structural organisation: complementary base pairing, hydrogen bonding patterns; double helix, RNA secondary structures e.g. DNA, mRNA, tRNA

Nucleic acid analysis: extraction, quantification, integrity assessment; spectrophotometry, A260, A260/A280; electrophoresis, agarose gel electrophoresis; enzymatic manipulation, nuclease action, polymerase action e.g. DNA extraction, polymerase chain reaction (PCR) product analysis.

LO2 **Explain enzymatic characteristics in biochemical reactions**

Enzyme structure, specificity and catalytic context:

Enzyme classes and roles: enzyme classification, biological function; hydrolases, digestion, amylase, lipase; oxidoreductases, respiration, dehydrogenases e.g. amylase, catalase, dehydrogenase

Active site and specificity: substrate binding, induced fit, enzyme–substrate complementarity; lactase, lactose; catalase, hydrogen peroxide; chemical interactions of catalysis e.g. lactase–lactose, catalase–hydrogen peroxide

Cofactors and coenzymes: apoenzyme, holoenzyme; metal ions, organic cofactors; NAD^+, NADH, redox reactions e.g. Zn^{2+}, coenzyme A

Techniques linked to enzyme structure and function: SDS-PAGE, agarose gel electrophoresis, native PAGE; chromatography, affinity chromatography, ion-exchange; bioinformatics, databanks, enzyme classification, pathway context e.g. protein separation, enzyme identification.

Catalytic mechanisms in biochemical reactions:

Catalysis concepts: activation energy, transition state; catalytic strategies, structure-linked features e.g. lowering activation energy

Catalytic mechanisms: acid–base catalysis, covalent catalysis, metal–ion catalysis; active-site residues, histidine, serine protease mechanism e.g. trypsin

Techniques for enzyme-catalysed reactions: spectrophotometry, colorimetry; product formation, substrate loss; peroxidase-linked colour change, NADH absorbance at 340 nm; pH measurement, buffer preparation, temperature control, water bath, incubator e.g. peroxidase assays, dehydrogenase assays.

Enzyme kinetics and reaction rates, including measurement and data handling techniques:

Reaction rates: initial rate, saturation behaviour, Michaelis–Menten, V_{max}, K_m e.g. rate–substrate concentration curves

Factors affecting enzyme activity: substrate concentration, enzyme concentration, temperature, pH; amylase, catalase, hydrogen peroxide e.g. amylase activity, catalase activity

Enzyme rate measurement: continuous assays, endpoint assays; spectrophotometric monitoring, colorimetric endpoint reading; calibration, standard curves, rate plots, saturation curves e.g. absorbance–time plots, standard curves; replicates, outliers, timing, units.

Regulation of enzyme activity, including inhibition and feedback within pathways:

Regulation of enzyme activity: competitive, non-competitive, uncompetitive, irreversible inhibition; allosteric regulation, cooperativity, covalent modification, phosphorylation, feedback regulation e.g. end-product inhibition

Applied contexts: drug action, pathway control e.g. aspirin, statins

Evidence of regulation: inhibitor studies, enzyme assays, comparative kinetic plots, apparent K_m, V_{max}; immunodetection, phosphorylation status; negative controls, condition-matched blanks e.g. inhibited versus uninhibited enzyme activity.

LO3 **Explore metabolic pathways and their roles in bioenergetics**

Respiration-based bioenergetics:

Bioenergetics in respiration: energy transfer, ATP, coupling of reactions, substrate-level phosphorylation, oxidative phosphorylation e.g. ATP generation in respiration

Redox in respiration: electron carriers, reducing equivalents, NAD^+, NADH, FAD, $FADH_2$; oxidation of carbon compounds, energy capture e.g. NADH production in glycolysis

Glycolysis: key stages, energy investment, energy payoff, net ATP yield, NADH production, pyruvate formation e.g. glucose breakdown

Pyruvate processing and metabolic fates: acetyl-CoA, link reaction, anaerobic fates, redox balance, fermentation e.g. lactate fermentation, alcoholic fermentation

TCA cycle: carbon flow, decarboxylation, reducing equivalents, biosynthetic precursors e.g. citrate formation, CO_2 release

Electron transport chain: proton gradients, chemiosmotic theory, ATP synthase, oxygen as terminal electron acceptor, aerobic respiration e.g. oxidative phosphorylation

Respiration techniques: respirometry, redox indicators, spectrophotometry, NADH-linked reaction monitoring, metabolite measurement, calibration, controls, simple respirometers, DCPIP, absorbance at 340 nm, glucose assays, lactate assays e.g. respiration rate measurement.

Photosynthesis-based bioenergetics:

Chloroplast organisation: thylakoid membranes, compartmentalisation, pigments, light absorption e.g. chlorophyll

Light-dependent reactions: photolysis of water, oxygen evolution, electron transport, proton gradient formation, photophosphorylation, ATP synthase, $NADP^+$, NADPH e.g. ATP and NADPH production

Carbon fixation: Calvin cycle, ATP, NADPH, intermediates, carbohydrate production, chemical energy storage e.g. glucose synthesis

Photosynthesis techniques: oxygen production measurement, redox dyes, pigment separation, pigment identification, colorimetry, spectrophotometry, oxygen probes, leaf-disc flotation, DCPIP reduction, paper chromatography, TLC, absorbance-based pigment estimation, calibration, controls e.g. chlorophyll separation, photosynthetic rate measurement.

Integration and regulation of energy metabolism, including data interpretation approaches:

Integration of energy metabolism: catabolic pathways, anabolic pathways, metabolic flexibility, interconversion of macromolecules, carbohydrate metabolism, lipid metabolism, protein metabolism e.g. links between glycolysis, lipid breakdown and amino acid metabolism

Regulation of metabolic flux: control points, rate-limiting steps, cellular energy status, ATP, ADP, AMP, redox state, NADH, NAD^+, NADPH, $NADP^+$ e.g. phosphofructokinase regulation

Compartmentalisation and coordination: cytosol, mitochondria, chloroplast; cellular energy demand, metabolic adaptation e.g. glycolysis in cytosol, TCA cycle in mitochondria

Data interpretation approaches: pathway mapping, databases, calibration curves, control samples, rates, comparisons, variability, repeatability, limitations e.g. comparison of respiration rates under different conditions.

LO4 **Present, using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in biochemistry, to an intended audience**

Application of biochemistry techniques:

Application of biochemistry techniques: purpose, principles, application; practical laboratory investigation, theoretical analysis, real-world case studies; investigation questions, aims, sample type, constraints, technique selection, rationale e.g. biomolecule analysis, enzyme assays, metabolic investigations

Controls and comparators: positive controls, negative controls, blanks, standards, reference materials; replicates, repeatability, variable control, contamination control; buffer blank, no-enzyme control, ladder, marker lane, calibration curve, process blank e.g. control samples, standard series

Calibration and verification: quantitative outputs, instrument set-up checks, standard curves, traceable calculations, units, uncertainty, error sources; protein concentration, balance checks, calibration masses, pipette performance, wavelength checks, zeroing checks e.g. standard curves, instrument calibration.

Biochemical techniques and evidence generation:

Biochemical techniques and evidence generation: separation, detection, quantification, characterisation; chromatograms, electrophoresis banding patterns, spectra, absorbance–time traces, microplate assay outputs e.g. gels, chromatograms, assay traces

Technique workflows: sample preparation, sequencing, compatibility of methods, limitations, fitness for purpose; matrix interference, detection limits, linear range, carryover, contamination risk, reagent stability, sample stability e.g. sample extraction followed by chromatographic analysis.

Data handling, processing and presentation of outcomes:

Data handling and processing: raw data capture, traceability, data integrity, record quality, anomalies, outliers, limitations, confidence in findings; repeat runs, deviations, anomalous readings, rationale; AI-supported outputs with human verification e.g. repeat measurements, exclusion of outliers

Data presentation: structured tables, units, labelled calculations, visual formats; standard curve plots, bar charts, error bars, annotated gels, chromatograms, summary tables e.g. processed results tables, labelled figures.

Communication to an intended audience: format, feedback and improvement:

Communication to an intended audience: audience identification, audience needs, terminology, level of detail, scientific communication conventions, clarity, structure, accuracy, visual materials

Format: technical summary, briefing, poster-style layout, labelled figures, units, concise captions e.g. scientific poster, technical presentation; inclusive communication practices e.g. clear figure labelling, avoidance of unnecessary jargon, appropriate visual aids

Presentation style: ethical scientific communication e.g. transparency, accuracy, avoidance of overclaiming and cultural bias in data selection, interpretation, presentation

Feedback and improvement: qualitative feedback, quantitative feedback, evaluation of communication effectiveness, improvement actions; structured feedback forms, clarity, accuracy, visual effectiveness, Q&A capture, revision of visuals, revision of terminology e.g. audience feedback, revised presentation slides.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss how the fundamentals of organic chemistry determine the structure and function of macromolecules</td><td rowspan="8">LO1, LO2 and LO3

D1 Evaluate how the chemical structure and interactions of macromolecules, enzymes and metabolic pathways determine biochemical function, energy metabolism and regulation in biological systems.</td></tr>
<tr><td>P1 Discuss how functional groups and bonding determine the structure of macromolecules.

P2 Explain how intermolecular interactions and chemical properties influence the function and behaviour of macromolecules in biological systems.</td><td>M1 Analyse how chemical structure determines the properties of macromolecules.</td></tr>
<tr><td colspan="2">LO2 Explain enzymatic characteristics in biochemical reactions</td></tr>
<tr><td>P3 Explain how enzyme structure and catalytic mechanisms enable biochemical reactions.

P4 Describe how kinetics and regulation influence enzyme activity in biochemical reactions.</td><td>M2 Assess the relationships between enzyme catalysis, kinetic behaviour and regulatory control in biochemical reactions.</td></tr>
<tr><td colspan="2">LO3 Explore metabolic pathways and their roles in bioenergetics</td></tr>
<tr><td>P5 Explore how respiration and photosynthesis support energy transfer in biological systems.

P6 Outline how key metabolic pathways contribute to bioenergetic demand and regulation.</td><td>M3 Analyse the roles and interconnections of metabolic pathways in bioenergetics.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Present using either real-world case studies or laboratory-based investigation, the practical applications of techniques used in biochemistry, to an intended audience		**LO4**
P7 Carry out, using either real-world case studies or laboratory-based practice, an investigation into the practical applications of techniques used in biochemistry. **P8** Present the findings of the investigation to an intended audience using appropriate scientific language and formats.	**M4** Analyse the investigation findings in relation to the scientific outcomes.	**D2** Evaluate the investigation findings and conclusions in relation to the scientific outcomes.

Recommended Resources

Textbooks

Ahern, K.G., Rajagopal, I. and Tan, T. (2018) *Biochemistry: Free for All*. Corvallis, OR: Oregon State University.

Berg, J.M., Tymoczko, J.L., Gatto, G.J. and Stryer, L. (2019) *Biochemistry*. 9th edn. New York: W.H. Freeman and Company.

Fromm, H.J. and Hargrove, M.S. (2012) *Essentials of Biochemistry*. Heidelberg: Springer.

Jakubowski, H. and Flatt, P. (2021) *Fundamentals of Biochemistry*. LibreTexts.

Nelson, D.L. and Cox, M.M. (2021) *Lehninger Principles of Biochemistry*. 8th edn. New York: W.H. Freeman and Company.

Voet, D., Voet, J.G. and Pratt, C.W. (2016) *Fundamentals of Biochemistry: Life at the Molecular Level*. 5th edn. Hoboken, NJ: John Wiley & Sons.

Websites

https://bio.libretexts.org	Biology LibreTexts Open educational resources covering biomolecular structure, enzymes, kinetics, metabolism and laboratory applications. (General reference)
https://www.ncbi.nlm.nih.gov	National Center for Biotechnology Information (NCBI) Biomedical and molecular bioscience resources, including biochemical pathways, enzyme information and applied research context. (Research)
https://www.khanacademy.org	Khan Academy Student-facing explanations and videos on biomolecules, enzyme structure and function, kinetics, metabolism and bioenergetics. (Tutorial)

https://www.thermofisher.com	Thermo Fisher Scientific Technical resources on protein assays, enzyme activity assays, spectroscopy, sample preparation and laboratory applications. (Technical reference)
https://www.rsc.org	Royal Society of Chemistry Chemistry education resources supporting organic chemistry principles, analytical chemistry and applied laboratory contexts. (Professional body)
https://www.biochemistry.org	Biochemical Society Molecular bioscience education, careers, events and professional resources for biochemistry and related disciplines. (Professional body)

Journals and articles

Judge, A. and Dodd, M.S. (2020) 'Metabolism', *Essays in Biochemistry*, 64(4), pp. 607–647. Available at: https://doi.org/10.1042/EBC20190041.

Robinson, P.K. (2015) 'Enzymes: principles and biotechnological applications', *Essays in Biochemistry*, 59, pp. 1–41. Available at: https://doi.org/10.1042/bse0590001.

Levitsky, Y., Pegouske, D.J., Hammer, S.S., Frantz, N.L., Fisher, K.P., Muchnik, A.B., Saripalli, A.R., Kirschner, P., Bazil, J.N., Busik, J.V. and Proshlyakov, D.A. (2019) 'Micro-respirometry of whole cells and isolated mitochondria', *RSC Advances*, 9(57), pp. 33257–33267. Available at: https://doi.org/10.1039/C9RA05289E.

Ma, Y. and Eser, B.E. (2025) 'Bridging Disciplines in Enzyme Kinetics: Understanding Steady-State, Transient-State and Performance Parameters', *Catalysts*, 15(12), 1139. Available at: https://doi.org/10.3390/catal15121139.

Johnson, M.P. (2016) 'Photosynthesis', *Essays in Biochemistry*, 60(3), pp. 255–273. Available at: https://doi.org/10.1042/EBC20160016.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 408: Human Anatomy and Physiology

Unit 419: Bioinformatics

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set).

Unit 408: Human Anatomy and Physiology

Unit code: J/652/3040

Unit level: 4

Credit value: 15

Introduction

This unit develops students' understanding of the anatomical structure and physiological function of the human body, providing a foundation for further study in applied science, biomedical science and health-related disciplines. It introduces the organisation of the body from cells and tissues to organs and integrated body systems and supports students in using anatomical and physiological terminology accurately within scientific and clinical contexts.

Students will examine the structure and organisation of the major human body systems and explore how anatomical arrangement supports physiological function. The unit also develops understanding of the mechanisms that maintain homeostasis, including feedback control, thermoregulation, fluid balance, and neural and endocrine coordination. Consideration of functional relationships between organs and systems will enable students to recognise the body as an integrated whole in which structure, regulation and performance are interdependent.

The unit further introduces the ways in which common disorders alter anatomical structure and physiological processes, requiring students to interpret relevant evidence and relate changes in normal function to wider effects on system performance and health outcomes. Where appropriate, delivery may be supported through practical activities using anatomical models, histological slides, imaging resources and non-invasive physiological measurements to develop observational, recording and interpretive skills.

On successful completion of this unit, students will be prepared for further study in areas such as biomedical science, human biosciences, physiology, health sciences and pathophysiology, and for progression towards roles in laboratory science, healthcare support, clinical physiology and related life science settings.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the structure and organisation of human anatomical systems

LO2 Describe the physiological mechanisms that maintain homeostasis in the human body

LO3 Examine the functional relationship between key organs within major body systems

LO4 Investigate how common disorders manifest and impact on human anatomical and physiological systems.

Essential Content

LO1 **Explain the structure and organisation of human anatomical systems**

Anatomical terminology:

Anatomical position: directional language e.g. anterior, posterior, superior, inferior, medial, lateral, proximal, distal, superficial, deep

Anatomical planes: sagittal, frontal, transverse; body cavities, regions e.g. cranial, thoracic, abdominal, pelvic, dorsal, ventral

Anatomical landmarks: axial regions, appendicular regions, quadrants, surface markings

Application of terminology: position, orientation, relationship of structures, accurate communication in scientific and clinical contexts.

Levels of biological organisation:

Hierarchical organisation: cells, tissues, organs, organ systems, whole body; structural progression e.g. cellular specialisation, tissue formation, organ formation

System integration: functional integration e.g. life processes, homeostasis, regulation, protection, movement, transport, exchange

Tissue types: epithelial, connective, muscle, nervous; tissue structure, tissue function e.g. lining, support, contraction, communication; tissue location e.g. skin, blood, bone, cardiac muscle, brain

Investigation of tissues: tissue sampling techniques e.g. staining, light microscopy, digital microscopy, basic histological interpretation.

Major body systems and organisation:

Body systems e.g. skeletal, muscular, nervous, endocrine, cardiovascular, respiratory, digestive, urinary, reproductive, integumentary, lymphatic/immune

Structural features and roles: protection, movement, transport, exchange, regulation

Anatomical variation: developmental differences, sex-based differences, organ size variation; organisational efficiency e.g. compartmentalisation, regional organisation, protective structures, body cavities, membranes, branching arrangements

Visual representations: labelled diagrams, scans, three-dimensional anatomical models

Organ and system level investigation and diagnostic methodologies: anatomical imaging techniques, physiological measurements, digitally enabled diagnostics, AI-powered image processing solutions.

LO2 **Describe the physiological mechanisms that maintain homeostasis in the human body**

Principles of homeostasis:

Regulated variables: blood glucose concentration, core body temperature, blood pH, blood pressure, water balance; set points and tolerance ranges e.g. normal limits, acceptable variation, physiological baselines

Dynamic internal stability: responses to internal change, responses to external change, maintenance of cellular conditions; homeostatic imbalance e.g. dehydration, hypothermia, hyperglycaemia, acidosis, hypertension

Physiological monitoring: temperature, pulse, respiratory rate, blood pressure, blood glucose.

Feedback and control mechanisms:

Control pathways: stimulus, receptor, sensory input, control centre, motor output, effector, response; negative feedback e.g. temperature regulation, blood glucose regulation, blood pressure regulation; positive feedback e.g. blood clotting, childbirth, suckling–oxytocin–milk-ejection reflex

Regulatory signalling: detection of deviation, coordinated correction, pathway activation, return to set point; interaction of control mechanisms e.g. nervous and endocrine regulation, short-term and long-term responses.

Thermoregulation and fluid balance:

Temperature regulation: heat production, heat conservation, heat loss, shivering, sweating, vasoconstriction, vasodilation; thermoregulatory control e.g. hypothalamus, skin receptors, skeletal muscle, sweat glands, blood vessels

Fluid and electrolyte balance: osmoregulation, fluid compartments, electrolyte regulation, sodium and potassium balance; renal contribution e.g. filtration, reabsorption, urine concentration, antidiuretic hormone response

Influencing factors: hydration status, environmental temperature, physical activity, diet, illness.

Neural and endocrine coordination:

Neural regulation: rapid signalling, reflex responses, autonomic nervous system control, sympathetic effects, parasympathetic effects

Endocrine regulation: hormone secretion, target cells, slower systemic control, longer-lasting responses; key endocrine examples e.g. insulin, glucagon, adrenaline, thyroxine, ADH

Integrated coordination: stress responses, metabolic regulation, combined regulation of physiological processes, digital monitoring of physiological variables

Effects of altered neural and endocrine coordination: disrupted physiological regulation, abnormal stress responses, dysregulation in common disorders such as diabetes mellitus.

LO3 **Examine the functional relationship between key organs within major body systems**

Functional relationships and interdependence:

Organ interdependence: coordination, communication, shared physiological variables, complementary functions; system integration e.g. oxygen availability, nutrient supply, waste removal, fluid balance, acid–base balance, temperature control

Structural and functional links: blood supply, innervation, ducts, membranes, exchange surfaces; cross-system influence e.g. effects of organ change on wider system performance, effects on cellular and tissue function, effects on homeostatic regulation.

Cardiovascular and respiratory interactions:

Transport and gas exchange: heart, blood vessels, blood, lungs, alveoli, diaphragm; continuous physiological processes e.g. ventilation, diffusion, perfusion, circulation, tissue oxygen delivery, carbon dioxide removal

Organ relationships: right and left sides of the heart, pulmonary circulation, systemic circulation, capillary exchange

Changing physiological demand: exercise responses, increased breathing rate, increased heart rate, increased stroke volume, increased cardiac output; monitoring examples e.g. pulse, blood pressure, respiratory rate, oxygen saturation.

Digestive and renal interactions:

Digestive coordination e.g. mouth, stomach, small intestine, large intestine, liver, gallbladder, pancreas; nutrient processing and distribution e.g. mechanical digestion, chemical digestion, absorption, transport to the liver, storage, metabolism, tissue supply

Endocrine links: insulin, glucagon, regulation of blood glucose after feeding and fasting; renal regulation e.g. blood filtration, fluid balance, electrolyte concentration, blood pressure control, removal of metabolic waste

Organ relationships: hepatic portal circulation, bile production, pancreatic enzyme secretion, kidney contribution to internal stability.

Functional consequences of organ dysfunction:

Impaired organ performance: reduced efficiency, altered regulation, increased system demand, reduced reserve capacity; compensatory responses e.g. increased heart rate, increased breathing rate, altered hormone secretion, organ adaptation, increased workload on other organs

Wider physiological consequences: disrupted balance across systems, reduced oxygen delivery, fluid accumulation, altered waste removal, multi-system effects

Investigation of dysfunction: physiological measurements, imaging outputs, laboratory findings, comparison with expected normal function.

LO4 **Investigate how common disorders manifest and impact on human anatomical and physiological systems**

Pathology and disorder concepts:

Disorder concepts: acute and chronic conditions, infectious and non-infectious disorders, congenital and acquired disorders, localised and systemic effects; deviation from normality e.g. altered anatomical structure, altered physiological function, abnormal regulation, tissue injury

Disease processes: inflammation, infection, degeneration, ischaemia, obstruction, autoimmune response, abnormal cell growth; disease progression e.g. signs and symptoms, stages of disease, exacerbation, remission, complications, recovery.

System-specific anatomical and physiological change:

Common disorders: e.g. cardiovascular disease, hypertension, asthma, chronic obstructive pulmonary disease, diabetes mellitus, kidney disease, stroke, dementia, digestive disorders

Anatomical change: e.g. tissue damage, inflammation, narrowing, blockage, organ enlargement, atrophy, structural abnormality

Physiological change: e.g. impaired blood flow, reduced gas exchange, altered glucose regulation, reduced filtration, impaired neural signalling, altered digestion and absorption

System effects: e.g. reduced oxygen delivery, altered waste removal, fluid imbalance, disrupted temperature regulation, altered movement, impaired communication between organs.

Evidence, functional impact and health outcomes:

Evidence sources: clinical observations, patient history, signs and symptoms, physiological measurements, imaging outputs, laboratory data, histological findings

Interpretation of evidence: comparison with expected normal structure and function, identification of abnormal results, links between evidence and system performance

Functional impact: reduced physiological capacity, reduced mobility, breathlessness, fatigue, pain, altered cognition, limitations in activities of daily living; health outcomes e.g. multi-morbidity, acute deterioration, chronic impairment, complications, reduced life expectancy, impaired quality of life

Digital solutions for diagnosis, monitoring and treatment: diabetes mellitus (DM), continuous glucose monitoring (CGM) systems, remote monitoring, patient applications, associated clinical platforms; digitally enabled diagnostics e.g. image analysis, digital twins, AI-enabled disease modelling, therapeutic target identification.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the structure and organisation of human anatomical systems</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate how anatomical organisation, physiological regulation and organ interdependence collectively support effective integrated body system function.</td></tr>
<tr><td>P1 Describe the organisation of major human anatomical systems.

P2 Explain how anatomical organisation supports effective system function.</td><td>M1 Analyse how the organisation of anatomical structures contributes to the effective functioning of human body systems.</td></tr>
<tr><td colspan="2">LO2 Describe the physiological mechanisms that maintain homeostasis in the human body</td></tr>
<tr><td>P3 Describe the principles of homeostasis and physiological regulation.

P4 Explain the role of neural and endocrine coordination in maintaining internal stability.</td><td>M2 Assess how physiological control mechanisms interact to maintain homeostasis under changing conditions.</td></tr>
<tr><td colspan="2">LO3 Examine the functional relationship between key organs within major body systems</td></tr>
<tr><td>P5 Describe how key organs contribute to the function of major body systems.</td><td>M3 Analyse how organ interdependence influences overall body system performance.</td></tr>
<tr><td colspan="2">LO4 Investigate how common disorders manifest and impact on human anatomical and physiological systems</td><td rowspan="2">LO4

D2 Evaluate the impact of common disorders on anatomical structure, physiological function and overall system performance.</td></tr>
<tr><td>P6 Investigate the effects of common disorders on anatomical structure and physiological function.

P7 Explain the impact of common disorders on system performance using anatomical and physiological evidence.</td><td>M4 Assess how anatomical and physiological evidence explains the impact of common disorders on system function.</td></tr>
</table>

Recommended Resources

Textbooks

Betts, J.G., *et al.* (2022) *Anatomy and Physiology 2e*. 2nd edn. Houston, TX: OpenStax.

Kumar, V., *et al*. (2025) *Robbins, Cotran & Kumar Pathologic Basis of Disease*. 11th edn. Philadelphia, PA: Elsevier.

Hoehn, K., Haynes, L.W. and Abbott, M.A. (2025) *Marieb Human Anatomy & Physiology*. 12th edn. Harlow: Pearson.

McArdle, W.D., Katch, F.I. and Katch, V.L. (2023) *Exercise Physiology: Nutrition, Energy, and Human Performance*. 9th edn. Philadelphia, PA: Wolters Kluwer.

Pawlina, W. (2024) *Histology: A Text and Atlas: With Correlated Cell and Molecular Biology*. 9th edn. Philadelphia, PA: Wolters Kluwer.

Scanlon, V.C. and Sanders, T. (2018) *Essentials of Anatomy and Physiology*. 8th edn. Philadelphia, PA: F.A. Davis.

Tortora, G.J. and Derrickson, B.H. (2020) *Principles of Anatomy and Physiology*. 16th edn. Hoboken, NJ: Wiley.

Widmaier, E.P., Raff, H. and Strang, K.T. (2022) *Vander's Human Physiology: The Mechanisms of Body Function*. 16th edn. New York, NY: McGraw Hill.

Websites

https://openstax.org/books/anatomy-and-physiology/pages/1-introduction	OpenStax General introduction to Anatomy and Physiology (General reference)
https://teachmeanatomy.info	TeachMeAnatomy Anatomy learning tutorials (Tutorials)
https://www.frontiersin.org	Frontiers in Physiology (Research)
https://plos.org	*PLOS Biology* (Research)
https://www.nhsinform.scot/illnesses-and-conditions/a-to-z/	NHS Inform A to Z description of human diseases and conditions. (General reference)

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Journals and articles

Bartsch, R.P., *et al.* (2015) 'Network Physiology: How Organ Systems Dynamically Interact', *PLOS ONE*, 10(11), e0142143. Available at: https://doi.org/10.1371/journal.pone.0142143.

Bechtel, W. and Bich, L. (2024) 'Situating homeostasis in organisms: maintaining organization through time', *The Journal of Physiology*, 602(22), pp. 6003–6020. Available at: https://doi.org/10.1113/JP286883.

Billman, G.E. (2020) 'Homeostasis: The Underappreciated and Far Too Often Ignored Central Organizing Principle of Physiology', *Frontiers in Physiology*, 11, 200. Available at: https://doi.org/10.3389/fphys.2020.00200.

Cano-Martínez, A., Rubio-Ruiz, M.E. and Guarner-Lans, V. (2024) 'Homeostasis and evolution in relation to regeneration and repair', *The Journal of Physiology*, 602(11), pp. 2627–2648. Available at: https://doi.org/10.1113/JP284426.

Ivanov, P.Ch. (2021) 'The New Field of Network Physiology: Building the Human Physiolome', *Frontiers in Network Physiology*, 1, 711778. Available at: https://doi.org/10.3389/fnetp.2021.711778.

Kuang, S.Y. (2023) 'Advancing physiology education by understanding the multiple dimensions of homeostasis', *Frontiers in Physiology*, 14, 1234214. Available at: https://doi.org/10.3389/fphys.2023.1234214.

Modell, H., *et al.* (2015) 'A physiologist's view of homeostasis', *Advances in Physiology Education*, 39(4), pp. 259–266. Available at: https://doi.org/10.1152/advan.00107.2015.

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 503: Applied Molecular Biology

Unit 506: Medical Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 520: Stem Cell Biology

Unit 522: Histology and Haematology

Unit 524: Immunology.

Unit 409: Fundamentals of Forensic Science

Unit code: K/652/3041

Unit level: 4

Credit value: 15

Introduction

Forensic science plays a central role in the criminal justice system by applying scientific principles to the investigation and interpretation of evidence. This unit introduces students to the foundational concepts that underpin forensic science practice, providing an overview of how scientific reasoning supports investigations from the initial consideration of evidence through to its use in legal contexts. It is designed for students progressing within applied science pathways who require a clear understanding of the scope, purpose and professional context of forensic science without engaging in procedural crime scene or laboratory work.

The unit focuses on the principles that guide forensic decision making, including objectivity, proportionality and evidence integrity. Students explore how forensic scientists operate within regulated and ethically sensitive environments, where integrity, reliability, transparency and accountability are essential. Consideration is given to professional responsibilities, legal expectations and the importance of accurate documentation, secure data handling and traceability in supporting confidence in forensic findings.

Students are introduced to key analytical techniques used across forensic disciplines at a conceptual level, covering biological, chemical and physical evidence types. The unit focuses on what the different analytical techniques are used for, their strengths and limitations, and how quality assurance and quality control support reliable outcomes. Attention is also given to sustainability and resource responsibility in forensic science, including the avoidance of unnecessary testing and the use of proportionate, fit-for-purpose approaches. The role of contemporaneous notes, digital records, imagery and data systems in supporting interpretation, auditability and professional communication is embedded throughout.

On completion of this unit, students will be able to interpret simulated crime scenes using forensic science principles, recognising limitations, uncertainty and the importance of justified conclusions. The knowledge and understanding developed

provide a foundation for progression to units focused on criminal investigation, applied forensic practice and evidence evaluation, as well as supporting further study or employment within forensic and related scientific contexts.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles underpinning forensic science

LO2 Describe key analytical techniques used in forensic science

LO3 Discuss the legal, ethical and regulatory frameworks governing forensic practice

LO4 Interpret simulated evidence using forensic science principles, techniques and regulatory frameworks.

Essential Content

LO1 **Explain the fundamental principles underpinning forensic science**

Forensic science purpose and investigative context:

Forensic science roles and functions: e.g. relationships between laboratory, police force, court functions

Roles and responsibilities: e.g. investigators, forensic scientists, crime scene examiners, police force, legal professionals

Key principles: impartiality, objectivity, proportionality e.g. avoiding unnecessary testing or duplication of work, preserving evidential integrity and resources.

Evidence concepts, transfer and sustainability considerations:

Evidence classifications and characteristics: biological, chemical, physical/trace and digital evidence; Locard's exchange principle and transfer mechanisms e.g. primary transfer, secondary transfer, persistence, loss and absence of evidence

Evidential integrity concepts: contamination, degradation, trace persistence; sustainability considerations e.g. minimising avoidable contamination, preventing re-sampling, reduction of evidential waste through careful planning and handling.

Scientific methodology, inference, and digital context:

Scientific methods: observation, hypothesis formation, testing, interpretation and reporting

Inductive and deductive reasoning: forensic problem solving: uncertainty and limitations; contemporaneous notes, digital records, documentation systems to support traceability, transparency and auditability e.g. secure storage of notes, imagery and analytical outputs.

LO2 **Describe key analytical techniques used in forensic science**

Biological evidence examination techniques:

Biological evidence types and analytical techniques: identification, confirmation tests e.g. AP screening test for semen, appropriate confirmatory examination

DNA profiling concepts and workflows: overview level e.g. sampling considerations, interpretation boundaries, limitations

Sustainability: e.g. proportional testing strategies, avoidance of unnecessary repeat analysis, preservation of samples for future examination.

Chemical evidence examination techniques:

Chemistry evidence types and analytical techniques: detection, identification, comparison e.g. controlled drugs, ignitable liquids, chemical residues

Instrumental analysis: conceptual overview e.g. chromatographic, spectroscopic

Sustainability and resource efficiency: analytical decision making e.g. fitness-for-purpose method selection, minimisation of solvent and consumable use, avoidance of redundant testing.

Physical and trace evidence examination techniques, including quality systems and digital tools:

Evidence categories: physical, trace; class and individual characteristics

Comparative examination principles and limitations: quality assurance, quality control e.g. contamination control; reliability e.g. validation, repeatability, documentation

Digital tools: recording, storing, reviewing analytical observations e.g. digital imagery, comparison records, secure data handling; evidential integrity.

LO3 **Discuss the legal, ethical and regulatory frameworks governing forensic practice**

Legal frameworks and evidence governance:

Admissibility principles and evidence standards: relevance, reliability and disclosure expectations; documentation and traceability expectations supported by digital record-keeping systems e.g. audit trails and version control

Health and safety and regulatory frameworks: the Forensic Science Regulators, statutory code of practice, relevant national or regional data protection regulation

Professional judgement and interpretation: expert evidence roles and boundaries e.g. duty to the court and limits of opinion.

Ethical responsibilities, sustainability and professional judgement:

Ethical responsibilities: ethical principles underpinning forensic practice: e.g. integrity, competence, transparency, confidentiality

Professional responsibilities: proportionality, sustainability, responsible use of forensic resources; avoidance of over analysis and unnecessary testing

Human factors: error pathways in forensic decision making e.g. bias awareness, mitigation strategies.

Regulatory oversight and digital information management:

Regulatory bodies: professional oversight structures relevant to forensic science practice; expectations for standards-based working, quality governance, accountability

Digital data protection: principles relevant to forensic information e.g. secure storage, controlled access, management of sensitive electronic case materials.

LO4 **Interpret simulated evidence using forensic science principles, techniques and regulatory frameworks**

Evidence interpretation using forensic principles:

Simulated evidence features and constraints: time, environment, transfer risk, contamination risk

Interpretation of scenarios: use of forensic science principles: transfer expectations, persistence and evidential relevance; consideration of sustainability in interpretation: proportionality of analytical conclusions, avoidance of speculative or unsupported inference.

Appropriateness, limitations, and digital support for interpretation:

Appropriateness of forensic approaches: e.g. sensitivity, selectivity, contextual constraints

Limitations: e.g. recognition, uncertainty, alternative explanations

Digital support: use of digital records, imagery and data representations to support interpretation, transparency and review of evidential reasoning e.g. contemporaneous notes, annotated images and structured case records.

Evidential value, reliability, and justified conclusions:

Concepts of evidential value and weight: introductory level e.g. factors influencing reliability and strength of evidence; justification of interpretive conclusions through clear linkage between forensic principles, observations and stated limitations

Communication: communication of conclusions e.g. professional, digitally supported documentation, ensuring clarity, traceability, avoidance of over-statement.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental principles underpinning forensic science</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate how forensic science principles, analytical techniques, and legal and ethical frameworks collectively influence the reliability, interpretation and professional use of forensic evidence.</td></tr>
<tr><td>P1 Outline the role of forensic science within the criminal justice system.

P2 Explain core forensic science principles relating to evidence and integrity.</td><td>M1 Analyse how core forensic science principles influence the interpretation and use of evidence within forensic investigations.</td></tr>
<tr><td colspan="2">LO2 Describe key analytical techniques used in forensic science</td></tr>
<tr><td>P3 Describe analytical techniques used for biological and chemical evidence.

P4 Explain analytical techniques used for physical and trace evidence.</td><td>M2 Assess the suitability of analytical techniques for different forensic evidence types.</td></tr>
<tr><td colspan="2">LO3 Discuss the legal, ethical and regulatory frameworks governing forensic practice</td></tr>
<tr><td>P5 Discuss legal frameworks relevant to forensic science practice.

P6 Outline ethical and regulatory responsibilities of forensic practitioners.</td><td>M3 Justify forensic practitioner responsibilities within legal, ethical and regulatory frameworks.</td></tr>
<tr><td colspan="2">LO4 Interpret simulated evidence using forensic science principles, techniques and regulatory frameworks</td><td rowspan="2">LO4

D2 Evaluate the evidential value and reliability of simulated evidence against professional and regulatory expectations.</td></tr>
<tr><td>P7 Interpret simulated evidence using forensic science principles, techniques and regulatory frameworks.

P8 Discuss the limitations of simulated evidence interpretation.</td><td>M4 Analyse the evidential value and reliability of simulated evidence in line with professional expectations.</td></tr>
</table>

Recommended Resources

Textbooks

Bell, S. (2019) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 5th edn. Boca Raton, FL: CRC Press.

Ijeh, A.C. and Curran, K. (eds.) (2021) *Crime Science and Digital Forensics: A Holistic View*. Boca Raton, FL: CRC Press.

Jackson, A.R.W., Jackson, J.M. and Mount, H. (2016) *Forensic Science*. 4th edn. Harlow: Pearson Education.

McCartney, C. (2012) *Forensic Identification and Criminal Justice: Forensic Science, Justice and Risk*. London: Routledge.

Mozayani, A. and Noziglia, C. (2006) *The Forensic Laboratory Handbook: Procedures and Practice*. Totowa, NJ: Humana Press.

Nic Daéid, N. and White, P.C. (eds.) (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. London: Royal Society of Chemistry.

Robertson, J., Roux, C. and Wiggins, K. (2017) *Forensic Examination of Fibres*. 3rd edn. Boca Raton, FL: CRC Press.

Doyle, S. (2019) *Quality Management in Forensic Science*. London: Academic Press.

Websites

https://www.a2la.org	American Association for Laboratory Accreditation Forensic laboratory accreditation and quality systems overview (Standards/regulatory guidance)
https://www.ascld.org	American Society of Crime Laboratory Directors Professional standards, quality, and laboratory governance (Professional guidance)
https://www.enfsi.eu	European Network of Forensic Science Institutes Best practice manuals, quality and contamination control guidance (Professional guidance)

https://www.gov.uk/government/organisations/forensic-science-regulator	Forensic Science Regulator (UK) Codes of practice and regulatory expectations for forensic science (Regulatory guidance)
https://www.interpol.int	Interpol Forensic science, evidential integrity, and international cooperation (General reference)
https://www.justice.gov	United States Department of Justice Forensic science standards, evidence integrity and admissibility (General reference)
https://www.nist.gov	National Institute of Standards and Technology Forensic science standards, measurement science, and reliability (Standards/research)
https://www.nuffieldfoundation.org	Nuffield Foundation Review of forensic science, reliability, and evidence interpretation (Research)
https://www.unodc.org	United Nations Office on Drugs and Crime Forensic science guidance, ethics, and capacity building (General reference)

Journals and articles

Jones, N., Forry, E. and Sirk, D. (2023) 'Demystifying Accreditation A Framework for Accreditation of Forensic Units', *NIST Grant/Contract Reports*. Available at: https://doi.org/10.6028/NIST.GCR.23-043.

Overill, R.E. and Collie, J. (2021) 'Quantitative Evaluation of the Results of Digital Forensic Investigations: A Review of Progress', *Forensic Sciences Research*, 6(1), pp. 13–18. Available at: https://doi.org/10.1080/20961790.2020.1837429.

Tewari, S., *et al.* (2024) 'Measurement uncertainty in testing of biologicals in national control laboratories for ISO/IEC 17025: practical approaches', *Accreditation and Quality Assurance*, 29, pp. 253–261. Available at: https://doi.org/10.1007/s00769-024-01589-8.

Wüllenweber, S. and Giles, S. (2021) 'The effectiveness of forensic evidence in the investigation of volume crime scenes', *Science & Justice*, 61(5), pp. 542–554. Available at: https://doi.org/10.1016/j.scijus.2021.06.008.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 410: Criminal Investigation

Unit 501: Personal and Professional Development for Scientists

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 510: Forensic Evidence Evaluation and Reporting.

Unit 410: Criminal Investigation

Unit code: **L/652/3042**

Unit level: **4**

Credit value: **15**

Introduction

Criminal investigation is a core component of the criminal justice process, requiring the structured and lawful application of investigative principles to establish facts and support fair outcomes. This unit introduces students to the practical and professional foundations of criminal investigation, focusing on how investigations are planned, conducted and managed, including evidence handling and crime scene management from the initial response onwards. It is designed to build investigative understanding at Level 4 without requiring specialist laboratory facilities or advanced forensic analysis. The unit is delivered within a UK criminal justice context; however, centres should recognise that legal procedures, court structures and regulatory requirements may vary across national and regional jurisdictions.

The unit explores the principles that underpin effective criminal investigation, including legality, proportionality, objectivity and accountability. Students examine how investigative decisions are shaped by ethical, professional and operational considerations, and how investigators balance thoroughness with the responsible use of resources. This includes the need for fair, impartial and respectful practice that avoids bias and supports appropriate consideration of individual circumstances and communication needs. Emphasis is placed on the importance of clear decision making, accurate record keeping and the role of written and digital documentation in supporting transparency, traceability and professional review.

A significant focus of the unit is the identification, gathering and classification of evidence, alongside the management of crime scenes. Students develop an understanding of procedures used to recognise and preserve evidence, prevent contamination and maintain continuity throughout the investigative process. The unit also considers how crime scenes are secured, coordinated and documented, highlighting the importance of effective communication, sequencing of actions and sustainability in complex or resource-limited investigative contexts.

Through the application of criminal investigation methodologies to simulated crime scenes, students develop practical insight into how investigative principles are implemented in realistic scenarios. This includes consideration of documentation, sequencing and continuity of evidence, as well as reflection on the effectiveness and

limitations of investigative approaches. The unit provides a strong foundation for progression to further study in criminal investigation, forensic practice or applied forensic science, and supports the development of skills relevant to investigative and criminal justice roles.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles of criminal investigation

LO2 Describe procedures for evidence identification, collection and classification

LO3 Explain processes for crime scene management

LO4 Apply principles of criminal investigation, evidence handling procedures and crime scene management processes to a simulated crime scene.

Essential Content

LO1 **Explain the fundamental principles of criminal investigation**

Purpose and scope of criminal investigation:

Purpose and scope of criminal investigation: e.g. establishing facts, identifying suspects, lawful outcomes, fair outcomes

Relationships: relationship between criminal investigation, forensic science, legal processes; distinction between investigative decision making and scientific examination; distinguishing investigative actions from laboratory analysis

Effective and appropriate use of investigative resources; scale e.g. based on seriousness of offence; proportionality, sustainability, thoroughness.

Investigative principles and models:

Investigative principles and models: structured investigative models; avoidance of unnecessary investigative actions and wasted resources; legality, proportionality, objectivity, accountability, transparency

Information gathering: forming and reviewing working hypotheses e.g. hypothesis-led thinking; decision making; sequential approaches; communication

Avoiding the risk of compromised evidence: fair and impartial practice; avoidance of bias; consideration of individual circumstances.

Roles, responsibilities and decision making:

Roles and responsibilities in criminal investigations: police force, crime scene investigation (CSI), Crime Scene Manager (CSM), Senior Investigating Officer (SIO), first responders, forensic scientists, pathologist, coroner; first responder responsibilities

Decision making: accurate and timely recording of decisions e.g. investigation log, written records, digital records; prioritisation, risk assessment, ethical considerations, accountability, later review.

LO2 **Describe procedures for evidence identification, collection, and classification**

Evidence identification at crime scenes:

Evidence identification at crime scenes: physical evidence, biological evidence, digital evidence, scene context

Sustainable practice: avoidance of unnecessary disturbance of scenes; prevention of damage to evidential material e.g. minimisation of contamination, loss, degradation; identification of trace evidence e.g. visibility, fragility.

Evidence collection and preservation procedures:

Evidence collection: reduction of repeat collection; minimisation of contamination risks and cross-transfer; environmental effects; consistent following of established procedures

Preservation procedures: preservation of integrity; safe handling; appropriate packaging, short-term storage; minimisation of waste; prevention of cross-contamination.

Evidence classification and documentation:

Evidence classification: classification of evidence by type and investigative relevance; continuity of evidence; evidence labels, notes, records

Documentation: secure paper-based documentation systems; digital documentation systems; professional standards of record keeping e.g. maintaining a continuity record, traceability, accountability.

LO3 **Explain processes for crime scene management**

Scene control and preservation:

Scene control: preservation of a crime scene e.g. establishment of boundaries, controlled access, inner and outer cordons, controlled entry

Preserving evidential integrity: prevention of contamination, damage, interference

Effective use of personnel: prioritisation of actions in dynamic scenes; avoidance of duplicated effort.

Coordination and communication:

Coordination: communication between first responders, investigators and specialist personnel; management of multiple activities at a crime scene, scene control; evidential integrity; shared records, briefings, efficient investigative practice, sustainable investigative practice

Communication: clear and respectful communication e.g. inclusive, adapted to individual circumstances, needs and roles; ensuring instructions are understood.

Documentation, digital records, and review:

Documentation: e.g. maintenance of a scene log, access records, observational notes, written documentation systems

Digital documentation systems: electronic logs; transparency, auditability, accurate records

Review: later review of scene management decisions; continuity of evidence.

LO4 **Apply principles of criminal investigation, evidence handling procedures and crime scene management processes to a simulated crime scene**

Application of investigative principles:

Criminal investigation principles: principles applied within a simulated crime scene e.g. legality, proportionality, objectivity, accountability

Decision making: scene assessment, priorities, appropriate actions.

Application of evidence handling procedures:

Evidence handling: procedures applied within a simulated crime scene e.g. identification, handling, packaging, labelling

Preservation of evidential material: e.g. contamination prevention, loss prevention, damage prevention, continuity maintenance.

Application of crime scene management processes:

Crime scene management processes: applied within a simulated crime scene e.g. scene control, access management, sequencing of activities, coordination of actions

Evidential integrity protection: e.g. preservation, contamination prevention.

Documentation and review:

Documentation: e.g. actions, observations, decisions, continuity of evidence

Strengths and limitations: areas for improvement e.g. scene log, review of approach used, improvements identified following review.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental principles of criminal investigation</td><td rowspan="8">LO1, LO2 and LO3

D1 Evaluate how criminal investigation principles, evidence handling procedures and crime scene management processes collectively influence the integrity, reliability and usability of evidence within criminal investigations.</td></tr>
<tr><td>P1 Explain the purpose and scope of criminal investigation within the criminal justice system.

P2 Outline key investigative principles, roles and decision-making processes used in criminal investigations.</td><td>M1 Analyse how investigative principles influence decision making in criminal investigations.</td></tr>
<tr><td colspan="2">LO2 Describe procedures for evidence identification, collection and classification</td></tr>
<tr><td>P3 Describe procedures used to identify and collect evidence at a crime scene.

P4 Outline procedures used to classify evidence and maintain continuity through documentation.</td><td>M2 Assess evidence identification, collection and classification in relation to contamination control and documentation.</td></tr>
<tr><td colspan="2">LO3 Explain processes for crime scene management</td></tr>
<tr><td>P5 Examine processes used to control and preserve a crime scene.

P6 Explain processes used to coordinate activities and documentation during crime scene management.</td><td>M3 Analyse how crime scene management processes support evidential integrity and effective investigation.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Apply principles of criminal investigation, evidence handling procedures and crime scene management processes to a simulated crime scene		**LO4**
P7 Apply the principles of criminal investigation, evidence handling procedures and crime scene management processes to a simulated crime scene. **P8** Review the application of criminal investigation, evidence handling procedures and crime scene management processes in a simulated crime scene.	**M4** Evaluate the application of criminal investigation principles, evidence handling procedures and crime scene management processes in a simulated crime scene.	**D2** Justify the selection of the criminal investigation principles, evidence handling procedures and crime scene management processes for a simulated crime scene, including strengths, limitations and areas for improvement.

Recommended Resources

Textbooks

Brookman, F., Brown, S. and Fleming, J. (2021) *Understanding Criminal Investigation*. 2nd edn. London: Routledge.

Dale, A., Davies, G. and Martin, J. (2020) *Criminal Investigation*. Oxford: Oxford University Press.

Fisher, B.A.J. and Fisher, D.R. (2022) *Techniques of Crime Scene Investigation*. 9th edn. Boca Raton, FL: CRC Press.

Fish, J.T., *et al*. (2021) *Crime Scene Investigation*. 4th edn. New York: Routledge.

Horswell, J. (2023) *The Practice of Crime Scene Investigation*. London: Routledge.

Newburn, T., Williamson, T. and Wright, A. (2021) *Handbook of Criminal Investigation*. 2nd edn. London: Willan.

Pepper, I. (2020) *Crime Scene Investigation: Methods and Procedures*. London: Palgrave Macmillan.

Ribaux, O., Walsh, S.J. and Margot, P. (2020) *The Forensic Intelligence Model*. Boca Raton, FL: CRC Press.

Stelfox, P. (2009) *Criminal Investigation: An Introduction to Principles and Practice*. London: Routledge.

Tong, S. (2021) *Police Investigation: Theory and Practice*. 2nd edn. London: Palgrave Macmillan.

Websites

https://www.college.police.uk	College of Policing Criminal investigation guidance, professional practice and decision-making models (Professional guidance)
https://www.cps.gov.uk	Crown Prosecution Service Evidential standards, disclosure principles and case progression (General reference)

https://www.enfsi.eu	European Network of Forensic Science Institutes Best practice guidance supporting investigation and scene management (Professional guidance)
https://www.fcn.police.uk/	Forensic Capability Network Advice and guidance from a variety of sources (Professional guidance)
https://www.gov.uk/government/organisations/forensic-science-regulator	Forensic Science Regulator (UK) Codes of practice influencing crime scene management and evidence handling (Regulatory guidance)
https://www.gov.uk/government/organisations/home-office	Home Office (UK) Criminal justice policy, policing frameworks and investigation context (General reference)
https://www.interpol.int	Interpol International investigation cooperation and crime scene coordination principles (General reference)
https://www.justice.gov	United States Department of Justice Criminal investigation frameworks and evidential integrity guidance (General reference)
https://www.met.police.uk	Metropolitan Police Service Public information on investigative processes and crime scene management (General reference)
https://www.ncjrs.gov	National Criminal Justice Reference Service Criminal investigation research and practitioner reports (Research)

https://www.unodc.org	UN Office on Drugs and Crime Criminal investigation standards, ethics and capacity-building guidance (General reference)

Journals and articles

Brown, C., Julian, R. and Howes, L.M. (2024) 'Strands in a cable: effective investigator decision-making using forensic identification evidence in volume crime investigations', *Policing and Society*, 34(5), pp. 417–433. Available at: https://doi.org/10.1080/10439463.2023.2279063.

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McCartney, C. and Shorter, L. (2024) 'You don't know what you've got 'til it's gone: Police retention of investigative materials', *International Journal of Police Science & Management*, 26(1), pp. 94–106. Available at: https://doi.org/10.1177/14613557231203493.

OSAC/NIST (2024) 'OSAC 2023-N-0002 Standard for Scene Documentation Procedures, Version 2.0'. Available at: https://www.nist.gov/document/osac-2023-n-0002-standard-scene-documentation-procedures-version-20.

Rossmo, D.K. (2021) 'Dissecting a Criminal Investigation', *Journal of Police and Criminal Psychology*, 36, pp. 639–651. Available at: https://doi.org/10.1007/s11896-021-09434-1.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 409: Fundamentals of Forensic Science

Unit 501: Personal and Professional Development for Scientists

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 510: Forensic Evidence Evaluation and Reporting.

Unit 411: Inorganic Chemistry

Unit code: **M/652/3043**

Unit level: **4**

Credit value: **15**

Introduction

Inorganic chemistry is central to a wide range of scientific disciplines and industrial applications, including materials science, chemical manufacturing, environmental analysis, pharmaceuticals and energy technologies. An understanding of inorganic chemistry is essential for those working in laboratory, analytical and technical roles where the behaviour of elements, compounds and materials must be interpreted and applied in practical contexts. This unit provides students with a structured introduction to the fundamental principles that govern inorganic chemical systems and supports progression within applied science pathways.

The unit emphasises the relationship between atomic structure, periodic trends and the properties of inorganic substances, enabling students to make informed predictions about chemical behaviour. Students examine how atoms combine through different bonding models to form molecular and solid structures, and how these structures influence the physical and chemical properties of materials encountered in laboratory and industrial settings. The unit also introduces coordination chemistry as a distinctive area of inorganic chemistry with relevance to catalysis, analysis and applied chemical technologies.

Alongside theoretical understanding, the unit develops applied skills through the use of stoichiometric and redox principles to interpret inorganic reactions. Students engage with quantitative relationships in chemical equations and consider accuracy, limitations and reliability when applying calculations to reaction systems. The unit supports the development of practical scientific thinking through the use of data handling, calculation tools and contextual examples that reflect contemporary laboratory practice and responsible material use.

On completion of this unit, students will be equipped with a sound foundation in inorganic chemistry that supports further study in chemistry-related disciplines or progression into technical and scientific roles. The knowledge and skills developed provide a basis for understanding more advanced chemical concepts and for applying inorganic chemistry principles within academic, research and industrial environments.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain atomic structure and periodic trends to interpret and predict the properties of elements

LO2 Describe and compare primary bonding models and the structures of inorganic molecular and solid substances

LO3 Explain the fundamental principles of coordination chemistry

LO4 Apply stoichiometric and redox principles in practical inorganic reaction contexts.

Essential Content

LO1 **Explain atomic structure and periodic trends to interpret and predict the properties of elements**

Atomic structure and electronic configuration:

Atomic number and mass number: subatomic particles; isotopes and relative atomic mass; electronic configuration using shell and subshell notation (*s* and *p* subshells), with reference to elements up to krypton ($Z = 36$)

Orbital occupancy principles: Aufbau principle, Pauli exclusion principle, Hund's rule; ion formation from atoms linked to electronic configuration e.g. $Na \rightarrow Na^+ + e^-$; $O + 2e^- \rightarrow O^{2-}$; relationship between electronic configuration and position in the periodic table e.g. period number, group number, block.

Periodic trends:

Trends: trends in atomic and ionic radius, first ionisation energy and electronegativity across Periods 2 and 3 and down Groups 1 and 7; explanation of trends e.g. effective nuclear charge, shielding, electron configuration

Shell structure: successive ionisation energies as evidence for shell structure e.g. large jump after removing all valence electrons in Group 1; metallic and non-metallic character across a period; typical ion formation patterns e.g. Group 1 +1 ions; Group 2 +2 ions; Group 7 −1 ions.

Predictive use and limitations:

Structure-property prediction using periodic trends: reactivity patterns and typical bonding behaviour e.g. increasing reactivity down Group 1, decreasing reactivity down Group 7; interpretation of periodic trends e.g. graphical or tabulated

Prediction of oxide type and behaviour from periodic position: basic, acidic, amphoteric oxides e.g. MgO basic; SO_3 acidic; Al_2O_3 amphoteric; limitations of prediction based on periodicity and simplified atomic models e.g. electron–electron repulsion and subshell effects influencing ionisation energies

Material selection: abundance and criticality as contextual factors influencing material selection e.g. relative availability of aluminium, iron and copper compared with scarce elements e.g. lithium or cobalt.

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LO2 **Describe and compare primary bonding models and the structures of inorganic molecular and solid substances**

Primary bonding models:

Ionic, covalent and metallic bonding models: electron transfer, electron sharing, delocalised electrons; electronegativity difference as an indicator of bond type; bond polarity as a continuum between ionic and covalent bonding
e.g. sodium chloride as predominantly ionic, hydrogen chloride as polar covalent

Descriptive tools for bonding and composition: formal charge and oxidation state e.g. SO_4^{2-}; Fe^{2+} vs Fe^{3+} in ionic compounds.

Intermolecular forces:

Intermolecular forces of attraction in molecular substances: hydrogen bonding, permanent dipole-dipole interactions and London dispersion forces; relative strengths of intermolecular forces

Influence on physical properties: boiling point, melting point and solubility
e.g. higher boiling point of H_2O compared with H_2S due to hydrogen bonding; iodine as a molecular solid with relatively low melting point compared with ionic solids.

Types of inorganic structures and solids:

Ionic solids: characterised by extended lattices of oppositely charged ions
e.g. sodium chloride-type structures; magnesium oxide; lattice energy as a qualitative explanation for stability and melting point trends e.g. higher lattice energy in MgO than NaCl due to higher ionic charges

Metallic solids: characterised by positive metal ions in a lattice surrounded by delocalised electrons e.g. aluminium, iron, copper; alloys as modified metallic structures e.g. steel as Fe with C; brass as Cu with Zn

Simple molecular solids: composed of discrete molecules held together by intermolecular forces e.g. iodine, sulfur

Giant covalent (macromolecular) solids: characterised by extended covalent networks e.g. diamond, graphite, silicon dioxide

Bond models: introductory localised bond models of covalent bonding
e.g. Lewis concepts (shared electron pairs); introductory valence bond concepts e.g. resonance and hybridisation; introductory valence shell electron pair repulsion (VSEPR) theory and shapes of simple molecules.

Structure–property relationships and material context:

Influence of bonding and structure on physical properties: melting point and boiling point e.g. high melting points of ionic and giant covalent solids compared with simple molecular solids; electrical conductivity e.g. metals conducting in the solid state; ionic compounds conducting when molten or dissolved; hardness, brittleness and malleability e.g. brittle nature of ionic solids; malleability of metals; hardness differences between diamond and graphite

Solubility patterns of ionic and molecular substances in water: comparison of inorganic substances based on bonding type and structure to explain observed properties; use of structural representations and models to support comparison of bonding and solid structures

Contextual consideration of material choice: consideration of structure–property relationships e.g. corrosion resistance of aluminium due to oxide layer; durability of ionic ceramics; recyclability of metallic materials; energy demands associated with producing and processing different inorganic solids.

LO3 **Explain the fundamental principles of coordination chemistry**

Coordination compounds:

Coordination geometries: limited to octahedral, tetrahedral and square planar; central metal ions; ligands; coordinate (dative) bonding; coordination number; oxidation state of the central metal ion in complexes; illustrative first-row transition metal ions as examples e.g. Cu^{2+}, Fe^{2+}/Fe^{3+}, Ni^{2+}; common ligands e.g. H_2O, NH_3, Cl^-

Complex ions: overall charge e.g. $[Cu(NH_3)_4(H_2O)_2]^{2+}$; $[Fe(CN)_6]^{3-}$; introductory crystal field concepts e.g. splitting of d-orbitals and relationship to colour in simple transition metal complexes.

Ligand type and geometry:

Ligand type: monodentate and polydentate ligands; denticity concepts; chelation and chelate effect as a qualitative stability concept e.g. EDTA forming more stable complexes than comparable monodentate ligands; ligand substitution as a concept

Isomerism: in coordination compounds as an introductory concept e.g. linkage isomerism with NO_2^-/ONO^-; links between ligand type and coordination geometry and the observable properties of coordination compounds e.g. colour changes in Cu^{2+} complexes with different ligands

Conductivity: conductivity changes between neutral complexes and ionic complexes; stability trends in simple comparisons; introductory metal–ligand interaction concepts sufficient to explain property differences without extended theory.

Applications and limitations:

Coordination chemistry in applied contexts: catalysis; complexing agents in analysis e.g., chelation therapy; complex formation in qualitative and quantitative analysis e.g. complexometric titrations with EDTA; masking agents

Presentation and interpretation of coordination data: contextual support; sustainability-related considerations e.g. toxicity and handling of metal salts, resource availability of selected transition metals, catalytic processes as routes to lower energy demand and reduced waste; limitations of simple coordination models at introductory level.

LO4 **Apply stoichiometric and redox principles in practical inorganic reaction contexts**

Stoichiometric principles and inorganic reaction equations:

Chemical formulae and balanced chemical equations: state symbols; ionic equations for aqueous reactions; mole concept and molar mass; stoichiometric coefficients and reacting ratios; limiting reagent as a calculation context

Quantitative interpretation of inorganic reactions consistent with balanced equations: precipitation reactions e.g. $AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$; synthesis reactions e.g. $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$; displacement reactions e.g. $Zn(s) + CuSO_4(aq) \rightarrow ZnSO_4(aq) + Cu(s)$

Concentration and dilution calculations: standard solutions used in inorganic reaction systems; practical titration calculations e.g. acid–base titrations, redox titrations, endpoint determination, titre concordance; gravimetric analysis calculations e.g. precipitation, filtration, drying and weighing of insoluble products; percentage composition, empirical formula and percentage yield from mass data.

Redox principles and reaction contexts:

Oxidation numbers: definitions of oxidation and reduction; identification of oxidising and reducing agents; half-equations as representations of electron transfer

Recognition of redox processes in inorganic reactions e.g. metal/metal–ion displacement reactions, halogen displacement reactions, oxidation of metals; redox in corrosion and prevention strategies as applied context e.g. sacrificial protection using Zn on steel; passivation of Al.

Quantitative outcomes, accuracy and limitations:

Outcomes: comparison of theoretical and actual outcomes in inorganic reactions; atom economy as a measure of reaction efficiency e.g. comparison of addition and substitution routes where relevant; calculation and interpretation of percentage yield and efficiency

Sources of error and limitation in practical applications: incomplete reactions, side reactions, measurement uncertainty, loss of material; significant figures and unit consistency in reporting calculated outcomes

Digital tools: use of digital calculation and checking tools to support accuracy e.g. spreadsheet-based mole, concentration and yield calculations; contextual consideration of efficiency, waste minimisation and material use in practical inorganic chemistry e.g. minimisation of excess reagents in precipitation reactions; recovery/recycling of metals from displacement reactions.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain atomic structure and periodic trends to interpret and predict the properties of elements</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate the extent to which atomic, bonding, structure and coordination models account for the properties of inorganic substances, considering their limitations.</td></tr>
<tr><td>P1 Explain atomic structure in terms of electronic configuration and sub-shell occupancy.

P2 Describe periodic trends in atomic radius, ionisation energy and electronegativity in relation to electronic structure.</td><td>M1 Analyse how atomic structure and periodic trends influence the properties of selected elements.</td></tr>
<tr><td colspan="2">LO2 Describe and compare primary bonding models and the structures of inorganic molecular and solid substances</td></tr>
<tr><td>P3 Describe ionic, covalent and metallic bonding models in inorganic substances.

P4 Compare the structures of inorganic molecular and solid substances.</td><td>M2 Assess how bonding and structure models account for the properties of inorganic molecular and solid substances.</td></tr>
<tr><td colspan="2">LO3 Explain the fundamental principles of coordination chemistry</td></tr>
<tr><td>P5 Explain the formation of coordination compounds in terms of metal ions, ligands and coordination number.

P6 Describe common geometries of coordination compounds.</td><td>M3 Analyse how coordination chemistry principles account for the properties of coordination compounds.</td></tr>
<tr><td colspan="2">LO4 Apply stoichiometric and redox principles in practical inorganic reaction contexts</td><td rowspan="2">LO4

D2 Evaluate the validity of stoichiometric and redox applications in practical inorganic reactions, considering the limitations of methods, measurements and assumptions.</td></tr>
<tr><td>P7 Apply stoichiometric and redox principles in practical inorganic reaction contexts.

P8 Discuss the quantitative outcomes, accuracy and limitations of inorganic reactions.</td><td>M4 Assess quantitative outcomes in practical inorganic reactions in relation to stoichiometric and redox principles.</td></tr>
</table>

Recommended Resources

Textbooks

Burrows, A., *et al*. (2021) *Chemistry: Introducing Inorganic, Organic and Physical Chemistry*. 4th edn. Oxford: Oxford University Press.

House, J.E. (2025) *Inorganic Chemistry*. 4th edn. London: Academic Press.

Housecroft, C.E. and Sharpe, A.G. (2025) *Inorganic Chemistry*. 6th edn. Harlow: Pearson Education.

Norman, N.C. (2021) *Periodicity and the s- and p-block Elements*. 2nd edn. Oxford: Oxford University Press.

Overton, T., *et al*. (2025) *Inorganic Chemistry*. 8th edn. Oxford: Oxford University Press.

Pfennig, B.W. (2021) *Principles of Inorganic Chemistry*. 2nd edn. Hoboken: Wiley.

Winter, M. J. (2016) *Chemical Bonding*. 2nd edn. Oxford: Oxford University Press.

Winter, M. J. and Andrew, J. (2001) *Foundations of Inorganic Chemistry*. Oxford: Oxford University Press.

Zumdahl, S.S. and Zumdahl, S.A. (2020) *Chemistry*. 10th edn. Boston: Cengage Learning.

Websites

https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry	Chemistry LibreTexts Inorganic Chemistry bookshelf, including atomic structure, periodic trends, bonding and coordination chemistry (General reference)
https://www.chemguide.co.uk/inorgmenu.html	Chemguide Inorganic chemistry menu covering redox, periodic trends, Group chemistry, transition metals and complex ions (General reference)
https://pubchem.ncbi.nlm.nih.gov/periodic-table/	PubChem Periodic Table Element data, atomic properties, periodic trends, isotopes, uses and safety information (Data set)

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https://edu.rsc.org/experiments/properties-of-the-transition-metals-and-their-compounds/472.article	Royal Society of Chemistry Education Transition metals and their compounds: practical observations, properties and compound behaviour (Teaching resource)
https://www.chemguide.co.uk/inorganic/complexions/whatis.html	Chemguide Introduction to complex ions, ligands, coordination number and coordinate bonding (Student reference)
https://www.chemguide.co.uk/inorganic/redoxmenu.html	Chemguide Redox definitions, oxidation states and writing redox equations (Student reference)

Journals and articles

Aziz, K., *et al*. (2025) 'A review of coordination compounds: structure, stability, and biological significance', *Reviews in Inorganic Chemistry*, 45, pp. 1–19. Available at: https://doi.org/10.1515/revic-2024-0035.

Juraj, N., *et al*. (2021) 'Inorganic stereochemistry: Geometric isomerism in bis-tridentate ligand complexes', *Coordination Chemistry Reviews*, 445, 214051. Available at: https://doi.org/10.1016/j.ccr.2021.214051.

Macciò, D., *et al*. (2023) 'Solving Redox Reactions: The Advantages of the Thermodynamic Method', *Journal of Chemical Education*, 100, pp. 2215–2223. Available at: https://doi.org/10.1021/acs.jchemed.2c01151.

Rosa, V., States, N.E., Corrales, A., Nguyen, Y. and Atkinson, M.B. (2022) 'Relevance and equity: should stoichiometry be the foundation of introductory chemistry courses?', *Chemistry Education Research and Practice*, 23(3), pp. 662–685. Available at: https://doi.org/10.1039/D1RP00333J.

Woldu, A.R., *et al*. (2022) 'Electrochemical CO_2 reduction (CO_2RR) to multi-carbon products over copper-based catalysts', *Coordination Chemistry Reviews*, 454, 214340. Available at: https://doi.org/10.1016/j.ccr.2021.214340.

Yang, J., *et al*. (2022) 'Metal nanocluster-based hybrid nanomaterials: Fabrication and application', *Coordination Chemistry Reviews*, 456, 214391. Available at: https://doi.org/10.1016/j.ccr.2021.214391.

Links

This unit links to the following related units:

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 412: Organic Chemistry

Unit 413: Physical Chemistry

Unit 512: Solid State and Transition Metal Chemistry

Unit 526: Further Analytical Chemistry.

Unit 412: Organic Chemistry

Unit code: R/652/3044

Unit level: 4

Credit value: 15

Introduction

Organic chemistry is a central discipline within chemistry that focuses on the structure, properties and reactions of carbon-based compounds. These compounds form the basis of a vast range of substances used across scientific, industrial and everyday contexts, including fuels, pharmaceuticals, polymers, agrochemicals, solvents, fragrances and biological molecules.

This unit provides students with a structured introduction to the fundamental principles that underpin organic chemistry at Level 4. It develops understanding of how organic molecules are represented and how molecular structure, bonding and three-dimensional arrangement influence physical properties and chemical behaviour. Students explore carbon catenation, functional groups and stereochemistry, building the foundations needed to recognise and compare the major families of organic compounds and to predict trends in reactivity and application. A strong emphasis is placed on organic reaction mechanisms as a means of explaining how and why chemical reactions occur. Students examine key reaction types and mechanistic pathways in order to link reaction conditions, intermediates and molecular structure to observed reaction outcomes.

Alongside theoretical knowledge, the unit develops applied analytical and communication skills relevant to contemporary laboratory practice. Students investigate the practical application of analytical techniques commonly used in organic chemistry to identify organic compounds and assess purity. Digital tools are used to support data handling, interpretation and presentation of findings.

On completion of this unit, students will have developed the knowledge and skills needed to understand the structure, properties and reactivity of organic compounds, and to apply analytical techniques used to identify, characterise and assess organic substances. This will support progression to further study in applied science, chemistry, biochemistry, pharmaceutical science and related disciplines. The unit will also support progression to laboratory, analytical, chemical manufacturing, quality control and research support roles where knowledge of organic compounds and their behaviour is required.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles of organic molecular structure

LO2 Discuss the major families of organic compounds

LO3 Describe a range of key organic reaction mechanisms

LO4 Present, using either real-world case studies or laboratory-based investigation, the practical applications of analytical techniques used in organic chemistry, for an intended audience.

Essential Content

LO1 **Explain the fundamental principles of organic molecular structure**

Molecular representations and structural features:

Molecular representations used in organic chemistry: formulae e.g. displayed, condensed, skeletal formulae; three-dimensional representations using wedge and dash notation

Structural features of organic molecules: carbon chains, branching, ring structures, the position and type of functional groups

Structural isomerism: differences in connectivity, chain isomerism, positional isomerism

Nomenclature: IUPAC terminology.

Bonding models and electron distribution:

Covalent bonding in organic molecules: the tetravalency of carbon and its ability to form stable strong covalent bonds; the role of bond polarity and electronegativity to describe polar and non-polar bonds and molecular dipoles

Sigma and pi bonding: models to explain single, double and triple bonds; e.g. relationship between bonding type, hybridisation, molecular geometry

Electron distribution effects: explanation of molecular stability and reactivity e.g. inductive effects, introductory resonance concepts.

Molecular structure and stereochemistry:

Molecular shape and bond angles in organic compounds: tetrahedral, trigonal planar and linear arrangements; conformational features arising from rotation about single bonds; staggered and eclipsed conformations, cyclohexane conformations

Stereoisomerism: geometric isomerism (*cis*/*trans* and *E*/*Z*), optical isomerism through the recognition of chirality and enantiomers.

Structure–property relationships:

Intermolecular forces: dispersion forces, dipole–dipole interactions, hydrogen bonding; influence on physical properties e.g. boiling/melting point; molecular polarity: solubility (in polar and non-polar solvents); the unique properties of water attributed to hydrogen bonding

Physical properties: the influence of molecular structure, functional-group type and branching.

LO2 **Discuss the major families of organic compounds**

Functional groups and classification of compound families:

Classification: major families of organic compounds and their defining functional groups; hydrocarbons, haloalkanes, alcohols, ethers, carbonyl compounds, amines and amides

Naming: use of IUPAC naming convention to classify organic compounds; identification of parent carbon chain length, position of branching groups and functional groups; recognition of functional-group priority.

Characteristic chemistry and reactivity patterns:

Characteristic reactions of hydrocarbons: combustion and substitution for alkanes; electrophilic addition for alkenes

Characteristic chemistry of haloalkanes: substitution reactions, elimination reactions

Reactions of alcohols: oxidation, dehydration

Chemistry of carbonyl compounds: nucleophilic addition, oxidation and reduction reactions of aldehydes and ketones

Representative condensation reactions; basicity of amines, formation of amides.

Structure, reactivity and applications:

Structure and reactivity: relationships between functional-group structure and chemical reactivity across compound families; identification of reactive centres and polarity effects; relationships between functional-group structure and physical properties across compound families; boiling point and solubility trends

Applications of organic compounds: fuels, solvents, pharmaceuticals, polymers, agrochemicals, fragrances, flavourings.

Links between compound families:

Similarities and differences between organic compound families: structure and reactivity; functional-group interconversions linking compound families e.g. alcohols to haloalkanes, alkenes to alcohols and aldehydes to carboxylic acids, within the scope of centre delivery.

Environmental and sustainability considerations:

Environmental considerations: persistence, pollution, toxicity, biodegradability

Sustainability considerations; greener solvents, reduced-waste reactions, safer chemical alternatives; selection of organic compounds and reactions in laboratory and applied contexts.

LO3 **Describe a range of key organic reaction mechanisms**

Reaction participants and reaction types:

Reactive species involved in organic reactions: nucleophiles, electrophiles, free radicals, acids and bases in organic contexts; the role of leaving groups in reaction feasibility and pathway

Classification of organic reactions: addition, substitution, elimination, rearrangement, condensation.

Mechanistic representation and conventions:

Notation: curly arrow notation to represent electron movement; heterolytic and homolytic bond fission; movement of lone-pair electrons

Representation: stepwise representation of reaction mechanisms; intermediates and transition states e.g. carbocation intermediates, activated complexes

Concepts: activation energy and catalysis in organic reactions.

Key organic reaction mechanisms:

Nucleophilic substitution mechanisms: characteristic features of SN1 and SN2 reactions, the conditions that favour each pathway

Elimination mechanisms: E1 and E2 reactions and examples; factors influencing predominance of elimination over substitution and vice versa e.g. molecular structure, nature of nucleophile, temperature, solvent

Electrophilic addition reactions of alkenes: orientation effects

Nucleophilic addition: reactions of aldehydes and ketones as electrophilic carbonyl compounds

Free-radical substitution reactions: alkane halogenation.

Factors influencing reaction outcomes:

Factors: effects of conditions on reaction pathway and outcome e.g. solvent, temperature, concentration, reagent strength; effects of regioselectivity and stereochemical consequences on reaction pathway and observed outcome

Stability of intermediates in reaction pathways: carbocations, activated complexes, free radicals

LO4 **Present, using either real-world case studies or laboratory-based investigation, the practical applications of analytical techniques used in organic chemistry, for an intended audience.**

Investigation contexts and evidence sources:

Contexts: practical application of analytical techniques in organic chemistry e.g. laboratory-based investigations or real-world case studies

Investigation purposes: identification of organic compounds, assessment of purity, reaction monitoring e.g. changes in composition over time; quality control

Evidence sources: spectra, chromatograms; physical observations e.g. melting/boiling range, appearance, odour where appropriate and safe; clear links between evidence and investigation conclusions.

Analytical techniques used in organic chemistry:

Application of analytical techniques: identification from physical and chemical properties e.g. melting/boiling point, solubility behaviour, characteristic functional-group tests; spectroscopic techniques for identification and characterisation e.g. infrared spectroscopy, nuclear magnetic resonance spectroscopy, UV/visible spectroscopy, mass spectrometry

Chromatographic techniques: separation, purity assessment, monitoring; paper chromatography, thin-layer chromatography, gas chromatography, high-performance liquid chromatography; the meaning of retention/relative movement and use of reference materials where relevant.

Factors influencing technique selection: sample type and quantity, sensitivity, selectivity, information required, time/cost constraints, whether the context is investigative e.g. unknown identification or routine quality control.

Data interpretation and evaluation:

Interpretation of analytical outputs: key patterns and features e.g. diagnostic IR absorptions, chemical shifts and integration in nuclear magnetic resonance (NMR), key peaks/ions in mass spectra, retention behaviour and peak area trends in chromatograms

Evidence: evidence from multiple techniques e.g. to support identification, purity assessment, characterisation; reconciliation of consistent and inconsistent findings

Limitations: limitations and sources of uncertainty in analytical data e.g. sample contamination/impurities, overlapping peaks, instrument resolution, baseline/noise, calibration/reference quality; effect on confidence in conclusions.

Scientific communication, audience awareness and inclusion:

Presentation: preparation and delivery suitable for an intended audience; communication of the practical application of analytical techniques in organic chemistry

Communication: investigation aims/context, summary of methods/techniques applied, rationale for technique choice, analytical evidence used; conclusions about identity, purity, reaction progress or quality; limitations where relevant

Use of scientific language, appropriate referencing and visuals to support clarity, accuracy and inclusion e.g. annotated spectra/chromatograms, tables of key results; communication adapted for audiences with different levels of prior knowledge e.g. clear figure labelling, avoidance of unnecessary jargon, appropriate visual design

Reflection: use of audience feedback, assessment of effectiveness of the communication e.g. the practical application, interpretation, conclusions.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Explain the fundamental principles of organic molecular structure.		**LO1, LO2 and LO3** **D1** Evaluate how molecular structure and functional group chemistry determine likely reaction pathways and observed outcomes across major organic compound families.
P1 Explain organic representations, structural features and stereochemistry. **P2** Describe bonding, electron distribution and structure-property relationships in organic molecules.	**M1** Analyse how molecular structure influences the properties of organic molecules.	
LO2 Discuss the major families of organic compounds		
P3 Describe major organic compound families by functional group, naming and characteristic features. **P4** Explain characteristic reactions, applications and links between major organic compound families.	**M2** Analyse similarities and differences between major organic compound families in terms of structure, properties and reactivity.	
LO3 Describe a range of key organic reaction mechanisms		
P5 Describe reaction types, reactive species and mechanistic conventions in organic chemistry. **P6** Explain key organic reaction mechanisms and the factors influencing reaction outcomes.	**M3** Analyse how reaction conditions and intermediate species influence the course of organic reactions.	

Pass	Merit	Distinction
LO4 Present, using either real-world case studies or laboratory-based investigation, the practical applications of analytical techniques used in organic chemistry, for an intended audience.		**LO4** **D2** Evaluate the effectiveness of the selected techniques in a real-world case study or laboratory-based investigation.
P7 Outline the practical applications of selected analytical organic chemistry techniques through a real-world case study or laboratory-based investigation. **P8** Deliver a presentation on the results of the investigation into the practical applications of the analytical organic chemistry techniques to an intended audience.	**M4** Assess the practical applications of selected analytical organic chemistry techniques in a real-world case study or laboratory-based investigation.	

Recommended Resources

Textbooks

Anastas, P.T. and Warner, J.C. (1998) *Green Chemistry: Theory and Practice*. Oxford: Oxford University Press.

Fleming, I. and Williams, D.H. (2020) *Spectroscopic Methods in Organic Chemistry*. 7th edn. Cham: Springer.

Lancaster, M. (2025) *Green Chemistry: An Introductory Text*. 4th edn. Cambridge: Royal Society of Chemistry.

Moloney, M.G. (2025) *Organic Reaction Mechanisms 2021*. Chichester: Wiley.

Smith, J.G. (2020) *Organic Chemistry*. 6th edn. New York: McGraw-Hill Education.

Solomons, T.W.G., Fryhle, C.B. and Snyder, S.A. (2016) *Organic Chemistry*. 12th edn. Hoboken: Wiley.

Valiulin, R. (2020) *Organic Chemistry: 100 Must-know Mechanisms*. Berlin: De Gruyter.

Vollhardt, K.P.C. and Schore, N.E. (2018) *Organic Chemistry: Structure and Function*. 8th edn. New York: W.H. Freeman.

Websites

https://www.chemguide.co.uk/analysismenu.html	Chemguide Instrumental analysis: mass spectrometry, infrared spectroscopy, NMR spectroscopy, UV-visible spectroscopy and chromatography (Tutorials)
https://www.chemguide.co.uk/mechmenu.html	Chemguide Organic reaction mechanisms: substitution, elimination, electrophilic addition, nucleophilic addition and free-radical substitution (Tutorials)
https://openstax.org/details/books/organic-chemistry/	OpenStax Organic Chemistry: functional groups, stereochemistry, mechanisms, spectroscopy and reaction families (eBooks)

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https://organicchemistrydata.org/reusch/virtualtext/	Organic Chemistry Data Virtual textbook spectroscopy resources: IR, NMR, UV-visible and mass spectrometry for structure determination (General reference)
https://edu.rsc.org/download?ac=114811	Royal Society of Chemistry Education Chromatography teaching resources, practical activities and technique support (General reference)
https://pubs.rsc.org/en/content/articlehtml/2024/su/d3su00324h	Royal Society of Chemistry Publishing Tutorial review on sustainable and green synthetic chemistry practice in research laboratories (Article)
https://institute.acs.org/subject/organic-chemistry.html	American Chemical Society Institute Organic chemistry professional learning resources including FTIR spectroscopy, chromatography and organic synthesis (Training)

Journals and articles

Baxter, A., *et al*. (2025) 'Examining Student Learning of Infrared Spectroscopy in Organic Chemistry', *Journal of Chemical Education*, 102(1), pp. 45–52. Available at: https://doi.org/10.1021/acs.jchemed.5c00031.

van Beek, T.A. (2021) 'Low-field benchtop NMR spectroscopy: status and prospects in natural product analysis', Phytochemical Analysis, 32(1), pp. 24–37. Available at: doi.org/10.1002/pca.2921

Crandell, O.M., *et al*. (2020) 'Arrows on the page are not a good gauge: Evidence for the importance of causal mechanistic explanations', *Journal of Chemical Education*, 97(2), pp. 313–322. Available at: doi.org/10.1021/acs.jchemed.9b00815.

Kareti, M.S. and Howitz, W.J. (2023) 'A Thin Layer Chromatography Prelaboratory Activity Using a 3D-Printed Model to Address Student Misconceptions about Polarity and Intermolecular Forces', *Journal of Chemical Education*, 100(5), pp. 2076–2082. Available at: https://doi.org/10.1021/acs.jchemed.2c01142.

Lanke, V. and Marek, I. (2020) 'Stereospecific nucleophilic substitution at tertiary and quaternary stereocentres', *Chemical Science*, 11(35), pp. 9378–9385. Available at: https://doi.org/10.1039/D0SC02562C.

Liotta, L.J., *et al*. (2008) 'Identification of an Unknown Compound by Combined Use of IR, 1H NMR, 13C NMR, and Mass Spectrometry: A Real-Life Experience in Structure Determination', *Journal of Chemical Education*, 85(6), pp. 832–835. Available at: https://doi.org/10.1021/ed085p832.

Pearson, D.L. and Kitson, R.R.A. (2022) 'Quinone Synthesis and a Visual Introduction to Column Chromatography: An Undergraduate Experiment', *Journal of Chemical Education*, 99(4), pp. 1724–1730. Available at: https://doi.org/10.1021/acs.jchemed.1c00940.

Links

This unit links to the following related units:

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 411: Inorganic Chemistry

Unit 413: Physical Chemistry

Unit 513: Aromatic and Carbonyl Compounds

Unit 514: Spectroscopy, Surface Chemistry and Equilibria.

Unit 413: Physical Chemistry

Unit code: **T/652/3045**

Unit level: **4**

Credit value: **15**

Introduction

Physical chemistry sits at the core of applied chemistry, providing the models and quantitative reasoning used to explain and predict how chemical systems behave. Students who progress into laboratory, analytical and technical roles need to interpret structure, energy change and reaction behaviour to support decisions about materials, conditions and process performance. This unit therefore underpins both further study in chemistry and applied practice across industrial, environmental and research contexts.

The aim of this unit is to develop students' understanding of the physical principles that govern chemical systems and how these principles are used to interpret evidence and make predictions under defined conditions. Students will study how quantum ideas are used to describe atomic and molecular structure and bonding, which will develop a basis for explaining observable properties in terms of electronic structure and models.

Students will then apply thermodynamic concepts to chemical change, including thermodynamic systems and state functions, energy changes, and the use of Gibbs free energy and equilibrium relationships to assess feasibility and likely outcomes. They will also study phase behaviour and equilibrium, using heating and cooling curves, phase diagrams and equilibrium ideas to explain how systems respond when conditions such as temperature, pressure and concentration change.

On successful completion of this unit, students will be able to explain and apply key physical chemistry principles to interpret the behaviour of chemical systems. They will be able to use models and data to analyse atomic and molecular structure, thermodynamic change, phase behaviour, equilibrium and reaction kinetics, and they will be able to draw reasoned conclusions under defined conditions. These skills support progression within applied science and chemistry and prepare students for entry-level roles such as Laboratory Technician, Analytical Science Assistant, Quality Control Technician, Process Technician and Research Laboratory Assistant.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain atomic and molecular structure using fundamental quantum principles

LO2 Review how the laws of thermodynamics are applied to chemical systems

LO3 Discuss phase behaviour and equilibrium in chemical systems

LO4 Implement a methodology to determine rate laws and kinetic parameters from experimental data.

Essential Content

LO1 **Explain atomic and molecular structure using fundamental quantum principles**

Quantum concepts for atomic and molecular structure:

Quantisation of energy: discrete electronic energy levels, electronic transitions, line spectra

Wave–particle duality and uncertainty principle: probabilistic behaviour, position–momentum uncertainty, limits of measurement; wavefunction as probability model e.g. electron probability distribution, conceptual description; no mathematical formulation

Atomic orbitals: regions of electron probability, s- and p-orbital shapes, relative energies, introductory d and f trends, shielding and penetration effects.

Electronic structure as a predictive model:

Electron configuration: Aufbau principle, Pauli exclusion principle, Hund's rule, organisation of electrons

Quantum numbers: e.g. descriptors of electron states, orbital identification, energy levels

Effective nuclear charge: e.g. shielding effects, periodic trends, ionisation energy trends; prediction of ion formation patterns.

Bonding models and molecular structure interpretation:

Atomic and molecular orbitals: bonding and antibonding interactions, simple molecules, qualitative MO descriptions

Bond order: e.g. stability indicator, bond strength, bond length trends

Sigma and pi bonding: single and multiple bonds, structural descriptors

Valence bond and molecular orbital models: interpretation of bonding and properties e.g. paramagnetism in O_2; model scope and limitations.

LO2 **Review how the laws of thermodynamics are applied to chemical systems**

Thermodynamic laws, systems and state functions:

Zeroth, first, second and third laws of thermodynamics: application to chemical systems; thermodynamic systems and surroundings e.g. open, closed, isolated systems; classification of a laboratory set-up as open/closed for analysis of heat/work exchange

State variables and constraints: *T*, *P*, *V*, *n*; intensive and extensive properties; state functions and significance e.g. internal energy (*U*), enthalpy (*H*), entropy (*S*),

Gibbs free energy (G); sign conventions at an applied level; simple process comparisons of state functions versus path-dependent quantities.

Energy changes and thermochemical relationships:

Enthalpy changes: chemical reactions, physical processes; enthalpy of combustion, formation, neutralisation, solution, hydration, lattice enthalpy, dissociation, mean bond enthalpy, ionisation enthalpy, electron affinity, fusion, vaporisation, sublimation

Standard states and standard conditions: reference concepts, limitations; Hess's law and thermochemical cycles e.g. calculate reaction enthalpy changes; building a Hess cycle from formation enthalpies to estimate $\Delta H°$

Thermodynamic data interpretation: qualitative data e.g. process efficiency, reduced energy demand, comparing reaction routes to discuss energy demand and atom economy drivers.

Feasibility and equilibrium relationships:

Gibbs energy: negative change in Gibbs energy e.g. feasibility of a chemical reaction; signs of ΔH and ΔS and the significance; calculations e.g. $\Delta G = \Delta H° - T\Delta S°$; standard Gibbs free energy and equilibrium e.g. $\Delta G° = -RT\ln K$; relationship with equilibrium

Interpretation of feasibility under defined conditions using thermodynamic data: equations of state; ideal behaviour, limitations, what large compared with small K implies about equilibrium composition; what large and small values of k imply about equilibrium composition when ideal gas assumptions are acceptable at room conditions; when deviations matter at high pressure or low temperature.

Practical thermodynamics contexts:

Calorimetry and heat capacity: determining energy changes; practical considerations e.g. heat loss, insulation, mixing consistency, instrument resolution, safe working

Applications: coffee-cup calorimetry for neutralisation or dissolution enthalpy with discussion of uncertainty sources; comparison of temperature–time curves to infer systematic heat loss and impact on calculated ΔH.

LO3 **Discuss phase behaviour and equilibrium in chemical systems**

Phase behaviour and phase diagrams:

Phases and phase changes: pure substances; heating and cooling curves; phase diagrams e.g. phase boundaries, triple point, critical point; prediction of phase stability e.g. changing temperature and pressure

Selection of operating conditions: minimisation of energy use in physical and chemical processes; phase diagrams to justify process conditions that maintain a single phase; interpretation of a heating curve plateau as latent heat during a phase transition.

Energetics of phase change and vapour pressure:

Enthalpy and entropy changes: phase transitions; vapour pressure e.g. concept, temperature dependence; boiling behaviour e.g. temperature, external pressure

Clausius–Clapeyron relationship e.g. qualitative use, simple trend interpretation, why substances with stronger intermolecular forces have lower vapour pressures and higher boiling points; interpretation of a vapour–pressure–temperature plot to compare volatility.

Chemical equilibrium and system response:

Dynamic equilibrium: chemical reactions; equilibrium constants e.g. interpretation, determination; reaction quotient e.g. directional indicator, conceptual use; Le Chatelier's principle e.g. effects of changes in conditions on equilibrium position

Limitations: e.g. oversimplified rules when conditions are not specified; equilibrium concepts e.g. improve yield, reduce waste, predicting how pressure affects equilibria involving gases; direction of shift e.g. use of Q versus K qualitatively.

Practical equilibrium/phase contexts:

Observable phase-change measurements and equilibrium shift demonstrations: interpretation of observations; limitations; melting point measurement as an indicator of purity and intermolecular interactions; colour-change equilibrium system to illustrate concentration effects; boiling under reduced pressure to link external pressure to phase-change behaviour.

LO4 **Implement a methodology to determine rate laws and kinetic parameters from experimental data**

Reaction rates and kinetic descriptors:

Reaction rate: e.g. definition, measurement, appropriate units

Concentration–time behaviour and initial rate: descriptors of kinetic behaviour e.g. order of reaction and molecularity; interpreting a concentration–time curve to identify changing rate over time; using half-life consistency as an indicator of first-order behaviour e.g. conceptual/introductory.

Experimental methods for rate determination:

Experimental determination of reaction rates: initial rates methods, concentration–time data; monitoring approaches e.g. selection, method constraints, time resolution, mixing, quenching, sampling error

Methods: e.g. colorimetry to track a coloured reactant/product, gas syringe or mass loss to track gas evolution, conductivity or pH monitoring for suitable aqueous reactions.

Temperature dependence and kinetic parameters:

Arrhenius equation ($k = Ae^{-E_a/RT}$): model relating rate constant to temperature; kinetic parameters e.g. activation energy (E_a) and pre-exponential factor (A)

Graphical determination of kinetic parameters: experimental data, determination of E_a from a plot of ln$k$ versus $1/T$ using data collected at multiple temperatures

Catalysis: qualitative effect on reaction rate, comparison of catalysed versus uncatalysed conditions to interpret changes in rate and link to activation energy.

Mechanistic ideas and quality of kinetic evidence:

Rate-determining step: qualitative descriptive concept; steady-state behaviour e.g. illustrative only, not a formal approximation

Validity, reliability and accuracy of kinetic data: control of variables, sources of error, digital tools and software for data capture and graphical analysis; identification of random versus systematic error sources in timing and endpoint detection; justification of sampling interval choice to improve data resolution without excessive reagent; spreadsheet tools to fit straight-line transforms; comparison of goodness-of-fit qualitatively.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain atomic and molecular structure using fundamental quantum principles</td><td rowspan="8">LO1, LO2 and LO3

D1 Evaluate how structure, thermodynamics and equilibrium principles are used to predict chemical system behaviour under defined conditions, considering assumptions and limitations.</td></tr>
<tr><td>P1 Explain atomic and molecular structure using fundamental quantum principles.

P2 Describe how electronic structure, bonding models and molecular structure are used to interpret chemical properties.</td><td>M1 Analyse how quantum principles, electronic structure and bonding models explain atomic and molecular properties.</td></tr>
<tr><td colspan="2">LO2 Review how the laws of thermodynamics are applied to chemical systems</td></tr>
<tr><td>P3 Explain thermodynamic systems, state functions and thermodynamic laws in chemical systems.

P4 Use thermodynamic relationships and measurements to determine energy changes and reaction feasibility.</td><td>M2 Assess the feasibility of chemical reactions under defined conditions using thermodynamic data and relationships.</td></tr>
<tr><td colspan="2">LO3 Discuss phase behaviour and equilibrium in chemical systems</td></tr>
<tr><td>P5 Discuss phase behaviour using heating and cooling curves and phase diagrams.

P6 Explain chemical equilibrium using practical observations and simple equilibrium calculations.</td><td>M3 Analyse the effects of changes in conditions on phase behaviour and chemical equilibrium in chemical systems.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Implement a methodology to determine rate laws and kinetic parameters from experimental data		**LO4**
P7 Implement a methodology to determine rate laws and kinetic parameters from experimental data. **P8** Review the findings of kinetic investigations, explaining results in relation to relevant rate concepts and method limitations.	**M4** Evaluate the experimental evidence used to determine reaction rates and kinetic parameters, focusing on appropriateness of method choice and control of variables.	**D2** Justify the validity, reliability and limitations of experimental evidence used to determine reaction rates and kinetic parameters, including sources of error and improvements to method and data handling.

Recommended Resources

Textbooks

Atkins, P. and de Paula, J. (2017) *Elements of Physical Chemistry*. 7th edn. Oxford: Oxford University Press.

Burrows, A., *et al*. (2021) *Chemistry: Introducing Inorganic, Organic and Physical Chemistry*. 4th edn. Oxford: Oxford University Press.

Engel, T. and Reid, P. (2022) *Physical Chemistry: Thermodynamics, Statistical Mechanics, and Kinetics*. 5th edn. Harlow: Pearson Education.

Ge, Y. (2026) *Physical Chemistry*. Central Washington University. Open Textbook Library. https://open.umn.edu/opentextbooks/textbooks/1955

McQuarrie, D.A. and Simon, J.D. (2013) *Physical Chemistry: A Molecular Approach*. Sausalito: University Science Books.

Zumdahl, S.S. and Zumdahl, S.A. (2020) *Chemistry*. 10th edn. Boston: Cengage Learning.

Zumdahl, S.S., Zumdahl, S.A. and DeCoste, D.J. (2020) *World of Chemistry*. 4th edn. Boston: Cengage Learning.

Websites

https://chem.libretexts.org/Bookshelves/	Chemistry LibreTexts Open textbook and topic reference (General reference)
https://digitalcommons.cwu.edu/cotsfac/889/	Open Textbook Library Physical Chemistry (Open-access textbook)
https://www.acs.org/education/resources.html	American Chemical Society Chemistry Education Resources (Teaching and learning resources)
https://teachchemistry.org/classroom-resources/topics	AACT TeachChemistry Chemistry Topics (General resources)
https://www.rsc.org/funding-and-support/education	Royal Society of Chemistry Education Resources (General resources)

https://ocw.mit.edu/courses/5-61-physical-chemistry-fall-2017/	MIT OpenCourseWare Physical Chemistry (General resources)

Journals and articles

Bain, K. and Towns, M.H. (2018) 'Investigation of undergraduate and graduate chemistry students' understanding of thermodynamic driving forces in chemical reactions and dissolution', *Journal of Chemical Education*, 95(4), pp. 512–520. Available at: https://doi.org/10.1021/acs.jchemed.7b00874.

Ge, Y. (2026) 'Physical chemistry pedagogy for undergraduate learners', *Open Textbook Library*. Available at: https://open.umn.edu/opentextbooks/textbooks/1955

Hofer, E. and Steininger, R. (2023) 'Does it occur or not? A structured approach to support students in determining the spontaneity of chemical reactions', *Chemistry Teacher International*. Available at: https://www.degruyterbrill.com/document/doi/10.1515/cti-2022-0046/html

Namkeaw, J., Lazaro, S.E. and Boonyang, U. (2025) 'Teaching Kinetic Reaction Chemistry Concepts to High School Students through Interactive Rock-Paper-Scissors and LEGO Brick Models', *Journal of Chemical Education*, 102(8), pp. 3725–3729. Available at: https://doi.org/10.1021/acs.jchemed.5c00179

Wissinger, J.E., *et al*. (2021) 'Integrating Sustainability into Learning in Chemistry', *Journal of Chemical Education*, 98(4), pp. 1061–1063. Available at: https://doi.org/10.1021/acs.jchemed.1c00284

Links

This unit links to the following related units:

Unit 411: Inorganic Chemistry

Unit 412: Organic Chemistry

Unit 414: Introduction to Chemistry

Unit 423: Analytical Chemistry

Unit 512: Solid State and Transition Metal Chemistry

Unit 514: Spectroscopy, Surface Chemistry and Equilibria

Unit 526: Further Analytical Chemistry.

Unit 414: Introduction to Chemistry

Unit code: Y/652/3046

Unit level: 4

Credit value: 15

Introduction

Chemistry underpins many of the techniques, measurements and interpretations used across biological and forensic science, even where students are not following a specialist chemistry pathway. In laboratory, clinical, environmental and forensic settings, practitioners are routinely required to understand the behaviour of substances, interpret chemical data and apply quantitative reasoning in order to work safely and effectively. This unit provides students with a focused introduction to the chemical principles that support applied science practice, ensuring that they can engage confidently with chemistry-related aspects of biology and forensic investigations without requiring progression into advanced chemistry study.

The unit emphasises core chemical concepts that inform laboratory practice and professional decision making, including atomic structure, bonding and the relationships between structure and properties. Students develop an understanding of how chemical interactions influence the physical and chemical behaviour of substances encountered in applied science contexts. Quantitative chemistry forms a key component of the unit, supporting accurate preparation, expression and interpretation of solutions using units and conventions commonly encountered in biological and forensic laboratories, alongside consideration of data validity and effective use of digital tools.

Chemical processes are explored through oxidation–reduction, acid–base behaviour, equilibrium and reaction rate principles, providing students with a conceptual framework for understanding how conditions influence chemical change. The role of catalysts, including enzymes as applied examples, is considered in relation to reaction efficiency and energy demand. The unit also introduces essential aspects of organic chemistry, focusing on functional groups and isomerism and their influence on the properties and behaviour of organic compounds relevant to biological and forensic applications.

On completion of this unit, students will be able to apply core chemical principles in applied science contexts, interpret chemical information and data, perform quantitative solution calculations, and relate structure and bonding to the properties and behaviour of substances. This unit supports progression to further study in

biological, biomedical, forensic and broader applied science disciplines, including chemistry-related units within the programme and higher-level study in science-based courses. The knowledge and skills developed in this unit also support progression to employment in laboratory-based and technical roles e.g. Laboratory Technician, Quality Control Technician, Manufacturing Technician and scientific support roles, where an understanding of chemistry is essential for safe and effective practice.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the atomic structure, bonding and structure–property relationships that determine the behaviour of substances

LO2 Apply quantitative chemical principles to solutions

LO3 Discuss how oxidation–reduction, pH, equilibrium and reaction rate principles influence chemical processes

LO4 Explain how functional groups and isomerism influence the properties of organic compounds.

Essential Content

LO1 **Explain the atomic structure, bonding and structure–property relationships that determine the behaviour of substances**

Atomic structure and electron configuration:

Atomic structure: atomic number, mass number, isotopes, relative atomic mass, relative formula mass (M_r); electron shells, subshells, orbitals, electron configuration, valence electrons

Periodic table: groups, periods, blocks (s-, p-, d-block), chemical behaviour; ion formation e.g. electron configurations for Na, Mg, Cl, Ca; outer-shell electrons related to common ion charges; use of group number to predict ion formation trends; representation of ions using bracket notation and charge

Practical context: e.g. use of the periodic table to predict ion formation prior to preparing salts or solutions; use of molecular model kits or digital visualisers to support discussion of orbitals, ions and bonding.

Periodic trends and chemical behaviour:

Periodic trends: atomic radius, first ionisation energy, electronegativity; reactivity patterns for metals and non-metals e.g. why Group 1 reactivity increases down the group; electron configuration, ion formation, shielding, nuclear attraction; comparison of electronegativity values to predict bond polarity; relationship between ionisation energy changes across a period and outer-shell electron arrangement

Practical context: e.g. interpretation of simple data tables or graphs to identify periodic trends, microscale or demonstration comparison of metal reactivity in water to link periodic position to observed chemical change.

Bonding and structure:

Bonding: ionic, covalent (polar and non-polar), metallic bonding

Structures: molecular and giant structures, simple molecular, giant ionic, giant covalent, metallic lattices

Chemical formulae: balancing chemical equations, state symbols; electronegativity difference, dipoles, partial charges (δ+/δ−); dot-and-cross representations for NaCl and MgO; displayed formulae for H_2O and CO_2 to compare polarity; balanced equations for combustion and acid–carbonate reactions

Practical context: e.g. conductivity testing of ionic solutions compared with covalent molecular substances (demonstration or simulation), interpretation of melting point data to compare ionic and simple molecular substances and support structure–property reasoning.

Intermolecular forces and structure-property relationships:

Intermolecular forces: London dispersion forces, permanent dipole–dipole interactions, hydrogen bonding

Physical properties: melting point; boiling point e.g. comparison of boiling points of methane, ethane and propane to show chain length and dispersion forces; volatility; solubility, polarity e.g. comparison of ethanol and hexane for polarity and solubility; aqueous and non-aqueous systems e.g. 'like dissolves like'; explanation of the high boiling point of water using hydrogen bonding

Practical context: simple solubility comparisons using water, ethanol, oil analogues; evaporation-rate comparisons (covered versus open containers) to connect volatility with intermolecular forces.

LO2 **Apply quantitative chemical principles to solutions**

Amount of substance and molar relationships:

Amount of substance: mass, molar mass, $n = m/M_r$, mole concept e.g. conversion of mass to moles for NaCl and $CaCl_2$

Stoichiometric relationships: balanced equations, solution calculations; use of a balanced equation to determine moles of product formed; M_r values related to chemical formulae for simple salts and acids

Practical context: e.g. weighing by difference and accurate mass recording, use of balances, weighing boats, spatulas to support reliable reagent measurement.

Solution concentration and units:

Solution concentration: concentration calculations e.g. $c = n/V$; unit conventions e.g. mol dm^{-3} (mol L^{-1}), g dm^{-3} (g L^{-1}), % (w/v), % (v/v), ppm, ppb, Molar (M), millimolar (mM), micromolar (µM)

Laboratory and biological contexts: M_r, density, concentration statements, solutions, reagents, stock solutions, working solutions; unit conversions e.g. 0.10 mol dm^{-3} NaCl to g dm^{-3} using M_r; % (w/v) saline to g L^{-1}; interpretation of ppm values for dilute aqueous contaminants; conversion of % (v/v) ethanol using density

Practical context: e.g. preparation of a standard solution using a volumetric flask, application of clear labelling conventions for concentration, date, initials, hazard symbols.

Dilution principles:

Dilution principles: dilution relationships, $c_1V_1 = c_2V_2$, dilution factor, ratio concept, concentration range; serial dilution e.g. creating a serial dilution for calibration purposes; calculation of dilution factor from stated volumes e.g. preparation of 100 cm^3 of a 0.020 mol dm^{-3} solution from a 0.10 mol dm^{-3} stock

Volumetric equipment: pipettes, burettes, volumetric flasks, measuring cylinders, meniscus reading, temperature awareness, accuracy

Practical context: use of pipette fillers; use of mixing by inversion in stoppered volumetric flasks to promote solution homogeneity; waste minimisation through preparing only required volumes.

Quality of quantitative outcomes:

Quantitative outcomes: results; rounding strategies e.g. significant figures; accuracy; scientific notation; consistent units

Dealing with quantitative errors: sources of error e.g. volume measurement error, weighing error, unit conversion error, calculated values, propagation of error in multi-step calculations; errors in input data; assumptions; reasonableness checks e.g. whether a calculated concentration is realistic for the mass weighed; the effect of misreading a meniscus on final concentration; use of a spreadsheet to automate calculations and highlight unit inconsistencies; comparison of results using two calculation routes

Practical context: digital tools; structured results table e.g. to record raw mass and volume data; replicate preparation of a working solution to explore variability linked to volume measurement and mixing.

LO3 **Discuss how oxidation–reduction, pH, equilibrium and reaction rate principles influence chemical processes**

Oxidation–reduction principles:

Principles: oxidation, reduction, electron transfer, oxidation state change, oxidation numbers, elements, ions, compounds, redox processes, oxidising agents, reducing agents, redox equations, half-equations

Assigning oxidation states in common ions and acids: oxidation and reduction in displacement reactions; linking of oxidising and reducing agents to electron acceptance and donation

Practical context: displacement reactions with metal salt solutions; observation of colour change or deposit formation linked back to electron transfer language.

Acid–base concepts and pH:

Acid–base concepts: Brønsted–Lowry acids, bases, conjugate acid–base pairs, strong acids, weak acids, strong bases, weak bases, concentration, dissociation, pH, logarithmic measure, pH calculations

Qualitative discussion: indicator selection, colour change range e.g. prediction of pH change on dilution of a strong acid; weak acid behaviour linked to partial ionisation; indicator selection based on expected equivalence pH; pH meter readings related to hydrogen ion concentration conceptually

Practical context: measurement of pH using meters or probes with routine calibration checks; indicator colour comparison using a standard pH chart.

Chemical equilibrium:

Chemical equilibrium, dynamic equilibrium, chemical reactions, equilibrium position, equilibrium constant, conceptual tools, Le Chatelier's principle

Concentration changes, temperature changes, feasibility, yield, optimisation, chemical processes e.g. prediction of the direction of equilibrium shift when concentration changes; temperature effects on equilibrium yield; interpretation of the meaning of large and small equilibrium constant values

Practical context: colour-change equilibrium demonstrations to show concentration and temperature effects; observation tables to link before-and-after changes to equilibrium position.

Reaction rates and catalysts:

Reaction rates: collision theory, activation energy, rate factors, concentration, temperature, surface area e.g. comparison of powdered versus lump reactants to illustrate surface area effects

Catalysts: homogeneous catalysis, heterogeneous catalysis, enzyme action, reaction efficiency, energy demand

Reaction profile diagrams: interpretation of reaction profile diagrams to show activation energy differences; explanation of enzyme optimum temperature and pH behaviour

Practical context: e.g. timed gas collection or mass–loss experiments using safe reactions to compare rate factors; simple rate–time graphs to support interpretation of changing reaction rates.

LO4 **Explain how functional groups and isomerism influence the properties of organic compounds**

Representation and functional-group identification:

Representation: displayed formulae, structural formulae, skeletal formulae, molecular formulae, composition; digital molecular representations, structure visualisation e.g. conversion of displayed formulae into skeletal formulae for simple alcohols and alkenes

Basic naming conventions: functional-group recognition e.g. of functional groups from structural formulae; 3D visualisation to relate structure to shape and polarity

Practical context: e.g. molecular model kits to show bond angles and functional-group positioning.

Functional groups and structure–property relationships:

Functional groups: alkanes, alkenes, alcohols, halogenoalkanes, aldehydes, ketones, carboxylic acids, esters, amines, amides

Structure–property relationships: polarity, intermolecular forces, boiling point, solubility, acidity, basicity, chemical behaviour e.g. explanation of higher boiling points of alcohols compared with alkanes of similar size; comparison of solubility patterns across alkane, alcohol and carboxylic acid series; prediction of which functional groups form hydrogen bonds

Practical context: solubility comparisons for representative organic liquids using safe analogues; microscale acidity or basicity tests using pH paper and dilute reagents.

Isomerism and its effects on properties:

Isomerism: structural isomerism, chain isomerism, positional isomerism, functional-group isomerism; stereoisomerism, geometric isomerism (*cis*/*trans* or *E*/*Z*), optical isomerism, chiral centres, enantiomers

Effects on properties: stereochemistry effects, physical interactions, biological interactions, biological activity, toxicity e.g. comparison of structural isomers with the same molecular formula but different functional groups; identification of *cis*/*trans* forms in alkenes; chiral centres from displayed formulae; explanation of differential biological interactions

Practical context: model-based identification of chirality; interpretation of simplified case studies showing contrasting enantiomer effects.

Organic compounds relevant to applied science contexts:

Organic compounds: functional groups, isomerism, properties of organic compounds, biological applications, forensic applications; polarity-driven behaviour, mixtures, partitioning between phases e.g. predicting phase partitioning behaviour based on functional-group polarity, solubility-driven extraction behaviour, relating polarity to extraction success in simple separations

Structural features: observed behaviour, environmental impact, biodegradability, persistence e.g. why certain organic compounds persist in the environment

Practical context: e.g. demonstration of liquid-liquid partitioning using safe analogues; chromatography as a conceptual separation context linked to polarity differences, with focus on interpretation rather than technique detail.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Explain the atomic structure, bonding and structure–property relationships that determine the behaviour of substances		**LO1**
P1 Describe atomic structure and electron configuration of elements. **P2** Explain how bonding and intermolecular forces influence the properties of substances.	**M1** Analyse how structure and bonding influence the physical and chemical properties of substances.	**D1** Evaluate the extent to which structure–property relationships explain the behaviour of substances.
LO2 Apply quantitative chemical principles to solutions		**LO2**
P3 Apply quantitative chemical principles to solutions. **P4** Review the quality of the quantitative outcomes of the applied chemical principles.	**M2** Assess the selection and use of concentration units and calculation methods in solution work.	**D2** Evaluate the validity of quantitative results obtained from solution calculations.
LO3 Discuss how oxidation–reduction, pH, equilibrium and reaction rate principles influence chemical processes		**LO3 and LO4**
P5 Discuss oxidation–reduction and pH in chemical processes. **P6** Explain equilibrium and reaction rate principles in chemical processes.	**M3** Analyse how oxidation–reduction, pH, equilibrium and reaction rate principles influence chemical processes under different conditions.	**D3** Evaluate how chemical process principles and structural features influence the properties and behaviour of organic compounds.
LO4 Explain how functional groups and isomerism influence the properties of organic compounds		
P7 Explain how functional groups influence the properties of organic compounds. **P8** Discuss how isomerism influences the properties of organic compounds.	**M4** Assess how functional groups and isomerism influence the properties of organic compounds.	

Recommended Resources

Textbooks

Anderson, G., *et al*. (2024) *Enhanced Introductory College Chemistry*. Ontario: eCampusOntario.

Brown, T.L., *et al*. (2021) *Chemistry: The Central Science*. 15th edn. Harlow: Pearson.

Flowers, P., *et al*. (2026) *Chemistry 2e*. Houston: OpenStax, Rice University.

Harris, D.C. and Lucy, C.A. (2020) *Quantitative Chemical Analysis*. 10th edn. New York: W.H. Freeman.

Oriakhi, C.O. (2021) *Chemistry in Quantitative Language: Fundamentals of General Chemistry Calculations*. 2nd edn. Oxford: Oxford University Press.

Silberberg, M.S. and Amateis, P. (2020) *Chemistry: The Molecular Nature of Matter and Change*. 9th edn. New York: McGraw-Hill.

Skoog, D.A., *et al*. (2022) *Fundamentals of Analytical Chemistry*. 10th edn. Boston: Cengage Learning.

Solomons, T.W.G., Fryhle, C.B. and Snyder, S.A. (2022) *Organic Chemistry*. 13th edn. Hoboken: Wiley.

Tro, N.J. (2021) *Chemistry: A Molecular Approach*. 5th edn. Harlow: Pearson.

Zumdahl, S.S. and Zumdahl, S.A. (2020) *Chemistry*. 10th edn. Boston: Cengage Learning.

Websites

https://www.acs.org	American Chemical Society Education and learning resources for general, analytical and organic chemistry (General reference)
https://www.chemguide.co.uk/	Chem Guide Education and learning resources for general, analytical and organic chemistry (General reference)

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https://chem.libretexts.org	Chemistry LibreTexts Open-access chemistry texts covering atomic structure, bonding, quantitative chemistry, equilibrium, pH, redox and organic functional groups (General reference)
https://www.rsc.org/learn-chemistry	Learn Chemistry - Royal Society of Chemistry Applied chemistry resources linking chemical principles to laboratory, biological and forensic contexts (Training)
https://webbook.nist.gov	NIST Chemistry WebBook Authoritative thermodynamic, kinetic and physical property data for chemical substances (Datasets)
https://kinetics.nist.gov	NIST Chemical Kinetics Database Reaction rate data supporting discussion of kinetics and catalysis (Datasets)
https://phet.colorado.edu	PhET Interactive Simulations - Chemistry Interactive simulations for bonding, equilibrium, pH and reaction rates (Development tool)
https://pubchem.ncbi.nlm.nih.gov	PubChem Chemical structures, functional groups and properties for organic and inorganic compounds (General reference)
https://www.ncbi.nlm.nih.gov/books	StatPearls Chemistry Applied chemistry explanations relevant to biological and clinical science contexts (Article)

Journals and articles

El-Ghaly, W., *et al*. (2025) 'A Comparative Analysis of Analytical Validation Approaches for Quality Assurance: Exploring Holistic Strategies in the Validation of Quantitative Methods—A Case Study of Hesperidin', *Journal of AOAC International*, 108(3), pp. 435–448. Available at: https://doi.org/10.1093/jaoacint/qsaf004.

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Merone, G.M., *et al*. (2020) 'Analytical Chemistry in the 21st Century: Challenges, Solutions, and Future Perspectives of Complex Matrices Quantitative Analyses in Biological/Clinical Field', *Analytica*, 1(1), pp. 44–59. Available at: https://doi.org/10.3390/analytica1010006.

Qiu, J., *et al*. (2020) 'Solubility Behaviors and Correlations of Common Organic Solvents', *Organic Process Research & Development*, 24(11), pp. 2702–2708. Available at: https://doi.org/10.1021/acs.oprd.0c00364.

Salomone, A., Oliveri, P. and Zadora, G. (2021) 'Editorial: New Approaches in Forensic Analytical Chemistry', *Frontiers in Chemistry*, 8, 638460. Available at: https://doi.org/10.3389/fchem.2020.638460.

Schwarz, G. (2024) 'Literature Survey on Quantitative Chemical Analyses Experiments for Students: Exploring Choices', *Journal of Chemical Education*, 102(8), pp. 3468–3484. Available at: https://doi.org/10.1021/acs.jchemed.5c00706.

Taouba, H., Hayen, J-L. and Liégeouis J-F. (2025) 'Solubility and Extractability in the Pharmaceutical Sciences: A Practical Exercise with Pure Compounds', *Journal of Chemical Education*, 102(2), pp. 729–736. Available at: https://pubs.acs.org/doi/10.1021/acs.jchemed.4c00241.

Zhu, Z., Wang, Z. and Geng J. (2024) 'A Comprehensive Teaching Laboratory Program on Titration Analysis: Transition from Classic to Modern Approaches', *Journal of Chemical Education*, 101(2), pp. 612–620. Available at: https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01091.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 407: Fundamentals of Biochemistry

Unit 423: Analytical Chemistry.

Unit 415: Managing Scientific Projects

Unit code: **A/652/3047**

Unit level: **4**

Credit value: **15**

Introduction

Managing scientific projects is an important aspect of work across research, laboratory, healthcare, environmental and industrial settings. Scientific projects are often carried out within regulated and quality-assured environments, where activities must be carefully planned, monitored and documented to ensure that objectives are met and outcomes are reliable, compliant and fit for purpose. This unit is designed to give students an overview of scientific project management, emphasising the importance of planning, control, governance and communication in supporting successful project delivery. It is essential for students aiming to develop the knowledge and skills needed to work within scientific and technical roles where structured project management approaches are required.

The primary aim of this unit is to provide students with an understanding of the key principles and practices involved in managing scientific projects. Through the study of project planning, governance, documentation, monitoring and communication, students will learn how scientific projects are organised and controlled across the project life cycle. This will help to equip students with the skills needed to respond to the practical and regulatory challenges that can arise in scientific project environments.

This unit covers a wide range of topics that are central to the management of scientific projects. Key focus areas include scientific project planning, stakeholder roles and responsibilities, governance requirements, project documentation, monitoring and control strategies, and the communication of project outcomes. Each topic is designed to build on the previous one, providing a structured and coherent learning experience. The unit content builds to a practical component, where students will develop and apply project management approaches for an identified scientific project scenario, taking account of governance, compliance and quality requirements.

On successful completion of this unit, students will have developed an understanding of how scientific projects are planned, documented, monitored and communicated within professional and regulated contexts. They will be able to apply project management principles, produce structured project documentation, implement monitoring and control approaches, and present project outcomes in a clear and

appropriate way. These skills are directly applicable to a range of job roles in scientific and technical sectors, such as Laboratory Coordinator, Project Support Officer, Quality Associate, Research Assistant and Scientific Operations Administrator.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the key principles of scientific project management and planning

LO2 Develop structured project management documentation for an identified scientific project scenario

LO3 Implement strategies for monitoring and controlling the identified scientific project scenario

LO4 Present the outcomes and impact of the identified scientific project scenario demonstrating compliance with scientific governance.

Essential Content

LO1 **Explain the key principles of scientific project management and planning**

Scientific project fundamentals:

Scientific project fundamentals: purpose, objectives, outcomes, uncertainty, evidence-based decision making, regulated environments

Life cycle: project life-cycle stages e.g. initiation, planning, execution, monitoring and control, closure

Constraints: constraints e.g. time, cost, scope, resources; measures of success e.g. quality, compliance, stakeholder requirements

Sustainability: sustainability considerations e.g. environmental impact of materials, long-term data storage, resource efficiency.

Project planning and governance in scientific contexts:

Project planning and governance in scientific contexts: objectives, deliverables, timelines, governance structures, roles, responsibilities, approval processes, compliance with scientific standards and policies

Project management: project management approaches e.g. predictive approaches, structured phase-based planning, iterative approaches, adapting tasks based on emerging results; relationships between planning, governance and control

Planning tools: digital planning tools e.g. task tracking, scheduling, AI-supported summaries with human review.

Stakeholders and roles in scientific projects:

Stakeholders in scientific projects: project manager, project team, subject specialists, stakeholders; stakeholder types e.g. internal stakeholders, external stakeholders, customers, regulatory bodies

Roles and responsibilities: communication, decision making, oversight; stakeholder engagement e.g. identifying needs, managing expectations, regular progress updates, reporting results, responding to regulatory requirements; inclusive communication, diverse stakeholder needs; ethical and professional conduct e.g. accountability, integrity, safe working practices.

Planning considerations in scientific project contexts:

Planning considerations in scientific project contexts: scope boundaries, assumptions, constraints; resource planning e.g. personnel, equipment, materials; risk awareness e.g. delays in sample availability, equipment failure, mitigation approaches

Data management: accuracy, traceability, record keeping; health and safety e.g. safe systems of work, compliance with relevant guidelines.

LO2 **Develop structured project management documentation for an identified scientific project scenario**

Core project documentation:

Core project documentation: project brief or charter e.g. purpose, objectives, scope, deliverables, milestones, roles, governance; project management plan e.g. organisation, control approaches

Documentation: document control e.g. version control, approvals, distribution, version numbering, authorised sign-off, controlled document storage.

Scope and scheduling documentation:

Scope and scheduling documentation: scope statement e.g. in-scope, out-of-scope, deliverables, acceptance criteria

Scheduling: work breakdown structure (WBS) e.g. task breakdown, manageable activities; schedule documentation e.g. timelines, milestone plans, simple Gantt charts, task sequencing, key deadlines, dependencies.

Resource planning documentation:

Resource planning documentation: personnel, equipment, materials; allocation of roles and responsibilities; resource availability e.g. laboratory space, specialist equipment, staff availability, capacity planning.

Risk, quality and communication documentation:

Risk and quality documentation: risk register e.g. risks, likelihood, impact, response actions, equipment failure, sample delays; quality planning e.g. quality objectives, checking procedures

Communication: communication planning e.g. stakeholder needs, frequency, methods, progress updates, reports, meetings.

Scientific governance within project documentation:

Scientific governance: governance requirements e.g. ethical approval, health and safety, data management; compliance documentation e.g. policies, standards, required records

Documentation: data management documentation e.g. accuracy, traceability, record keeping, laboratory records, audit trails.

LO3 **Implement strategies for monitoring and controlling the identified scientific project scenario**

Monitoring and performance tracking:

Progress tracking: tracking progress against plans e.g. milestones, activities; progress tracking methods e.g. milestone tracking, task completion, status indicators, red-amber-green (RAG) status, progress checklists

Performance tracking: performance measures e.g. scope, quality, timelines; reporting e.g. progress reports, briefings, review meetings.

Risk, issue and quality control:

Risk and quality control: risk monitoring e.g. emerging risks, reviewing risks, mitigation actions, delays in materials, equipment availability

Issue control: issue management e.g. identification, recording, corrective action; quality control e.g. checking outputs, peer review, supervisor checks, validation of results; continuous improvement e.g. reflection, improvement identification.

Change control and project adjustments:

Change control: change control processes e.g. identifying, recording, reviewing changes to scope, schedule, resources

Project adjustments: impact considerations e.g. timelines, resources, quality, compliance; implementation of changes e.g. applying approved adjustments; sustainability impacts e.g. resource use, outcomes.

Decision making and communication in project control:

Decision making: decision-making approaches e.g. selecting actions, project priorities; problem-solving approaches e.g. identifying causes, selecting responses

Communication: communication of status e.g. meetings, written summaries, dashboards.

LO4 **Present the outcomes and impact of the identified scientific project scenario demonstrating compliance with scientific governance**

Outcome reporting and presentation:

Outcome reporting: presentation of outcomes e.g. objectives, deliverables, milestones, results; information structured for different audiences e.g. technical stakeholders, non-technical stakeholders, reports, presentations, summary briefings

Presentation: formats and media e.g. written reports, presentation slides, visual summaries; clarity and accessibility e.g. structure, terminology, visual aids, accessible communication; technology-supported reporting e.g. dashboards, automated summaries, reviewed outputs.

Scientific governance and compliance in outputs:

Scientific governance and compliance in outputs: compliance e.g. ethical, health and safety, data management requirements

Documentation: documentation and record keeping e.g. laboratory records, audit trails; data integrity e.g. accuracy, reliability, storage; regulatory awareness e.g. different scientific contexts.

Evaluation of project outcomes and impact:

Evaluation of project outcomes and impact: assessment of success e.g. objectives, timelines, quality; impact considerations e.g. organisational impact, scientific impact, stakeholder impact, sustainability

Limitations: e.g. constraints, assumptions, residual risks; justification of decisions e.g. evidence, outcomes.

Stakeholder communication and professional practice:

Stakeholder communication: communication e.g. presenting findings, response to feedback; accessible reporting

Professional practice: professional conduct e.g. accountability, transparency, integrity; collaboration e.g. teamworking, coordination, stakeholder input; global and cultural considerations e.g. communication and reporting contexts.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the key principles of scientific project management and planning</td><td rowspan="8">LO1, LO2 and LO3

D1 Evaluate how scientific project management principles, planning documentation, and monitoring and control strategies support decision making, performance control and governance-aligned delivery in the identified project scenario.</td></tr>
<tr><td>P1 Review key principles of scientific project management, planning and governance.

P2 Explain the roles and responsibilities of key project stakeholders within a scientific project context.</td><td>M1 Analyse the application of project management principles to planning decisions within a scientific project context.</td></tr>
<tr><td colspan="2">LO2 Develop structured project management documentation for an identified scientific project scenario</td></tr>
<tr><td>P3 Develop structured project management documentation for an identified scientific project scenario.

P4 Maintain document control arrangements for project documentation, including version control and approvals.</td><td>M2 Assess the suitability of the developed project management documentation in relation to project requirements and constraints.</td></tr>
<tr><td colspan="2">LO3 Implement strategies for monitoring and controlling the identified scientific project scenario</td></tr>
<tr><td>P5 Implement monitoring and control strategies to track progress, risks, quality and change.

P6 Record and communicate project performance information.</td><td>M3 Analyse the effectiveness of the implemented monitoring and control strategies in maintaining project performance against planned parameters.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Present the outcomes and impact of the identified scientific project scenario demonstrating compliance with scientific governance		**LO4**
P7 Present the outcomes and impact of the identified scientific project scenario demonstrating compliance with scientific governance. **P8** Review the outcomes and impact of the identified scientific project scenario with selected stakeholders to identify strengths and areas to improve.	**M4** Analyse the effectiveness of the project outcomes and impact in demonstrating compliance with scientific governance.	**D2** Evaluate the impact of the project outcomes and governance compliance on scientific integrity and organisational decision making.

Recommended Resources

Textbooks

Kerzner, H. (2022) *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*. 13th edn. Hoboken, NJ: Wiley.

Meredith, J.R., Shafer, S.M. and Mantel, S.J. (2017) *Project Management: A Strategic Managerial Approach*. 10th edn. Hoboken, NJ: Wiley.

Müller, R., Sankaran, S. and Drouin, N. (eds.) (2023) *Research Handbook on the Governance of Projects*. Cheltenham: Edward Elgar.

Noy, S. (2024) *Project Management for Researchers: A Practical, Stress-Free Guide to Getting Organised*. Ann Arbor: University of Michigan Press.

Oguz, A. (2025) *Project Management: Navigating the Complexity with a Systematic Approach*. 2nd edn. Cleveland, OH: MSL Academic Endeavors.

Websites

www.apm.org.uk	Association for Project Management (APM) Project management resources (General reference)
www.fda.gov	U.S. Food and Drug Administration (FDA) (General reference)
picscheme.org	Pharmaceutical Inspection Co-operation Scheme (PIC/S) (General reference)
www.pmi.org	Project Management Institute (PMI) (General reference)
www.sqa.org	Society of Quality Assurance (SQA) Guidance and training around quality assurance (Training)

Journals and articles

Bakhshi, J., Matous, P. and Crawford, L. (2025) 'From Control to Adaptation: Mapping Theoretical Developments of Project Governance Research', *Project Management Journal*, 56(1), pp. 1–21. Available at: https://doi.org/10.1177/87569728251383503.

Brunet, M. and Choinière, O. (2025) 'Governance Framework Trajectory for Major Public Projects: The Case of Canada', *Project Management Journal*, 56(1), pp. 74-89. Available at: https://doi.org/10.1177/87569728241251710.

Hassani, H., Huang, X. and MacFeely, S. (2025) 'Mapping the evolution of data governance scientific research', *Data & Policy*, 7, e51. Available at: https://doi.org/10.1017/dap.2025.10014.

Huemann, M., Eskerod, P. and Ringhofer, C. (2016) 'Rethink! Project Stakeholder Management', *International Journal of Project Management*, 34(4), pp. 663–675. Available at: https://www.pmi.org/learning/library/rethink-project-stakeholder-management-11644.

Meijer, P., *et al*. (2025) 'Research Lifecycle Management: Using Analysis Reproducibility Research Software to Define Contextual Data Governance Policies', *Harvard Data Science Review*, 7(3). Available at: https://doi.org/10.1162/99608f92.08da1513.

Too, E.G. and Weaver, P. (2014) 'Competitive advantage from ERP projects: Examining the role of key implementation drivers', *International Journal of Project Management*, 32(8), pp. 1382–1394. Available at: https://doi.org/10.1016/j.ijproman.2013.08.004.

Zhang, L., *et al*. (2023) 'Sustainable Project Governance: Scientometric Analysis and Emerging Trends', *Sustainability*, 15(3), 2441. Available at: https://doi.org/10.3390/su15032441.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 416: Work-based Learning

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 519: Science Laboratory Management.

Unit 416: Work-based Learning

Unit code: D/652/3048

Unit level: 4

Credit value: 15

Introduction

Work-based learning is an important part of preparing students for employment in the applied sciences sector, where scientific knowledge and practical skills are applied in professional working environments. Employers increasingly expect individuals to understand how applied sciences organisations operate in practice, including how laboratory, industrial, environmental and healthcare science settings function, how teams work together and how responsibilities are managed safely and effectively. This unit introduces students to the purpose and value of work experience, and how it supports the development of practical competence, workplace awareness and professional behaviours.

The aim of this unit is to enable students to undertake structured work-based learning and to apply their knowledge within a professional applied sciences context. Students will develop an understanding of workplace expectations, the nature of work in the applied sciences sector and the behaviours required to operate effectively in professional and regulated environments. The unit also supports students in recognising how developments in technology and innovation are changing working practices, skills demand and career opportunities across the sector.

The unit covers key areas required to prepare for and undertake work experience in the applied sciences sector. Students will explore the structure of applied science workplaces, including organisational types, workplace settings, team structures, roles and responsibilities. They will examine professional expectations, workplace standards and the impact of technological change on working practices and workforce development. The unit also includes preparation for a work placement, participation in workplace activities and structured reflection on performance, learning and development.

On successful completion of the unit, students will be able to demonstrate professional behaviours in a workplace context, review their performance and evaluate their learning from practical experience. They will be able to identify skills developed and plan for future progression within the applied sciences sector. This supports progression to further study and to employment in roles such as Laboratory Technician, Science Technician, Quality Control Technician, Environmental Monitoring Assistant and healthcare science support roles.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Describe the key aspects of work experience in the applied sciences sector

LO2 Explore the changing nature of work within the applied sciences sector and the impact of technology

LO3 Undertake a work experience placement within the applied sciences sector

LO4 Review professional conduct and the learning experience following a placement in the applied sciences sector.

Essential Content

LO1 **Describe the key aspects of work experience in the applied sciences sector**

Work-based learning in the applied sciences sector:

Purpose and outcomes: purpose of work experience e.g. how applied sciences organisations operate and how workplace practices are applied; employability development e.g. communication, teamwork, professional conduct and time management; application of learning e.g. using scientific knowledge, laboratory techniques and analytical skills in practice; professional exposure e.g. observing procedures, participating in routine activities and understanding workplace expectations

Career and progression: career awareness e.g. technical, laboratory, industrial, environmental and healthcare science roles; workplace learning e.g. supervised practice, shadowing and supported task completion; sector relevance e.g. exposure to current scientific practice, industry standards and quality requirements; practical experience e.g. carrying out routine tasks, recording findings and supporting workplace activity

Skills and readiness: skills development e.g. practical, observational, communication and problem-solving skills; professional readiness e.g. following instructions, meeting expectations and working safely and responsibly; experiential learning e.g. reflective logs, workplace observation and task-based learning.

Applied sciences sector working environments:

Organisation types: public sector organisations e.g. NHS laboratories, environmental agencies and public health laboratories; private sector organisations e.g. pharmaceutical, food manufacturing, biotechnology and environmental consultancy organisations; education and research settings e.g. university laboratories and research institutes

Workplace settings: laboratory environments e.g. analytical, microbiology and pathology laboratories; industrial environments e.g. manufacturing sites, processing facilities and quality control laboratories; field-based environments e.g. ecological survey, environmental monitoring and agricultural settings; regulated work areas e.g. clean rooms, containment laboratories and controlled storage areas

Team structures: functional teams e.g. laboratory, quality, production and technical support teams; collaborative working e.g. scientists, technicians, supervisors and managers working together; multidisciplinary working e.g. collaboration with engineers, healthcare staff, environmental specialists and regulatory compliance personnel.

Roles and responsibilities:

Entry and role definition: entry-level roles e.g. laboratory assistant, science technician, quality control assistant; job responsibilities e.g. preparing materials, carrying out routine tests, recording results and maintaining work areas; role expectations e.g. accuracy, reliability, safe working and professional behaviour

Accountability and contribution: reporting structures e.g. supervisors, mentors, laboratory managers and team leaders; accountability e.g. following instructions, completing tasks and recording work accurately; teamwork e.g. assisting colleagues, supporting shared tasks and contributing to routine workflows.

Professional expectations:

Workplace standards: workplace conduct e.g. punctuality, reliability, professional attitude, respectful communication and inclusive behaviour

Compliance: compliance requirements e.g. following health and safety procedures, standard operating procedures (SOPs), risk assessments, equality, diversity and inclusion policies and quality procedures; documentation and confidentiality e.g. accurate record keeping, handling workplace information appropriately and protecting sensitive data.

LO2 **Explore the changing nature of work within the applied sciences sector and the impact of technology**

Technological change and innovation:

Scientific and technical developments: advances in scientific equipment e.g. automated analysers, digital microscopes and sensor-based monitoring equipment; laboratory technologies e.g. data logging systems, instrument interfaces and laboratory information systems; emerging technologies e.g. artificial intelligence in diagnostics, bioinformatics tools and environmental sensing technologies; innovation in practice e.g. improved testing methods, faster analysis and more accurate data capture

Data and digital systems: digital record systems e.g. laboratory information management systems, electronic laboratory notebooks and digital sample records; data analysis tools e.g. spreadsheets, statistical software and modelling software; data handling requirements e.g. secure storage, accurate entry, traceability and quality control; digital communication systems e.g. shared platforms, reporting systems and internal communication tools

Automation and efficiency: automated processes e.g. sample preparation systems, instrument-assisted testing and automated monitoring; workflow improvement e.g. reduced manual handling, improved consistency and faster turnaround times; quality enhancement e.g. reduced error, standardised procedures and improved repeatability; workplace impact e.g. changing task allocation and greater focus on monitoring, interpreting and recording results.

Work patterns and structures:

Working models: site-based working e.g. laboratory shifts, manufacturing schedules and fieldwork patterns; flexible arrangements e.g. rotating shifts, seasonal sampling schedules and project-based activity; team-based practice e.g. coordinated testing schedules, shared laboratory duties and supervised practical work; responsive working e.g. workload changes linked to demand, deadlines, production requirements or environmental conditions

Workplace organisation: structured workflows e.g. sample receipt, preparation, analysis and reporting; regulated environments e.g. clean areas, controlled storage, containment spaces and monitored work zones; collaborative organisation e.g. technicians, scientists and supervisors working across linked processes; cross-functional working e.g. laboratory, quality, production, environmental and healthcare teams working together

Employment patterns: permanent and temporary roles e.g. contracted laboratory staff, seasonal fieldwork assistants and project technicians; placement and trainee opportunities e.g. internships, industrial placements and supervised work-based learning; specialist roles e.g. quality assurance support, laboratory support and environmental monitoring assistance.

Skills demand and workforce development:

Technical and practical skills: laboratory competence e.g. measurement, observation, sampling, testing and equipment handling; analytical skills e.g. interpreting results, identifying trends, checking validity and recording outcomes accurately; digital skills e.g. using laboratory software, recording data electronically and accessing workplace systems; transferable skills e.g. communication, teamwork, problem solving and organisation

Learning and development: workplace training e.g. induction, SOP training, instrument training and health and safety updates; continuing development e.g. refresher training, supervised practice, mentoring and professional review; upskilling e.g. learning new techniques, adapting to new equipment and developing digital confidence; career development e.g. progression into technical, supervisory and specialist roles.

Organisational and sector impact:

Workforce and roles: changing job roles e.g. greater use of digital systems and AI, broader technical responsibilities and increased emphasis on quality and compliance; emerging opportunities e.g. roles linked to laboratory automation, environmental monitoring, diagnostics and biotechnology support; evolving expectations e.g. stronger data skills, improved technical adaptability, accessibility awareness and inclusive working practices

Operational and sector impact: productivity improvements e.g. faster processing, improved turnaround and more efficient workflows; quality improvements e.g. better consistency, improved traceability and reduced error; sector development e.g. changing laboratory practices, improved environmental monitoring, advances in diagnostics and greener laboratory practice; wider e.g. improved public health support, better product quality and enhanced environmental protection.

LO3 **Undertake a work experience placement within the applied sciences sector**

Placement preparation:

Planning and induction: placement objectives e.g. learning aims, role expectations and agreed responsibilities; role alignment e.g. matching existing knowledge and skills to workplace tasks and identifying areas for development; induction processes e.g. workplace induction, site orientation and introduction to team structures and working practices; preparation activities e.g. understanding placement requirements, confirming schedules and reviewing workplace expectations

Compliance set-up: health and safety awareness e.g. safety briefings, hazard identification and emergency procedures; risk assessment e.g. recognising workplace hazards, following control measures and understanding safe systems of work; documentation requirements e.g. placement agreements, confidentiality requirements, workplace policies and relevant equality, diversity and inclusion expectations; regulatory awareness e.g. SOPs, infection control, waste disposal procedures and quality requirements

Workplace readiness: workplace preparation e.g. appropriate dress, PPE requirements and personal organisation; organisational briefing e.g. understanding the role of the organisation, key staff and reporting arrangements; practical readiness e.g. awareness of equipment, materials, workplace routines and task expectations; personal goal setting e.g. setting targets for skills development, confidence, communication and professional practice.

Professional practice during placement:

Workplace behaviour: e.g. punctuality, reliability, professional attitude and respectful, inclusive conduct; professional communication e.g. speaking appropriately with colleagues and supervisors, contributing to team discussions and giving updates; policy adherence e.g. following health and safety procedures, SOPs, workplace rules and agreed boundaries; professional presentation e.g. appropriate dress, PPE use and maintaining standards of behaviour

Task management: responsibility management e.g. understanding allocated tasks, following instructions and recognising limits of responsibility; task execution e.g. completing routine activities accurately, following procedures and meeting expected standards; time management e.g. organising workload, prioritising activities and completing tasks within agreed timescales; accuracy and consistency e.g. recording work clearly, checking outcomes and following established methods.

Contribution and participation:

Workplace contribution: task engagement e.g. undertaking assigned activities, supporting routine operations and contributing to day-to-day practice; practical contribution e.g. preparing materials, handling samples and supporting testing or monitoring activities; application of knowledge e.g. using scientific principles, laboratory techniques, observational skills and analytical understanding in workplace tasks; initiative and responsiveness e.g. asking relevant questions, adapting to different tasks and improving through feedback.

Performance awareness:

Feedback and review: feedback mechanisms e.g. supervisor feedback, mentor discussions and review meetings; performance evaluation e.g. checking progress against placement objectives, reviewing completed tasks and considering workplace expectations; use of feedback e.g. responding to advice, making improvements and refining working practices

Self-assessment and improvement: self-assessment e.g. reflective notes, review of own performance and consideration of strengths and limitations; development areas e.g. identifying gaps in confidence, technical ability, workplace understanding and time management; reflection practices e.g. learning logs, journals and structured reflection; improvement planning e.g. setting short-term actions, identifying future targets and strengthening workplace performance.

LO4 **Review professional conduct and the learning experience following a placement in the applied sciences sector**

Professional conduct:

Core behaviours: professional behaviour e.g. reliability, punctuality, respectful conduct and responsible working; accountability e.g. taking responsibility for allocated tasks, working within agreed limits and recognising when to seek support; integrity e.g. honest record keeping, accurate reporting and following workplace procedures; professional attitude e.g. willingness to learn, positive response to feedback and commitment to safe and effective working

Workplace standards: workplace expectations e.g. maintaining accuracy, following instructions and meeting agreed standards; communication effectiveness e.g. providing clear updates, using appropriate verbal and written communication and engaging professionally and inclusively with colleagues and supervisors; consistency in practice e.g. completing tasks carefully, following procedures consistently and maintaining appropriate levels of care and attention; presentation and conduct e.g. professional appearance, appropriate PPE use and respectful interaction

Compliance and professionalism: compliance awareness e.g. following health and safety requirements, SOPs, risk controls and confidentiality procedures; professional responsibility e.g. maintaining records, protecting workplace information and working ethically; role professionalism e.g. understanding workplace boundaries, recognising limits of competence and acting appropriately in regulated environments.

Reflective learning:

Evaluation of experience: reflection practices e.g. reflective journals, learning logs, review notes and structured self-evaluation; reflection on practice e.g. considering what went well, what was challenging and how tasks were approached; workplace learning reflection e.g. reviewing tasks completed, knowledge applied and feedback received; reflective models e.g. structured reflection frameworks to support evaluation of learning and performance

Skills and development: skills recognition e.g. identifying practical, communication, teamwork and problem-solving skills developed during placement; knowledge application e.g. recognising how scientific knowledge supported workplace tasks and understanding; development needs e.g. identifying gaps in confidence, technical competence and workplace understanding; personal growth e.g. improved confidence, stronger professional awareness and greater readiness for future work.

Career development planning:

Future direction: career awareness e.g. identifying roles of interest in laboratory science, environmental science, healthcare science, industrial science and research support; progression understanding e.g. recognising next steps in study, training and employment; development priorities e.g. technical improvement, confidence building, communication development, broader workplace readiness and awareness of inclusive and equitable practice

Planning and goals: goal setting e.g. short-term and longer-term development goals linked to employability and progression; action planning e.g. identifying steps to improve practical competence, workplace confidence and sector knowledge; development planning e.g. setting targets for further study, training, work experience and independent learning; review and adjustment e.g. refining goals in response to placement learning and feedback

Opportunities and alignment: future opportunities e.g. further placements, volunteering, part-time roles and progression to higher-level study or specialist training; role alignment e.g. matching personal strengths and interests to possible career pathways; continued development e.g. building experience, strengthening technical skills and improving reflective practice; career preparation e.g. using placement evidence to support applications, interviews and progression planning.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Describe the key aspects of work experience in the applied sciences sector</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, how technology and innovation have changed the nature of work and work experience for individuals in the applied sciences sector.</td></tr>
<tr><td>P1 Describe, using a selection of real-world examples, the key aspects of work-based learning in different working environments in the applied sciences sector.
P2 Explain, using a selection of real-world examples, the roles, responsibilities and professional expectations for individuals carrying out work experience in the applied sciences sector.</td><td>M1 Analyse, using a selection of real-world examples, the interrelationship between workplace learning and organisational expectations for individuals carrying out work experience in the applied sciences sector.</td></tr>
<tr><td colspan="2">LO2 Explore the changing nature of work within the applied sciences sector and the impact of technology</td></tr>
<tr><td>P3 Examine, using a selection of real-world examples, how technology and innovation have changed the work patterns and skills demand within the applied sciences sector.

P4 Report, using a selection of real-world examples, on how the changing nature of work within the applied sciences sector has had an impact on organisations and the sector itself.</td><td>M2 Analyse, using a selection of real-world examples,
the impact of recent technological changes in the nature of work, roles and working practices within the applied sciences sector.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Undertake a work experience placement within the applied sciences sector		**LO3 and LO4** **D2** Evaluate how the overall learning experience, professional conduct and performance within the work experience placement contributes to future career development within the applied sciences sector.
P5 Carry out preparations to undertake a work experience placement within the applied sciences sector. **P6** Demonstrate professional practice and effective contribution during a work experience placement within the applied sciences sector.	**M3** Assess how professional practice and contribution supported the effective completion of work experience activities within the applied sciences sector.	
LO4 Review professional conduct and the learning experience following a placement in the applied sciences sector		
P7 Review, using reflective learning and self-evaluation, the professional conduct and the learning experience demonstrated during the work experience placement in the applied sciences sector. **P8** Develop a career development plan informed by reflective learning, self-evaluation and review of the work experience placement.	**M4** Assess the learning gained from the work experience placement in relation to professional practice within the applied sciences sector.	

Recommended Resources

Textbooks

Barr, M. (ed.) (2024) *Approaches to Work-Based Learning in Higher Education: Improving Graduate Employability*. 1st edn. London: Routledge.

Cottrell, S. (2019) *Skills for Success: Personal Development and Employability*. 4th edn. London: Red Globe Press.

Ferns, S.J., Rowe, A.D. and Zegwaard, K.E. (eds.) (2022) *Advances in Research, Theory and Practice in Work-Integrated Learning: Enhancing Employability for a Sustainable Future*. 1st edn. London: Routledge.

Moon, J.A. (2004) *A Handbook of Reflective and Experiential Learning: Theory and Practice*. London: RoutledgeFalmer.

Morley, D.A. (ed.) (2018) *Enhancing Employability in Higher Education through Work Based Learning*. Cham: Palgrave Macmillan.

Ng, B. (ed.) (2022) *Graduate Employability and Workplace-Based Learning Development: Insights from Sociocultural Perspectives*. Singapore: Springer.

Pham, T. and Soltani, B. (2021) *Enhancing Student Education Transitions and Employability: From Theory to Practice*. 1st edn. London: Routledge.

Websites

www.prospects.ac.uk	Prospects Careers guidance and job search (Research)
www.prospects.ac.uk/jobs-and-work-experience/work-experience-and-internships/	Work experience and internships (Student guidance)
www.ucas.com/applying/applying-to-university/work-experience-and-volunteering	UCAS Work experience and volunteering (Research)
www.apprenticeships.gov.uk/apprentices/browse-apprenticeships	Apprenticeships Browse apprenticeships (Research)
www.ase.org.uk/good-practical-science	Association for Science Education Good Practical Science (Teaching support)

www.rsb.org.uk/career-resources.html	Royal Society of Biology Careers Resources (Careers)

Journals and articles

Ferns, S.J., *et al.* (2025) 'Defining and designing work-integrated learning curriculum', *Higher Education Research & Development*, 44(2), pp. 371–385. Available at: https://doi.org/10.1080/07294360.2024.2399072.

Gomez, S., Lush, D. and Clements, M. (2004) 'Work placements enhance the academic performance of bioscience undergraduates', *Journal of Vocational Education & Training*, 56(3), pp. 373-385. Available at: https://doi.org/10.1080/13636820400200260.

Jackson, D. (2017) 'Developing pre-professional identity in undergraduates through work-integrated learning', *Higher Education*, 74(5), pp. 833–853. Available at: https://doi.org/10.1007/s10734-016-0080-2.

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Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 415: Managing Scientific Projects

Unit 424: Artificial Intelligence in Applied Science

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 519: Science Laboratory Management.

Unit 417: Principles of Ecology

Unit code: F/652/3049

Unit level: 4

Credit value: 15

Introduction

Ecology is central to our understanding of how natural systems function and how living organisms interact with each other and their environment. Within applied sciences, ecology provides essential tools for addressing major environmental challenges, including biodiversity loss, habitat degradation, climate change and sustainable resource use. This unit presents ecology as a core scientific discipline that supports environmental monitoring, conservation and ecosystem management across terrestrial, freshwater and marine systems, while developing skills relevant to further study and employment.

The purpose of this unit is to develop students' understanding of core ecological principles and their application to real-world ecological scenarios. Students will examine how ecosystems are structured and function, focusing on biotic and abiotic influences, population and community processes, and the movement of energy and nutrients. The unit also introduces key fieldwork and sampling techniques used to investigate ecological systems and measure environmental change.

Through this unit, students will gain experience in implementing ecological sampling and fieldwork methods appropriate to an identified scenario, alongside analysing ecological data to identify patterns and trends. Emphasis is placed on collecting reliable data and using digital tools to support accurate analysis and interpretation. Students will learn to evaluate ecological evidence in the context of environmental pressures and consider the implications of ecological change for ecosystem sustainability.

On successful completion of this unit, students will be able to apply core ecological principles, implement ecological sampling and fieldwork methods, analyse ecological data to identify trends, and communicate the results of an ecological study clearly to an identified audience. These skills support progression into roles such as Environmental Technician, Field Technician, Laboratory Technician, Conservation Assistant and Ecological Survey Assistant, as well as progression to further study in applied science, environmental science and ecology-related disciplines.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explore core ecological principles

LO2 Implement ecological sampling and fieldwork methods for an identified ecosystem

LO3 Review ecological data to generate trends for the identified ecosystem

LO4 Present the results of the ecological study for the identified ecosystem to an identified audience.

Essential Content

LO1 **Explore core ecological principles**

Ecological organisation and systems:

Ecological organisation: levels of ecological organisation from organism to population, community and ecosystem; ecosystems as interacting systems of biotic and abiotic components; habitat, ecological niche, fundamental and realised niches; ecosystem connectivity and habitat corridors linking landscapes e.g. ponds within catchments, hedgerows as corridors, woodland edge effects.

Energy flow and nutrient cycling:

Energy flow: trophic levels, inefficiencies and losses; food chains and food webs; ecological pyramids of number, biomass and energy; top-down and bottom-up trophic cascades; gross and net primary productivity and limiting factors

Nutrient cycles: carbon, nitrogen, phosphorus and water cycles; decomposition, detrital food webs and microbial activity; effect of nutrient enrichment and limitation on ecosystem functioning e.g. fertiliser run-off leading to algal blooms, reduced dissolved oxygen and community change.

Population and community ecology:

Population ecology: population size, density and distribution; exponential and logistic growth; carrying capacity; density-dependent and density-independent regulation; environmental variability

Community ecology: species richness, evenness and dominance; species interactions including competition, predation, herbivory, parasitism, mutualism and commensalism; keystone species, ecosystem engineers and invasive species; primary and secondary succession from pioneer species to later seral stages e.g. beavers increasing habitat heterogeneity, succession on restored quarries, invasive species altering native communities.

Environmental factors and ecological balance:

Abiotic influences: temperature, water availability, light, pH, salinity, oxygen, turbidity and soil properties as factors affecting species distribution and abundance; tolerance ranges and limiting factors

Ecological balance: disturbance and recovery; resistance, resilience and recovery time; dynamic equilibrium within ecosystems; long-term sustainability through maintenance of ecological processes over time e.g. drought effects on freshwater invertebrates, trampling causing soil compaction and plant community change.

LO2 **Implement ecological sampling and fieldwork methods for an identified ecosystem**

Ecological sampling design:

Sampling design: clear aim, hypothesis or prediction; identification of variables and potential confounding factors; selection of methods matched to habitat type, scale and ecological question; choice of sampling unit, sampling effort and sampling approach, including random, systematic and stratified sampling; replication, representativeness and sample size

Refinements: pilot surveys to refine methods; ethical, environmental and sustainable fieldwork practices to minimise disturbance e.g. stratified random quadrat surveys in mown and unmown margins, transects across dunes or riverbanks.

Fieldwork sampling methods:

Sampling methods: quadrats for abundance, cover and frequency; line and belt transects for zonation; timed searches, sweep netting, pitfall trapping and kick sampling; indirect evidence including tracks, signs and scat where appropriate

Population estimation: introduction to mark-release-recapture concepts and index counts; assumptions, limitations and suitability of methods in terrestrial and aquatic settings e.g. kick sampling upstream and downstream of a discharge point, belt transects to assess trampling effects.

Data quality and reliability:

Data quality: repeatable methods and representative sampling; sources of bias e.g. edge effects, accessibility bias, trap bias and observer effects; species identification accuracy and consistency of recording

Data recording and verification: metadata e.g. date, weather and site notes; digital tools such as electronic recording systems, location data and images to support consistency, verification and dataset management e.g. standardised kick-sample duration, photographs to confirm species identification, consistent coding across datasets.

Health, safety and professional practice:

Safety: safe working practices informed by risk assessment and dynamic decision making; use of appropriate PPE; awareness of hazards including terrain, weather, water and tides

Professional and environmental practice: minimising environmental damage during sampling; ethical and legal considerations when working in sensitive habitats or with protected species; biosecurity measures to reduce the spread of invasive species and pathogens e.g. cleaning boots and waders between sites, obtaining permissions for protected areas.

LO3 **Review ecological data to generate trends for the identified ecosystem**

Ecological data types and organisation:

Ecological data: species abundance, population measures and distribution records; numerical and categorical data collected across space and time

Data organisation: tabulation, coding and cleaning to address inconsistencies or missing values; use of digital tools, including spreadsheets, to support data management, graph selection and visualisation; basic descriptive statistics and identification of outliers e.g. bar and line graphs, annotated transects or maps.

Data interpretation and trend identification:

Trend identification: patterns including gradients, clustering and zonation; changes in size, abundance or distribution over time; seasonality and spatial variation; ecological indicators including sensitive taxa and indicator species

Interpretation: distinguishing correlation from causation; drawing on multiple lines of evidence to strengthen conclusions e.g. plotting abundance along transects, comparing diversity between sites.

Ecological factors influencing trends:

Factors: environmental pressures, biotic interactions, habitat quality, disturbance and human impacts e.g. pollution, land-use change, fragmentation

Implications of change: plausible ecological mechanisms used to explain observed trends e.g. low oxygen linked to loss of sensitive taxa, shading reducing macrophytes, soil compaction lowering plant richness; consequences for ecosystem services and long-term sustainability.

Validity and reliability of ecological data:

Validity and reliability: e.g. confidence in conclusions in relation to data quality, sampling effort and methodological limitations; sources of uncertainty and anomalous results

Evaluation of evidence: constraints of short-term or small-scale studies e.g. limits of one-day sampling; proportionate conclusions based on available evidence e.g. reduced representativeness in patchy habitats.

LO4 **Present the results of the ecological study for the identified ecosystem to an identified audience**

Audience and communication purpose:

Audience identification: communication purpose; audience needs and level of technical understanding; adaptation of language, terminology and detail for technical and non-technical audiences e.g. assessor audience, peer audience, local community group, land manager

Inclusive communication: consideration of presenter and audience needs to support accessible delivery of ecological findings e.g. readable visual formats, supportive presentation tools and adaptation of delivery methods.

Selection, organisation and presentation of ecological results:

Selection of results: selection of relevant ecological findings; logical structure and sequencing of methods, results and key messages; presentation formats including tables, charts, graphs, annotated images and simple diagrams e.g. bar charts for abundance, line graphs for change over time; presentation titles, labels, units, legends, captions e.g. annotated habitat images, summary tables.

Communication of findings and evidence-based conclusions:

Communication: clear communication of methods, results and main findings; interpretation of patterns, trends and simple comparisons; linkage of findings to study aims

Conclusions: evidence-based conclusions appropriate to the identified audience; transparent communication of limitations, uncertainty and study constraints e.g. small sample size, short sampling period, patchy distribution, weather effects during sampling.

Review and use of audience feedback:

Review: use of feedback to identify strengths and areas for improvement e.g. clarity, suitability, structure and effectiveness

Future presentations: use of feedback to inform improvement of future scientific presentations e.g. simplifying terminology, improving graph choice, adding clearer explanation of methods, strengthening conclusions.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Explore core ecological principles		**LO1**
P1 Explore key ecological principles using appropriate terminology. **P2** Explain how ecological processes influence ecosystem structure and function.	**M1** Analyse relationships between core ecological principles within ecosystems.	**D1** Evaluate the significance of core ecological principles in ecosystem structure and function.
LO2 Implement ecological sampling and fieldwork methods for an identified ecosystem		**LO2 and LO3**
P3 Select ecological sampling and fieldwork methods appropriate to the identified ecosystem. **P4** Implement ecological sampling and fieldwork methods to generate data for the ecosystem.	**M2** Analyse the application of ecological sampling and fieldwork methods in generating reliable data for the identified ecosystem.	**D2** Evaluate the effectiveness and limitations of ecological sampling and fieldwork methods in generating data trends for the identified ecosystem.
LO3 Review ecological data to generate trends for the identified ecosystem		
P5 Review ecological data to generate trends for the identified ecosystem. **P6** Discuss the factors that could impact the generated trends, including ecological factors, data validity and reliability.	**M3** Analyse the identified trends in ecological sampling data in relation to ecological factors and data limitations.	
LO4 Present the results of the ecological study for the identified ecosystem to an identified audience		**LO4**
P7 Deliver a presentation to an identified audience that communicates the results of the ecological study and the methods used. **P8** Review audience feedback to identify strengths and areas for improvement in the ecological study.	**M4** Analyse, using audience feedback, the effectiveness of the implemented ecological study on the identified ecosystem.	**D3** Justify the decisions made in the selection of fieldwork and data analysis methods in response to audience feedback on the implemented ecological study.

Recommended Resources

Textbooks

Ausden, M. (2007) *Habitat Management for Conservation: A Handbook of Techniques*. Oxford: Oxford University Press.

Begon, M., Townsend, C.R. and Harper, J.L. (2021) *Ecology: From Individuals to Ecosystems*. 5th edn. Oxford: Wiley-Blackwell.

Chapin, F.S., Matson, P.A. and Vitousek, P.M. (2011) *Principles of Terrestrial Ecosystem Ecology*. 2nd edn. New York: Springer.

Kent, M. (2012) *Vegetation Description and Data Analysis: A Practical Approach*. 2nd edn. Chichester: Wiley-Blackwell.

Lame, M. and Marcantonio, R. (2022) *Environmental Management: Concepts and Practical Skills*. Cambridge: Cambridge University Press.

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Odum, E.P. and Barrett, G.W. (2005) *Fundamentals of Ecology*. 5th edn. Belmont, CA: Thomson Brooks/Cole.

Roni, P. (2019) *Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats*. 2nd edn. Chichester: Wiley-Blackwell.

Walker, L.R., Walker, J. and Hobbs, R.J. (2022) *Linking Restoration and Ecological Succession*. 2nd edn. New York: Springer.

Websites

britishecologicalsociety.org	British Ecological Society Ecology learning resources and applied ecological research (General reference)
field-studies-council.org	Field Studies Council Ecological fieldwork, sampling techniques and habitat studies (Training)
jncc.gov.uk	Joint Nature Conservation Committee UK biodiversity indicators, habitats and ecological data (Datasets)

iucn.org	International Union for Conservation of Nature Conservation frameworks, ecosystem management and sustainability (General reference)
ser.org	Society for Ecological Restoration Ecosystem restoration principles and applied management approaches (General reference)
magic.defra.gov.uk	DEFRA MAGIC Map Spatial ecological data on habitats, land use and conservation designations (Development tool)
unep.org	United Nations Environment Programme Global environmental sustainability, ecosystem protection and applied ecology (General reference)
https://www.fao.org	Food and Agriculture Organization of the United Nations Ecosystem management, biodiversity, sustainable land and water use (General reference)

Journals and articles

Albert, C.H., *et al.* (2010) 'Sampling in ecology and evolution – Bridging the gap between theory and practice', *Ecography*, 33(6), pp. 1028–1037. Available at: https://nsojournals.onlinelibrary.wiley.com/doi/epdf/10.1111/j.1600-0587.2010.06421.x.

Chapin, F.S. III, Torn, M.S. and Tateno, M. (1996) 'Principles of Ecosystem Sustainability', *The American Naturalist*, 148(6), pp. 1016–1037. Available at: https://doi.org/10.1086/285969.

Dalongeville, A., *et al.* (2022) 'Benchmarking eleven biodiversity indicators based on environmental DNA surveys: More diverse functional traits and evolutionary lineages inside marine reserves', *Journal of Applied Ecology*. Available at: https://doi.org/10.1111/1365-2664.14276.

Dyson, K., *et al.* (2024) 'Coupling remote sensing and eDNA to monitor environmental impact: A pilot to quantify the environmental benefits of sustainable agriculture in the Brazilian Amazon', *PLOS ONE*, 19(2), e0289437. Available at: https://doi.org/10.1371/journal.pone.0289437.

Ford, H.V., *et al.* (2024) 'A technological biodiversity monitoring toolkit for biocredits', *Journal of Applied Ecology*, 61, pp. 2007–2019. Available at: https://doi.org/10.1111/1365-2664.14725.

Kitikidou, K., *et al.* (2024) 'Using Biodiversity Indices Effectively: Considerations for Forest Management', *Ecologies*, 5(1), pp. 42–51. Available at: https://doi.org/10.3390/ecologies5010003.

Müller, J., *et al.* (2023) 'Soundscapes and deep learning enable tracking biodiversity recovery in tropical forests', *Nature Communications*, 14, 6191. Available at: https://doi.org/10.1038/s41467-023-41693-w.

Otomo, Y., *et al.* (2023) 'Dynamics-based characterization and classification of biodiversity indicators', *Ecology and Evolution*, 13, e10271. Available at: https://doi.org/10.1002/ece3.10271.

Reynolds, K.M., *et al.* (2023) 'Latest features of the ecosystem management decision support system, version 8.0', *Frontiers in Environmental Science*, 11, 1231818. Available at: https://doi.org/10.3389/fenvs.2023.1231818.

Rowland, J.A., *et al.* (2019) 'Ecosystem indices to support global biodiversity conservation', *Conservation Letters*. Available at: https://doi.org/10.1111/conl.12680.

Links

This unit links to the following related units:

Unit 418: Managing Environmental Resources

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 529: Conservation and Biodiversity

Unit 531: Soil Science and Geochemical Processes.

Unit 418: Managing Environmental Resources

Unit code: K/652/3050

Unit level: 4

Credit value: 15

Introduction

Environmental resource management is a critical area of applied science that underpins sustainable development across industry, society and the natural environment. Growing demand for energy, materials, water and food places increasing pressure on natural systems through resource depletion, environmental damage and climate change. This unit introduces how environmental resources are managed within ecological limits, regulatory frameworks and sustainability goals relevant to modern scientific and professional practice.

The purpose of this unit is to introduce students to the core principles that underpin environmental resource management and to explore the pressures placed on the environment through the use of both finite and renewable resources. Students will examine how natural systems function, the importance of biodiversity and ecosystem services, and how sustainability frameworks are used to assess environmental performance. The unit also explores how human activities such as extraction, production and consumption contribute to environmental stress, and how these impacts are measured using scientific and digital tools.

Students will study the use and environmental impacts of renewable resources, recognising that renewable does not automatically equate to sustainable. The unit encourages critical evaluation of trade-offs linked to renewable resource use, including land use, water demand, pollution and ecosystem stability. Students will engage with approaches such as environmental monitoring, life-cycle thinking and data-driven decision making, reflecting the increasing role of digital technologies in environmental management.

On completion of this unit, students will be able to apply their knowledge to develop appropriate strategies for improving environmental resource management within an identified scenario. This includes evaluating mitigation and adaptation options, working within regulatory and stakeholder constraints, and assessing the effectiveness of management actions in meeting sustainability objectives.

The knowledge and skills developed support progression to higher-level study and employment in environmental, scientific and sustainability-focused roles where responsible resource management is essential.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain core principles underpinning environmental resource management

LO2 Discuss the pressures placed on the environment by consuming finite resources

LO3 Discuss the use and environmental impact of renewable resources

LO4 Develop appropriate strategies to improve environmental resource management for an identified scenario.

Essential Content

LO1 **Explain core principles underpinning environmental resource management**

Core environmental resource concepts:

Environmental resource management: biosphere and natural systems supporting life; ecosystem structure and function; ecosystem services and natural capital; resource cycles; system interdependence e.g. pollination enabling food production

Sustainability: carrying capacity, resilience, biodiversity and ecosystem stability; long-term sustainability; genetic, species and habitat diversity supporting ecosystem processes e.g. wetlands contributing to water purification and flood attenuation.

Sustainability principles and frameworks:

Sustainability principles: sustainable development; intergenerational equity; stewardship, conservation, precautionary approach and scientific uncertainty

Decision-making frameworks: carbon, water and ecological footprints; life-cycle thinking; circular economy models of reuse, repair, remanufacture and recycling

Evaluation of environmental performance: identification of hotspots; management of trade-offs across systems and supply chains e.g. reduced carbon emissions but increased water demand, lower-cost materials with higher toxicity risk.

Environmental resource databases:

Environmental resource databases: sources of data e.g. monitoring systems, field surveys, laboratory analysis, remote sensing, government and intergovernmental datasets, industry records, published scientific data

Data storage: storage of data e.g. spreadsheets, databases, cloud-based platforms, geographic information systems; data organisation, standardisation, traceability, quality assurance

Types of data: documents and reports e.g. dashboards, indicators, compliance records, sustainability reports; technical summaries to support environmental monitoring, decision making and performance review e.g. emissions inventories, water-quality records, biodiversity survey datasets, waste reporting returns.

Regulatory and professional context for resource management:

Regulatory and professional context: environmental legislation, standards and governance frameworks; environmental management systems; continuous improvement models e.g. ISO 14001

Compliance monitoring: compliance monitoring and reporting; performance improvement; stakeholder expectations; supply-chain responsibility; organisational target setting; environmental performance indicators e.g. science-based carbon targets, resource-efficiency KPIs, waste diversion rates.

LO2 **Discuss the pressures placed on the environment by consuming finite resources**

Finite resource categories and extraction contexts:

Finite resources: fossil fuels, metal ores, industrial minerals, critical raw materials e.g. rare earth elements in wind turbines, lithium and cobalt in batteries, copper in power networks; limited supply and depletion

Impact on ecosystems: extraction and use pressures on ecosystems through land disturbance, habitat loss, energy demand, waste generation; resource availability and strategic importance; supply-risk concepts; inventories; digital mapping; emissions datasets.

Environmental pressures associated with extraction and use:

Environmental pressures: biodiversity loss, landscape change, hydrological disruption e.g. elevated metal concentrations downstream of mines; greenhouse gas emissions, air pollution, noise; pollution pathways including soil and water contamination, acid mine drainage, heavy-metal release and sedimentation e.g. NO_x near quarry transport routes, methane leakage from fossil fuel extraction

Monitoring: use of environmental indicators, monitoring data, spatial analysis, remote sensing and modelling to assess pressures.

Environmental impacts associated with processing and consumption:

Processing and consumption impacts: energy demand e.g. energy-intensive aluminium smelting; water demand; chemical emissions; hazardous by-products e.g. toxic risks from electronic waste

Life-cycle impacts: life-cycle impacts across extraction, processing, use and end-of-life stages e.g. embedded carbon, recycling rates and contamination levels; cumulative effects e.g. microplastic pollution from plastics; burden shifting, material-flow analysis, efficiency metrics; identification of priority interventions.

LO3 **Discuss the use and environmental impact of renewable resources**

Use of renewable resources in industrial and societal contexts:

Renewable resources: biological materials and energy sources replenished through natural processes; timber, crops, biomass, renewable energy

Uses: use in construction, manufacturing, energy, food systems; regeneration rates e.g. harvesting rates relative to forest regrowth; land availability, water demand; competing uses e.g. land competition between biofuels and food crops; system boundaries; maintaining yields within ecological limits e.g. transport distances in biomass supply chains.

Environmental impacts and trade-offs associated with renewable resource use:

Environmental impacts and trade-offs: deforestation, habitat conversion, soil degradation, biodiversity loss; water stress e.g. irrigation increasing water scarcity; nutrient pollution e.g. nutrient run-off driving eutrophication; poorly managed intensive systems, monocultures, reduced ecosystem stability

Monitoring: use of monitoring data and modelling to balance productivity and ecosystem health e.g. peatland drainage raising carbon emissions; harvesting controls, certification traceability e.g. forestry certification schemes, fisheries quotas, traceable agricultural supply chains.

Renewable energy resources and environmental considerations:

Renewable energy resources: solar, wind, hydroelectric, tidal, geothermal, biomass; reduced reliance on finite resources

Environmental considerations: environmental considerations relating to land and marine use, materials demand, infrastructure and end-of-life waste e.g. embodied carbon in turbine foundations, mining for photovoltaic materials, habitat disruption from dams, collision risk for birds and bats, sensitive site selection, fish passes

Life cycle: life-cycle assessment beyond operational phase; planning and mitigation measures e.g. recycling of panels and turbine blades.

LO4 **Develop appropriate strategies to improve environmental resource management for an identified scenario**

Scenario definition and issue identification:

Scenario definition: organisation, site, process or supply chain with resource-management challenges; system boundaries, baseline conditions; flows of materials, energy and water e.g. high water use and effluent discharges in manufacturing

Environmental audits: monitoring systems, dashboards; identification and prioritisation of risks and inefficiencies by impact and feasibility e.g. material waste and embodied carbon on construction sites, energy-intensive refrigeration in food processing.

Strategies for improving environmental resource management:

Improvement strategies: pollution prevention e.g. closed-loop water systems; efficiency improvements e.g. heat recovery for energy efficiency; substitution e.g. recyclable packaging redesign; process optimisation; circular economy approaches e.g. sustainable procurement

Adaptation strategies: resilience planning, system redesign, conservation planning and nature-based solutions e.g. green infrastructure for flood reduction and biodiversity gain; evaluation of options using evidence, performance indicators, cost–benefit considerations and regulatory requirements.

Suitability and effectiveness of management strategies:

Suitability and effectiveness: feasibility, cost, stakeholder expectations, operational constraints; monitoring data e.g. selected indicators

Compliance: regulatory compliance, continuous improvement within environmental management systems e.g. alignment with sustainability frameworks; long-term decision making; unintended consequences and trade-offs e.g. carbon reduction measures increasing toxicity risk, recycling initiatives limited by contamination, renewable installations constrained by intermittency and grid access.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain core principles underpinning environmental resource management</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate the significance of environmental resource-management principles, data and frameworks in interpreting the pressures and impacts associated with finite and renewable resource use.</td></tr>
<tr><td>P1 Describe core environmental resource concepts underpinning environmental resource management.

P2 Explain sustainability, data and regulatory frameworks underpinning environmental resource management.</td><td>M1 Analyse how environmental resource-management principles, data and frameworks support sustainable management approaches.</td></tr>
<tr><td colspan="2">LO2 Discuss the pressures placed on the environment by consuming finite resources</td></tr>
<tr><td>P3 Discuss environmental pressures arising from the extraction and use of finite resources.

P4 Discuss environmental impacts associated with the processing and consumption of finite resources.</td><td>M2 Assess how the extraction, processing and consumption of finite resources contribute to environmental pressures and impacts.</td></tr>
<tr><td colspan="2">LO3 Discuss the use and environmental impact of renewable resources</td></tr>
<tr><td>P5 Discuss the use of renewable resources in industrial and societal contexts.

P6 Describe environmental impacts and trade-offs associated with renewable resource use.</td><td>M3 Analyse how renewable resource use can contribute to environmental impacts and trade-offs.</td></tr>
<tr><td colspan="2">LO4 Develop appropriate strategies to improve environmental resource management for an identified scenario</td><td rowspan="2">LO4

D2 Evaluate the suitability and effectiveness of the proposed strategies in relation to identified issues, constraints and sustainability priorities.</td></tr>
<tr><td>P7 Propose strategies to improve environmental resource management for the identified scenario.</td><td>M4 Justify the suitability of the proposed strategies for improving environmental resource management in the identified scenario.</td></tr>
</table>

Recommended Resources

Textbooks

Laine, M., Tregidga, H. and Unerman, J. (2021) *Sustainability Accounting and Accountability*. 3rd edn. London: Routledge.

Guo, W., Ngo, H.H., Surampalli, R.Y. and Zhang, T.C. (2021) *Sustainable Resource Management: Technologies for Recovery and Reuse of Energy and Waste Materials*. Hoboken, NJ: Wiley.

Hussain, C.M. (2021) *Sustainable Resource Management: Modern Approaches and Contexts*. Oxford: Elsevier.

Prasad, R., Jhariya, M.K. and Banerjee, A. (eds.) (2021) *Advances in Sustainable Development and Management of Environmental and Natural Resources*. New York: Apple Academic Press.

Twidell, J. (2021) *Renewable Energy Resources*. 4th edn. London: Routledge.

Will, M., Brauweiler, J. and Zenker-Hoffmann, A. (2021) *Environmental Management Systems According to ISO 14001*. Cham: Springer.

Websites

https://edgar.jrc.ec.europa.eu	Emissions Database for Global Atmospheric Research (EDGAR) Global greenhouse gas and air pollutant emissions data (Datasets)
https://www.eea.europa.eu	European Environment Agency Environmental data, indicators and assessments (Datasets)
https://www.iso.org	International Organization for Standardization ISO 14001 Environmental Management Systems (General reference)
https://www.lcacommons.gov	Federal Life Cycle Assessment Commons Life-cycle assessment data repositories and tools (Datasets)

https://www.lifecycleinitiative.org/resources-2/global-lca-data-network-glad-2/	UN Life Cycle Initiative Global Life Cycle Assessment (LCA) data access and interoperability (Datasets)
https://www.oecd.org/en/topics/resource-efficiency-and-circular-economy.html	Organisation for Economic Co-operation and Development (OECD) Resource efficiency and circular economy policy frameworks (Research)
https://www.unep.org/	United Nations Environment Programme Environmental sustainability, resource efficiency and circular economy (General reference)
https://www.wri.org	World Resources Institute Resource efficiency, environmental data and sustainability metrics (Research)

Journals and articles

Ali, M., Atanasovska, I. and Koh, L. (2026) 'Food waste management: evaluating environmental impacts of collection systems', *The International Journal of Life Cycle Assessment*. Available at: https://link.springer.com/article/10.1007/s11367-026-02666-5.

Aska, B., *et al.* (2025) 'Mining, biodiversity and social conflict in the renewable energy transition', *Nature Reviews Biodiversity*, 1(9), pp. 597–614. Available at: https://doi.org/10.1038/s44358-025-00076-3.

Cheng, Y.-T., *et al.* (2026) 'Mapping global resource-driven nature loss in the mining sector from 2001 to 2022', *Nature Communications*. Available at: https://doi.org/10.1038/s41467-026-73792-9.

Geissdoerfer, M., *et al.* (2017) 'The Circular Economy – A new sustainability paradigm?', *Journal of Cleaner Production*, 143, pp. 757–768. Available at: https://doi.org/10.1016/j.jclepro.2016.12.048.

Moreno Vargas, D.C., *et al.* (2023) 'The water-energy-food nexus in biodiversity conservation: A systematic review around sustainability transitions of agricultural systems', *Heliyon*, 9(7), e17016. Available at: https://doi.org/10.1016/j.heliyon.2023.e17016.

Ololade, O.O., *et al.* (2026) 'Editorial: Innovations in the water-energy-food nexus for sustainable management', *Frontiers in Sustainable Resource Management*, 5. Available at: https://doi.org/10.3389/fsrma.2026.1858871.

Rockström, J., *et al.* (2021) 'Identifying a Safe and Just Corridor for People and the Planet', *Earth's Future*, 9(4), e2020EF001866. Available at: https://doi.org/10.1029/2020EF001866.

Sala, S., Ciuffo, B. and Nijkamp, P. (2015) 'A systemic framework for sustainability assessment', *Ecological Economics*, 119, pp. 314–325. Available at: https://doi.org/10.1016/j.ecolecon.2015.09.015.

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Zhou, X. and Yang, X. (2026) 'Can corporate digital transformation mitigate greenwashing?', *Environment, Development and Sustainability*. Available at: https://doi.org/10.1007/s10668-026-07761-z.

Links

This unit links to the following related units:

Unit 417: Principles of Ecology

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 529: Conservation and Biodiversity

Unit 531: Soil Science and Geochemical Processes.

Unit 419: Bioinformatics

Unit code: L/652/3051

Unit level: 4

Credit value: 15

Introduction

The growth of data-driven methods has transformed modern biological science, with bioinformatics now playing a critical role across healthcare, research, genomics and biotechnology. Advances in sequencing technologies and computational capacity have led to the generation of vast quantities of genetic and protein data, requiring specialist tools and analytical approaches to extract meaningful biological insight. This unit is relevant to students preparing for technical and analytical roles within applied biological and life science sectors, where the ability to work confidently with digital biological data is increasingly essential.

The aim of this unit is to provide students with a solid foundation in the principles and practice of bioinformatics. It introduces how biological information is represented digitally, how computational methods are used to analyse genetic and protein data, and how bioinformatics supports biological research and discovery. Students develop an understanding of how computational approaches complement experimental science, enabling the identification of patterns, variation and functional relationships within complex biological datasets.

The unit covers a broad range of topics that reflect contemporary bioinformatics practice. Students explore core bioinformatics concepts, including sequence data, biological databases and sequence analysis techniques. Computational methods and algorithms such as alignment, motif discovery and statistical modelling are examined, alongside the practical application of bioinformatics tools to real-world biological scenarios. The unit also addresses the interpretation and presentation of bioinformatics results, with consideration given to ethical responsibilities, data governance requirements and professional standards in scientific communication.

Upon successful completion of this unit, students will be able to apply bioinformatics tools and methods to analyse genetic and protein data, interpret results using appropriate statistical approaches, and communicate findings to defined audiences. These skills support progression into roles such as Bioinformatics Technician, Laboratory Data Analyst, Genomics Research Assistant, Biomedical Data Analyst and Biotechnology Research Technician, as well as further study within applied biological, biomedical and data-focused science pathways.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core concepts of bioinformatics and their role in modern biological research

LO2 Describe computational methods and algorithms used in biological data analysis

LO3 Apply appropriate bioinformatics tools and databases to generate genetic and protein bioinformatic data for an identified scenario

LO4 Present the results of the bioinformatic study to an identified audience.

Essential Content

LO1 **Explain the core concepts of bioinformatics and their role in modern biological research**

Core bioinformatics concepts:

Genetic concepts: gene e.g. coding regions, functional genes; allele e.g. gene variants, alternative forms; genotype e.g. genetic makeup, allele combinations; phenotype e.g. observable traits, expressed characteristics

Protein information: protein sequence e.g. amino acid order, peptide chains; protein domains e.g. functional domains, conserved domains; protein expression datasets e.g. expression profiles, quantitative outputs; variant data e.g. sequence variants, altered residues

Sequence structure: nucleotide sequence e.g. DNA bases, base order; amino acid sequence e.g. protein chains, peptide sequences; base pairing e.g. complementary bases, paired nucleotides; codons e.g. triplet bases, stop codons; reading frame e.g. open reading frames, translated frames

Data concepts: biological information e.g. genetic information, functional information; biological data e.g. sequence data, experimental data; data representation e.g. digital formats, structured data; data types e.g. sequence data, annotation data.

Sequence analysis:

Similarity and variation: sequence similarity e.g. shared regions, similar sequences; homology e.g. conserved genes, related sequences; mutation e.g. point mutations, base substitutions; polymorphism e.g. genetic variants, population variation

Sequence change: insertion e.g. inserted bases, added residues; deletion e.g. removed bases, missing residues; indels e.g. insertion–deletion events, combined changes; reference sequence e.g. reference genome, database sequence

Alignment and interpretation: sequence alignment e.g. aligned sequences, matched regions; conserved regions e.g. shared motifs, preserved sites; functional interpretation e.g. predicted function, biological role; evolutionary interpretation e.g. species comparison, evolutionary relationships.

Biological databases:

Database foundations: database purpose e.g. data access, information storage; database function e.g. record storage, information lookup; reference databases e.g. curated databases, trusted resources

Records and identifiers: accession numbers e.g. unique IDs, dataset identifiers; database records e.g. stored entries, information records; database entries e.g. individual records, data entries; record fields e.g. data columns, information fields

Bioinformatic datasets: biological sequence data e.g. gene sequences, genomic datasets; DNA representation e.g. nucleotide strings, reference genomes; RNA representation e.g. transcript sequences, RNA reads; protein representation e.g. amino acid chains, protein sequences

Real-world biological database examples e.g. nucleotide sequence databases e.g. GenBank, EMBL-EBI ENA, DDBJ; protein sequence databases e.g. UniProt, Swiss-Prot, TrEMBL; protein structure databases e.g. Protein Data Bank, PDBe, RCSB PDB; genome browsers e.g. Ensembl, UCSC Genome Browser, NCBI Genome Data Viewer.

LO2 **Describe computational methods and algorithms used in biological data analysis**

Computational methods in bioinformatics:

Analysis approaches: computational methods e.g. algorithm-based analysis, data processing methods; algorithmic approaches e.g. stepwise processes, automated logic; biological data analysis e.g. sequence analysis, analytical workflows

Method characteristics: deterministic methods e.g. fixed rules, predictable outputs; probabilistic methods e.g. probability-based outcomes, uncertainty handling; statistical models e.g. applied statistics, biological modelling

Workflows and control: analysis pipelines e.g. multi-step workflows, processing pipelines; workflow design e.g. structured workflows, ordered steps; automation e.g. scripted analysis, automated runs; reproducibility e.g. repeatable analysis, consistent results; workflow consistency e.g. standardised steps, controlled execution.

Alignment algorithms:

Alignment types: sequence alignment e.g. aligned sequences, comparative analysis; pairwise alignment e.g. two-sequence comparison; multiple alignment e.g. multi-sequence comparison; local alignment e.g. partial matching; global alignment e.g. full-length comparison

Scoring and structure: scoring systems e.g. match scores, penalty scores; substitution matrices e.g. scoring tables; gap penalties e.g. insertion penalties, deletion penalties; gaps e.g. alignment gaps; matches e.g. identical positions

Results and limitations: mismatches e.g. differing residues; alignment scores e.g. similarity scores; alignment length e.g. aligned region size; low complexity regions e.g. repeated regions; algorithm limitations e.g. method constraints.

Motif discovery methods:

Motif types: sequence motifs e.g. conserved patterns; protein motifs e.g. functional regions; regulatory motifs e.g. binding sites

Pattern properties: conserved patterns e.g. shared features; motif context e.g. surrounding sequences; domains e.g. functional domains

Detection and significance: motif discovery e.g. pattern finding; motif detection e.g. computational detection; motif relevance e.g. biological importance; motif significance e.g. meaningful patterns; statistical significance e.g. confidence measures.

Statistical models in biological data analysis:

Model foundations: statistical models e.g. applied models; biological variation e.g. sample differences; probabilistic reasoning e.g. uncertainty reasoning

Model constraints: model assumptions e.g. defined conditions; model constraints e.g. simplified scope; statistical validation e.g. result checking

Statistical measures: mean e.g. average values; median e.g. middle value; range e.g. data spread; standard deviation e.g. variation measure; outliers e.g. unusual values.

LO3 **Apply appropriate bioinformatics tools and databases to generate genetic and protein bioinformatic data for an identified scenario**

Bioinformatics analysis tools:

Tool scope and selection: bioinformatics tools e.g. analysis software, bioinformatics applications; tool purpose e.g. analytical goals, research objectives; tool scope e.g. sequence analysis tasks, protein analysis tasks; tool selection e.g. context-based selection, task-driven choice

Workflow structure: workflow integration e.g. linked analysis steps, combined tools; analysis workflows e.g. ordered steps, multi-step analysis; scenario analysis e.g. defined scenarios, applied case studies

Data handling efficiency: data handling e.g. file handling, data loading, data preparation; workflow efficiency e.g. reduced steps, streamlined processes, efficient execution; file formats e.g. data file formats, structured files, standard formats; FASTA format e.g. sequence files, text-based sequences, biological sequence files.

Sequence similarity and database searching tools:

Search application: sequence search tools e.g. database search tools, alignment search tools; genetic analysis e.g. DNA analysis, gene identification; protein analysis e.g. protein comparison, similarity analysis

Outputs and metrics: search hits e.g. matching sequences, returned results; alignment scores e.g. similarity scores, match values; E-values e.g. significance scores, probability values; percent identity e.g. identity measures, similarity percentages; sequence coverage e.g. matched length, alignment coverage

Result interpretation: alignment length e.g. comparison span, aligned region size; functional inference e.g. predicted roles, inferred function; annotation use e.g. functional annotations, sequence features.

Structural and functional representation:

Structural data: protein structures e.g. three-dimensional structures, molecular models; structure repositories e.g. protein repositories, structure databases; reference resources e.g. curated resources, trusted databases

Visualisation and interpretation: structure visualisation e.g. molecular viewers, graphical models; structure viewers e.g. interactive viewers, 3D tools; structural interpretation e.g. understanding shape, interpreting form

Structure–function links: sequence–structure relationships e.g. residue effects, sequence influence; structure–function relationships e.g. functional regions, behaviour links; active sites e.g. catalytic sites, binding sites.

AI in bioinformatic analysis:

Predictive application: sequence classification e.g. categorising sequences, grouped data; variant prediction e.g. predicting changes, identifying variants; protein structure prediction e.g. predicted folds, structural models; functional annotation e.g. assigned functions, automated annotation

Model evaluation: model accuracy e.g. performance measures, prediction accuracy; model bias e.g. skewed predictions, data influence; prediction confidence e.g. confidence estimates, reliability measures.

Real-world examples:

DNA sequencing tools: sequence similarity tools e.g. BLAST, FASTA, HMMER; pairwise sequence similarity tools e.g. BLAST, FASTA, Smith-Waterman; profile-based similarity tools e.g. HMMER, PSI-BLAST, JackHMMER

Protein tools: protein domain analysis tools e.g. InterPro, Pfam, SMART; protein structure analysis tools e.g. RCSB PDB, PDBe, SWISS-MODEL Repository

Genome analysis: genome annotation tools e.g. Ensembl, Prokka, NCBI Genome Annotation Pipeline; domain and family search databases e.g. Pfam, InterPro, SMART.

LO4 **Present the results of the bioinformatic study to an identified audience**

Statistical representation of bioinformatics results:

Statistical measures: statistical measures e.g. numerical summaries, quantitative indicators; bioinformatics results e.g. analysis outputs, processed datasets; data types e.g. sequence data, variant data, expression data; data quality e.g. reliable data, accurate inputs; error sources e.g. processing errors, configuration errors

Visual presentation: data visualisation e.g. graphical displays, visual summaries; charts e.g. bar charts, comparison charts; tables e.g. summary tables, result tables; plots e.g. scatter plots, distribution plots

Accuracy and clarity: statistical accuracy e.g. correct calculations, valid summaries; computational accuracy e.g. correct outputs, valid results; communication clarity e.g. clear visuals, understandable presentation; labelled outputs e.g. labelled figures, titled tables.

Interpretation and analysis of results:

Pattern analysis: pattern identification e.g. recurring trends, common features; trend analysis e.g. increasing trends, comparative trends; result interpretation e.g. biological interpretation, analytical conclusions

Scenario relevance: scenario linkage e.g. linking results to scenarios, applied interpretation; method alignment e.g. appropriate methods, correct techniques; result alignment e.g. consistent outputs, method-result consistency

Limitations and uncertainty: statistical inference e.g. evidence-based conclusions, probability reasoning; data limitations e.g. incomplete data, limited samples; uncertainty recognition e.g. acknowledging variability, cautious interpretation; alternative explanations e.g. other causes, different interpretations.

Ethical, data governance and sustainability considerations:

Ethical use: ethical use e.g. responsible handling, appropriate practice; biological data e.g. genetic data, molecular data; data privacy e.g. confidential data, sensitive information

Governance controls: consent e.g. informed consent, usage permission; data ownership e.g. data rights, contributor rights; access control e.g. restricted access, permission settings; data governance e.g. governance frameworks, policy compliance

Standards and lifecycle: compliance frameworks e.g. regulatory frameworks, governance standards; FAIR principles e.g. Findable, Accessible, Interoperable and Reusable data; data lifecycle e.g. data creation, data use, archiving; data retention e.g. retained datasets, storage duration; data archiving e.g. preserved datasets, long-term storage.

Audience-appropriate communication:

Audience focus: audience identification e.g. target audience, stakeholders; result adaptation e.g. tailored outputs, adjusted detail; terminology selection e.g. appropriate language, technical terms

Presentation standards: visual formats e.g. charts, tables, figures; professional standards e.g. reporting conventions, scientific standards; scientific communication e.g. structured explanation, formal presentation.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core concepts of bioinformatics and their role in modern biological research</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the significance of core bioinformatics concepts, computational methods and algorithms in advancing modern biological research across identified biological contexts.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the core concepts of bioinformatics and sequencing data used in modern biological research.

P2 Describe, using a selection of real-world examples, the use of biological databases in supporting bioinformatics workflows and interpretation.</td><td>M1 Analyse, using a selection of real-world examples, the effectiveness of bioinformatics concepts and databases in supporting modern biological research.</td></tr>
<tr><td colspan="2">LO2 Describe computational methods and algorithms used in biological data analysis</td></tr>
<tr><td>P3 Describe, using a selection of real-world examples, the computational methods and statistical models used in biological data analysis.

P4 Discuss, using a selection of real-world examples, the application of alignment algorithms and motif discovery methods in biological data analysis.</td><td>M2 Assess, using a selection of real-world examples, the benefits and limitations of computational methods and algorithms for different biological data analysis contexts.</td></tr>
</table>

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO3 Apply appropriate bioinformatics tools and databases to generate genetic and protein bioinformatic data for an identified scenario</td><td rowspan="5">LO3 and LO4

D2 Justify the decisions made in the selection of bioinformatic tools and statistical analysis methods used to generate effective conclusions for the identified bioinformatic scenario.</td></tr>
<tr><td>P5 Apply appropriate bioinformatics tools and databases to generate genetic bioinformatic data for an identified scenario.

P6 Implement appropriate bioinformatics tools and databases to generate protein bioinformatic data for an identified scenario.

P7 Review the quality of data generated with internal stakeholders to identify strengths and limitations.</td><td>M3 Evaluate the strengths and limitations of the selection and configuration of the chosen bioinformatic tools and databases, including why certain options were rejected.</td></tr>
<tr><td colspan="2">LO4 Present the results of the bioinformatic study to an identified audience</td></tr>
<tr><td>P8 Interpret the generated bioinformatics data using appropriate statistical methods to obtain meaningful insights for an identified scenario.

P9 Present the findings of the bioinformatic study to an identified external audience and obtain feedback on the results.</td><td>M4 Analyse, using the findings of the bioinformatic study, the internal stakeholder and external audience feedback, the effectiveness of the results for an identified bioinformatic scenario.</td></tr>
</table>

Recommended Resources

Textbooks

Baxevanis, A.D., Bader, G.D. and Wishart, D.S. (2020) *Bioinformatics*. 4th edn. Hoboken, NJ: Wiley.

Chor, B. and Rubinstein, A. (2022) *Computational Thinking for Life Scientists* Cambridge: Cambridge University Press.

Haspel, N., Jagodzinski, F. and Molloy, K. (eds.) (2022) *Algorithms and Methods in Structural Bioinformatics.* Cham: Springer.

Mäkinen, V., *et al.* (2023) *Genome-Scale Algorithm Design: Bioinformatics in the Era of High-Throughput Sequencing.* 2nd edn. Cambridge: Cambridge University Press.

Momand, J. and Bush, E. (2025) *Concepts in Bioinformatics and Genomics.* 2nd edn. Oxford: Oxford University Press.

Prakash, K.B., Mallik, S. and Balas, V.E. (eds.) (2026) *Modern Bioinformatics: From Molecular Insights to Biomedical Innovation*. Oxford: Academic Press.

Ramsden, J. (2023) *Bioinformatics: An Introduction*. 4th edn. Cham: Springer.

Singh, T.R., Saini, H. and Comar Jr., M. (eds.) (2023) *Bioinformatics and Computational Biology: Technological Advancements, Applications and Opportunities*. Boca Raton: CRC Press.

Websites

https://www.ks.uiuc.edu/Training/Tutorials/science/bioinformatics-tutorial/bioinformatics.pdf	University of Illinois Introductory tutorial covering sequence alignment methods and interpretation in bioinformatics (Tutorial)
https://liulab-dfci.github.io/bioinfo-combio/	Harvard/Dana-Farber Cancer Institute Course materials introducing computational methods and workflows in bioinformatics (General reference)
https://www.mathworks.com/help/bioinfo/getting-started-with-bioinformatics-toolbox.html	MathWorks Bioinformatics Toolbox Overview of bioinformatics pipelines for genomic and proteomic data analysis (General reference)

https://omicstutorials.com/mastering-bioinformatics-your-essential-guide-to-computational-biology-skills/	Omics Tutorials Guide to bioinformatics tools, workflows, and digital data handling in biological research (Tutorial)
https://www.yourgenome.org/theme/what-is-bioinformatics-and-how-do-we-use-it/	YourGenome (Wellcome Sanger Institute) Clear explanation of what bioinformatics is and how biological data is analysed using computing (General reference)
https://www.genomicseducation.hee.nhs.uk/education/core-concepts/what-is-bioinformatics/	NHS Genomics Education Programme Clear explanation of bioinformatics, data pipelines and clinical relevance (Article)
https://learn.gencore.bio.nyu.edu/alignment/	NYU Langone - GenCore Step-by-step explanation of sequence alignment as a core bioinformatics method (Tutorial)
https://www.who.int/news/item/20-11-2024-who-releases-new-principles-for-ethical-human-genomic-data-collection-and-sharing	World Health Organization (WHO) Principles for ethical collection, use and sharing of genomic data (Article)
https://scikit.bio/docs/latest/alignment.html	scikit-bio Practical reference for DNA, RNA and protein sequence alignment concepts with worked examples (Tutorial)

Journals and articles

Amarasinghe, S.L., *et al.* (2020) 'Opportunities and challenges in long-read sequencing data analysis', *Genome Biology*, 21, article 30. Available at: https://link.springer.com/article/10.1186/s13059-020-1935-5.

McInnes, L., *et al.* (2018) 'UMAP: Uniform manifold approximation and projection', *Journal of Open Source Software*, 3(29), 861. Available at: https://doi.org/10.21105/joss.00861.

Pop, M., *et al.* (2025) 'Biological databases in the age of generative artificial intelligence', *Bioinformatics Advances*, 5(1), vbaf044. Available at: https://doi.org/10.1093/bioadv/vbaf044.

Sandve, G.K., *et al.* (2013) 'Ten Simple Rules for Reproducible Computational Research', *PLoS Computational Biology*, 9(10), e1003285. Available at: https://doi.org/10.1371/journal.pcbi.1003285.

Wilkinson, M.D., *et al.* (2016) 'The FAIR Guiding Principles for scientific data management', *Scientific Data*, 3, article 160018. Available at: https://doi.org/10.1038/sdata.2016.18.

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 424: Artificial Intelligence in Applied Science

Unit 503: Applied Molecular Biology

Unit 525: Genomics and Proteomics.

Unit 420: Cheminformatics

Unit code: M/652/3052

Unit level: 4

Credit value: 15

Introduction

The rapid growth of digital technologies has transformed the way chemical data is generated, managed and analysed across modern scientific environments. In areas such as pharmaceutical research, materials development and chemical analysis, large and complex datasets are now central to discovery and decision making. Cheminformatics sits at the intersection of chemistry and computing, providing the tools and methods needed to extract meaningful information from chemical data and support evidence-based scientific work.

The aim of this unit is to introduce students to the fundamental role of cheminformatics within contemporary chemical science. The unit develops an understanding of how chemical information is represented digitally, how different types of chemical data are analysed computationally, and how cheminformatics tools are used to support scientific and industrial decision making. Emphasis is placed on understanding the purpose of these tools, rather than their mathematical complexity, making the content accessible to students at Level 4.

The unit covers key topics including digital representations of chemical structures, chemical data types and sources, and the computational methods used to search, compare and analyse chemical information. Students will explore common cheminformatics approaches such as similarity analysis, basic classification techniques and data visualisation, and will apply these methods using industry-relevant tools. The unit also considers the benefits, limitations and professional responsibilities associated with using automated and data-driven chemical analysis methods.

On successful completion of this unit, students will be able to analyse chemical data using appropriate cheminformatics tools, interpret results in a scientific context, and communicate findings clearly to an identified audience. These skills support progression into a range of scientific and data-focused roles, including Laboratory Data Analyst, Cheminformatics Technician, Research Assistant, Scientific Data Officer and Pharmaceutical Data Analyst, as well as further study in computational chemistry, data science or related disciplines.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core concepts and purpose of cheminformatics in relation to chemical data

LO2 Describe computational methods and algorithms used by cheminformatics tools to analyse chemical data

LO3 Apply appropriate cheminformatics tools and databases to generate cheminformatic data for an identified scenario

LO4 Present the results of the cheminformatic study to an identified audience.

Essential Content

LO1 **Explain the core concepts and purpose of cheminformatics in relation to chemical data**

Core concepts and scope of cheminformatics:

Cheminformatics domain: cheminformatics e.g. chemical informatics, computational chemistry; interdisciplinary field e.g. chemistry and data science, chemistry and computing

Digital representation: chemical structures e.g. molecular structures, chemical entities; digital formats e.g. machine-readable representations, encoded structures; structural encoding, string or line representations e.g. SMILES and InChI

Computational purpose: chemical data handling e.g. data processing, digital analysis; information extraction e.g. descriptor calculation, feature generation; insight generation e.g. structure–property relationships, chemical trends.

Chemical data types, sources and quality:

Chemical data types: structural data e.g. molecular structures, connectivity data; physicochemical property data e.g. log*P*, molecular weight; experimental data e.g. assay results, measured values

Data sources: public repositories e.g. PubChem, ChEMBL; organisational datasets e.g. internal compound libraries, proprietary collections

Metadata and identifiers: chemical identifiers e.g. SMILES, InChI; metadata e.g. assay conditions, measurement context

Data quality issues: missing values e.g. incomplete records, absent properties; inconsistency e.g. unit variation, format differences; duplication e.g. repeated compounds, multiple identifiers.

Applications and decision making in science and industry:

Applied cheminformatics uses: chemical searching e.g. structure search, substructure search; similarity analysis e.g. fingerprint comparison, similarity scoring; compound prioritisation e.g. hit triage, candidate ranking

Analytical support: property estimation e.g. predicted log*P*, calculated descriptors; pattern analysis e.g. clustering, trend identification

Decision-support approaches: predictive methods e.g. model outputs, data-driven predictions; prioritisation strategies e.g. candidate selection, ranking approaches

Context of use: research applications e.g. discovery analysis, exploratory studies; industrial applications e.g. pharmaceuticals, materials science.

Benefits, limitations and professional considerations:

Benefits of cheminformatics: efficiency e.g. rapid analysis, scalable data handling; insight generation e.g. pattern recognition, informed decisions

Limitations and constraints: representation limitations e.g. fingerprint choice, descriptor dependence; model assumptions e.g. simplified chemistry, training data limits

Professional considerations: transparency e.g. explainable methods, clear assumptions; traceability e.g. reproducible workflows, documented decisions; responsible use e.g. cautious interpretation, appropriate reliance on automated outputs.

LO2 **Describe computational methods and algorithms used by cheminformatics tools to analyse chemical data**

Molecular representation and feature generation:

Structural representations: molecular graphs e.g. atom-bond graphs, connectivity models; string representations e.g. SMILES, InChI, XYZ; coordinate representations e.g. 2D layouts, 3D conformations

Feature generation: molecular descriptors e.g. molecular weight, log*P*; topological descriptors e.g. atom counts, ring counts; physicochemical descriptors e.g. polarity, hydrophobicity; encoded fingerprints e.g. substructure fingerprints, hashed fingerprints.

Similarity, substructure and database searching:

Similarity methods: chemical similarity e.g. feature-based similarity, fingerprint similarity; similarity metrics e.g. Tanimoto coefficient, similarity scores; result ranking e.g. ranked compound lists, similarity ordering

Substructure searching: pattern matching e.g. SMARTS queries, subgraph matching; functional-group identification e.g. amide groups, aromatic rings; hit detection e.g. matching structures, identified substructures

Database searching: compound databases e.g. structure databases, chemical repositories; query execution e.g. structure queries, similarity searches; retrieval outputs e.g. hit lists, matched records.

Classification, clustering and exploratory pattern analysis:

Clustering methods: compound clustering e.g. chemical series grouping, dataset structuring; distance measures e.g. fingerprint distance, descriptor distance; unsupervised analysis e.g. pattern discovery, natural groupings

Classification approaches: rule-based classification e.g. threshold rules, cut-off criteria; model-based classification e.g. statistical models, machine-learning classifiers; category assignment e.g. property classes, risk categories

Exploratory analysis: chemical space exploration e.g. diversity analysis, coverage assessment; pattern recognition e.g. recurring features, structural trends.

Visualisation, interpretation and method limitations:

Visualisation techniques: chemical plots e.g. scatter plots, projection plots; charts e.g. comparison charts, distribution plots; molecular visuals e.g. structure diagrams, highlighted substructures

Interpretation of outputs: trend identification e.g. correlations, property trends; outlier detection e.g. anomalous compounds, unusual values; uncertainty awareness e.g. confidence variation, ambiguous outputs

Method limitations: representation dependence e.g. fingerprint choice, descriptor selection; parameter sensitivity e.g. cut-off values, algorithm settings; automated output limitations e.g. apparent confidence, artefactual patterns.

LO3 **Apply appropriate cheminformatics tools and databases to generate cheminformatic data for an identified scenario**

Tool selection and workflow planning (fitness for purpose):

Tool selection: cheminformatics tools e.g. RDKit-based tools, web-based analysis tools; tool purpose e.g. similarity analysis, property calculation; dataset suitability e.g. dataset size, data complexity

Workflow planning: analysis workflows e.g. ordered analysis steps, computational pipelines; workflow design e.g. structured processes, repeatable sequences; automation use e.g. batch processing, scripted execution

Context-driven decisions: tool trade-offs e.g. local tools versus online services, speed versus flexibility; output requirements e.g. numerical outputs, visual summaries; scenario alignment e.g. analytical goals, decision context.

Data preparation and quality assurance:

Data preparation: data import e.g. loading structure files, reading datasets; data structuring e.g. tabular organisation, consistent schemas; data cleaning e.g. duplicate removal, error resolution

Standardisation processes: structure standardisation e.g. canonical SMILES, normalised representations; identifier consistency e.g. InChI, database IDs

Quality checks and traceability: data integrity checks e.g. completeness, validity; recorded assumptions e.g. inclusion rules, exclusion criteria; documentation e.g. preparation logs, workflow notes.

Application of analyses and generation of outputs:

Analytical methods: similarity analysis e.g. fingerprint similarity, Tanimoto scoring; substructure analysis e.g. SMARTS queries, functional-group matching; property calculation e.g. log*P* estimation, descriptor generation

Exploratory analysis: clustering e.g. chemical series identification, diversity analysis; classification e.g. rule-based categories, model-based labels; chemical space analysis e.g. projection plots, distribution assessment

Output generation: analytical outputs e.g. ranked compound lists, calculated property tables; visual outputs e.g. scatter plots, similarity maps; decision artefacts e.g. shortlisted compounds, prioritisation tables.

Interpretation, insight generation and reflection on limitations:

Interpretation of results: trend identification e.g. structure–property trends, clustering patterns; anomaly detection e.g. outliers, unexpected values; insight generation e.g. meaningful observations, scenario-relevant findings

Reflection on limitations: tool constraints e.g. fingerprint dependence, parameter sensitivity; data limitations e.g. incomplete metadata, biased datasets; model limitations e.g. prediction uncertainty, applicability domain

Evaluation and next steps: improvement actions e.g. alternative tools, additional analyses; data enhancement e.g. additional properties, enriched metadata; critical review of automated outputs e.g. AI-generated results, confidence assessment.

AI in cheminformatic analysis:

Predictive application: chemical classification e.g. grouping compounds, dataset categorisation; property prediction e.g. estimated physicochemical properties, risk indicators; pattern recognition e.g. recurring features, data trends

Model evaluation: model accuracy e.g. output reliability, comparison with known data; model bias e.g. data coverage limitations, representative chemical space; prediction confidence e.g. confidence scoring, appropriate use of predictions.

Real-world examples:

Structure representation and conversion tools: structure encoding e.g. RDKit, Open Babel; file format conversion e.g. Open Babel, Pybel; structure standardisation e.g. MolVS, Indigo

Similarity and searching tools: fingerprint similarity analysis e.g. DataWarrior, CDK; substructure searching e.g. CDK, ChemMine Tools; similarity-based ranking e.g. DataWarrior, ChemMine Tools

Descriptor calculation and property tools: physicochemical descriptor calculation e.g. PaDEL-Descriptor, ALOGPS; molecular fingerprint generation e.g. PaDEL-Descriptor, Open Babel; property estimation e.g. SwissADME, ALOGPS

Workflow, analysis and visualisation platforms: automated workflow execution e.g. KNIME Analytics Platform, Galaxy; exploratory data analysis e.g. KNIME Analytics Platform, Orange Data Mining; chemical space visualisation e.g. DataWarrior, Orange Data Mining.

LO4 **Present the results of the cheminformatic study to an identified audience**

Selection and prioritisation of findings:

Statistical metrics: statistical measures e.g. numerical summaries, quantitative indicators; cheminformatics results e.g. analysis outputs, calculated descriptors; chemical data types e.g. molecular structures, property data, similarity scores; data quality e.g. reliable data, valid chemical representations; error sources e.g. pre-processing errors, parameter selection errors

Result selection: relevant outputs e.g. decision-relevant results, meaningful findings; analytical focus e.g. scenario objectives, stated aims; significance e.g. key trends, important comparisons

Accuracy and clarity: statistical accuracy e.g. correct calculations, valid summaries; computational accuracy e.g. correct descriptor calculation, reliable similarity results; communication clarity e.g. clear visuals, interpretable presentation; labelled outputs e.g. labelled axes, titled tables

Decision context: prioritised evidence e.g. ranked compounds, shortlisted candidates; comparative results e.g. similarity rankings, property comparisons; confidence indicators e.g. score thresholds, uncertainty awareness.

Structure and professional communication of analysis:

Analysis structure: scenario context e.g. problem definition, analytical goal; methods overview e.g. tools used, workflows applied; results section e.g. outputs generated, key findings; interpretation e.g. chemical meaning, implications; limitations e.g. data quality, method constraints; recommendations e.g. next steps, further analysis

Scientific communication: appropriate terminology e.g. cheminformatics terms, chemical language; clarity e.g. logical progression, structured narrative; transparency e.g. data sources, analytical assumptions.

Use of formats and visual representations:

Communication formats: written reports e.g. analytical summaries, evaluation reports; presentations e.g. slide decks, briefings; decision documents e.g. ranked lists, selection rationales

Visual representations: tables e.g. log*P* tables, molecular-weight tables, similarity rankings; plots e.g. log*P* vs molecular-weight scatter plots, distribution plots; molecular visuals e.g. 2D structures, highlighted substructures; annotation e.g. axis labels, legends.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core concepts and purpose of cheminformatics in relation to chemical data</td><td rowspan="5">LO1 and LO2

D1 Evaluate, using a selection of real-world examples, the significance of cheminformatics concepts, computational methods and algorithms in advancing modern chemical research across identified scientific and industrial contexts.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the core concepts of cheminformatics and their benefits, limitations and professional applications.

P2 Describe, using a selection of real-world examples, the application and purpose of chemical data types for decision making in scientific and industrial contexts.</td><td>M1 Analyse, using a selection of real-world examples, the effectiveness of cheminformatics concepts in supporting modern chemical research in science and industry.</td></tr>
<tr><td colspan="2">LO2 Describe computational methods and algorithms used by cheminformatics tools to analyse chemical data</td></tr>
<tr><td>P3 Describe, using a selection of real-world examples, the computational methods used for molecular representation in cheminformatics.

P4 Discuss, using a selection of real-world examples, how cheminformatics algorithms support the analysis and visualisation of chemical data.</td><td>M2 Assess, using a selection of real-world examples, the benefits and limitations of computational methods and algorithms for the analysis and visualisation of chemical data.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Apply appropriate cheminformatics tools and databases to generate cheminformatic data for an identified scenario		**LO3 and LO4** **D2** Justify the decisions made in the selection of cheminformatic tools and analysis methods used to generate effective conclusions for the identified cheminformatic scenario.
P5 Implement appropriate cheminformatics tools and databases to generate cheminformatic data for an identified scenario. **P6** Review the quality of data generated with internal stakeholders to identify strengths and limitations.	**M3** Evaluate the strengths and limitations of the selection and configuration of the chosen cheminformatic tools and databases, including why certain options were rejected.	
LO4 Present the results of the cheminformatic study to an identified audience		
P7 Interpret the generated cheminformatics data using appropriate methods to obtain meaningful insights for an identified scenario. **P8** Present the findings of the cheminformatic study to an identified external audience and obtain feedback on the results.	**M4** Analyse, using the findings of the cheminformatic study, the internal stakeholder and external audience feedback, the effectiveness of the results for an identified cheminformatic scenario.	

Recommended Resources

Textbooks

Akitsu, T. (ed.) (2021) *Computational and Data-Driven Chemistry Using Artificial Intelligence: Fundamentals, Methods and Applications*. Amsterdam: Elsevier.

Basak, S.C. and Vračko, M. (eds.) (2022) *Big Data Analytics in Chemoinformatics and Bioinformatics*. Amsterdam: Elsevier.

Engel, T. and Gasteiger, J. (2018) *Chemoinformatics: Basic Concepts and Methods*. Weinheim: Wiley-VCH.

Ntie-Kang, F. (ed.) (2022) *Chemoinformatics of Natural Products: Advanced Concepts and Applications*. Berlin: De Gruyter.

Pathak, Y.V., Saikia, S., Pathak, S. and Patel, J. (eds.) (2024) *Artificial Intelligence in Bioinformatics and Chemoinformatics*. Boca Raton, FL: CRC Press.

Roy, K. (ed.) (2023) *Cheminformatics, QSAR and Machine Learning Applications for Novel Drug Development*. London: Academic Press.

Stefaniu, A., Rasul, A. and Hussain, G. (eds.) (2020) *Cheminformatics and its Applications*. London: IntechOpen.

Zhang, Z., Lu, H. and Wen, M. (2026) *Cheminformatics with Python*. Amsterdam: Elsevier.

Websites

https://learning.rc.virginia.edu/notes/dl-drug-discovery/cheminformatics/	RC Learning Portal Cheminformatics. (General reference)
https://chem.libretexts.org/Courses/Intercollegiate_Courses/Cheminformatics/01%3A_Introduction	Chemistry LibreTexts Introduction to cheminformatics. (General reference)
https://www.nature.com/subjects/cheminformatics	Nature Portfolio Cheminformatics. (Resource Hub)
https://molecularsciences.org/content/understanding-the-relationship-between-smiles-and-inchi-a-practical-guide/	Molecular Sciences Understanding the Relationship Between SMILES and InChI: A Practical Guide (Article)
https://chem.libretexts.org/Courses/University_of_Arkansas_Little_Rock/ChemInfo	Chemistry LibreTexts

rmatics_%282017%29%3A_Chem_4399_5399/2.3%3A_Chemical_Representations_on_Computer%3A_Part_III	Chemical Representations on Computer. (General reference)
https://chem.libretexts.org/Courses/Intercollegiate_Courses/Cheminformatics/03%3A_Database_Resources_in_Cheminformatics/3.03%3A_Public_Chemical_Databases	Chemistry LibreTexts Public Chemical Databases (General reference)
https://greglandrum.github.io/rdkit-blog/posts/2022-12-23-descriptor-tutorial.html	RDKit Blog Descriptor Calculation (Tutorial)
https://colab.research.google.com/github/MolSSI-Education/iqb-2025/blob/main/01_Cheminfo_crash_course.ipynb	MolSSI Digital Representation of Molecules (Tutorial)
https://www.rdkit.org/docs/RDKit_Book.html	RDKit RDKit Online Reference Book. (General reference)

Journals and articles

Esaki, T. and Ikeda, K. (2026) 'Data curation in cheminformatics: importance and implementation', *Journal of Cheminformatics*, 18(43). Available at: https://doi.org/10.1186/s13321-026-01174-w.

Martínez-Mayorga, K. and Medina-Franco, J.L. (2025) 'Milestones in cheminformatics', *Journal of Cheminformatics*, 17(104). Available at: https://doi.org/10.1186/s13321-025-01054-9.

Nittinger, E., *et al.* (2023) 'Biomedical data analyses facilitated by open cheminformatics workflows', *Journal of Cheminformatics*, 15(46). Available at: https://doi.org/10.1186/s13321-023-00718-8.

Rifaioglu, A.S., *et al*. (2019) 'Recent applications of deep learning and machine intelligence on *in silico* drug discovery: methods, tools and databases', *Briefings in Bioinformatics*, 20(5), pp. 1878–1912. Available at: https://doi.org/10.1093/bib/bby061.

Willett, P. (2020) 'The Literature of Chemoinformatics: 1978–2018', *International Journal of Molecular Sciences*, 21(15). Available at: https://doi.org/10.3390/ijms21155576.

Links

This unit links to the following related units:

Unit 407: Fundamentals of Biochemistry

Unit 411: Inorganic Chemistry

Unit 412: Organic Chemistry

Unit 413: Physical Chemistry

Unit 423: Analytical Chemistry

Unit 424: Artificial Intelligence in Applied Science

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 526: Further Analytical Chemistry.

Unit 421: Volume Crime Scene Science

Unit code: **R/652/3053**

Unit level: **4**

Credit value: **15**

Introduction

Volume crime scenes make up the majority of incidents attended by crime scene investigators and require rapid, proportionate and defensible decisions to protect evidential value. These scenes can occur in a range of settings, including domestic and commercial premises, outdoor environments and vehicles, and they typically generate evidence that must be located and recovered efficiently while maintaining integrity and continuity.

This unit introduces the characteristics and significance of volume crime scenes and examines routine approaches used to search for and recover the common evidence types. Students will explore how digital tools support scene tasking, contemporaneous note-taking, exhibit tracking, chain of custody and image handling, and how sustainable working practices can be applied in high-throughput operational contexts without compromising forensic requirements.

Through a simulated volume crime scene, students will apply routine search and recovery techniques and consider how evidence location, recovery sequencing and scene photography contribute to later interpretation. Students will also produce crime-scene documentation and appropriate forensic reports suitable for an identified audience, reflecting the way volume crime scene work is communicated in current professional practice.

On completion, students will have developed the applied skills needed to contribute to routine scene examinations, including search planning, recovery decision making, photography, and the production of clear, auditable documentation and reporting outputs. The unit supports progression into further forensic study and operational roles by strengthening scientific professional practice, including effective communication, digital competence and an awareness of sustainability considerations in forensic service delivery.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the characteristics and significance of volume crime scenes

LO2 Explore routine search and recovery approaches used at volume crime scenes

LO3 Implement a virtual volume crime scene investigation for an identified scenario

LO4 Produce crime-scene documentation and streamlined forensic reports from the simulated volume crime scene to communicate findings to an identified audience.

Essential Content

LO1 **Explain the characteristics and significance of volume crime scenes**

Volume crime scene definition and classification:

Definition and distinction: volume crime scenes and distinction from major/serious crime scenes; categories e.g. burglary, theft of/from motor vehicles, criminal damage; classes and contexts e.g. indoor, outdoor, conveyance, public/private spaces; digital support e.g. digital crime recording systems for consistent categorisation and rapid triage across high-throughput caseloads.

Volume crime scene characteristics and constraints:

Casework and proportionality: high-frequency casework and throughput; proportionality in scene attendance and examination

Constraints: factors affecting evidential opportunities e.g. time/resource pressures, scene access; environmental exposure e.g. weather, heat, moisture; transient/fragile evidence e.g. scene disturbance by victims, witnesses or first responders

Sustainable working: minimisation of travel; proportionate use of consumables and PPE in line with policy; waste segregation where available.

Evidential opportunities in volume crime:

Evidence locations: common points of contact and likely evidence locations e.g. entry and exit routes, handling surfaces, tool marks, paths of movement

Evidence types: fingerprints/finger marks, footwear marks, tool marks; trace evidence e.g. hairs, fibres, glass, paint, biological material suitable for swabbing where relevant

Contamination awareness: scene-based contamination and cross-transfer risk awareness e.g. PPE use and controlled movement through the scene

Digital consistency: digital checklists e.g. for consistent sequencing and reduced avoidable rework.

Significance for forensic practice and investigative outcomes:

Forensic and investigative support: outcomes e.g. suspect identification, intelligence development, elimination and narrowing of lines of enquiry, linkage or series potential

Evidential value and decision making: relationship between evidential value, investigative opportunities and limitations, and operational decision making in volume crime scenes

Digital case management: digital case management and information-sharing systems e.g. for timely decision making, reduced duplication of effort and associated resource impacts.

LO2 **Explore routine search and recovery approaches used at volume crime scenes**

Search planning and proportionality:

Purpose and objectives: search in volume crime; proportional decision making and prioritisation

Planning: factors affecting planning e.g. scene type, time since incident, access limitations, weather, likely offender routes

Digital tasking: digital tasking systems and standard operating procedures for consistent scene strategies across high caseloads.

Routine search approaches:

Search approaches: systematic search approaches used in volume crime scenes e.g. zone/sector, strip/line, grid, spiral

Selection approaches: indoor, outdoor and conveyance contexts and anticipated evidence distribution; high-yield areas e.g. points of entry and exit, target areas, likely handling surfaces; use of digital tools e.g. tablet-based scene plans, time-stamped search logs, geotagging where authorised.

Routine recovery approaches:

Recovery principles: preservation of evidential value e.g. minimisation of loss, avoidance of contamination and cross-transfer

Sequencing: staged recovery e.g. preservation of fragile marks first, management of movement through the scene, controlled contact with evidence-bearing surfaces

Sustainable practice: appropriate, not excessive, packaging and consumables in line with organisational policy and evidential requirements.

Evidence types and recovery considerations:

Evidence-specific recovery: common volume crime evidence types e.g. fingerprints/finger marks (surface selection and likely touch areas), footwear marks (surface and visibility considerations), tool marks (attack point selection), trace evidence e.g. taping, swabbing, hand picking, biological material suitable for swabbing where relevant

Limitations: limiting factors e.g. substrate, weathering, age of marks, risk of scene disturbance

Digital traceability: digital exhibit tracking e.g. barcoding, photo records, traceability, reduced transcription errors.

LO3 **Implement a virtual volume crime scene investigation for an identified scenario**

Simulated scene set-up and initial actions:

Initial assessment and strategy: simulated volume crime scenario; dynamic risk assessment and safe working practices e.g. selection of personal protective equipment (PPE)

Scene preservation: approach that preserves evidential value e.g. controlled entry and exit points, minimised movement

Sustainable practice: careful management of consumables e.g. appropriate decontamination processes, responsible waste disposal.

Application of routine search techniques:

Selection and application: systematic search approach appropriate to the simulated scene; evidential opportunities e.g. high-yield areas and items for recovery

Scene integrity: e.g. avoidance of unnecessary disturbance, prevention of cross-transfer

Digital records: digital notetaking for accurate reconstruction of actions taken e.g. templates, time-stamped logs.

Application of routine recovery techniques:

Application of recovery techniques: routine recovery techniques appropriate to evidence type and substrate within the simulated scene e.g. fingerprints/finger marks, footwear marks, tool marks, trace recovery methods e.g. taping, swabbing, hand picking

Sequencing: selection of proportionate recovery activities e.g. to minimise loss, degradation and contamination; choice of suitable packaging and consumables e.g. to reduce waste while maintaining integrity and traceability.

Forensic photography:

Purpose and role: crime scene photography as part of routine examination; capture sequence e.g. overall, mid-range, close-up

Image quality: scales and reference markers e.g. focus, lighting, exposure

Image management: digital image management e.g. secure transfer, file naming conventions; capture of relevant metadata; maintaining an audit trail; sustainable practice e.g. digital-first workflows to reduce printing and duplication, while meeting evidential requirements.

LO4 **Produce crime-scene documentation and streamlined forensic reports from the simulated volume crime scene to communicate findings to an identified audience**

Crime-scene documentation (from the simulated volume crime scene):

Documentation types and purposes: documentation generated from the simulated scene e.g. contemporaneous notes, scene logs, access records, search records, exhibit lists, photo log, scene sketches

Content: required content e.g. what was examined, what was recovered, where items were found; relevant limitations; digital documentation e.g. electronic scene notes, structured templates, legible, time-stamped records.

Continuity and traceability information (scene-to-submission):

Labelling and identifiers: labelling conventions and exhibit identifiers; continuity information e.g. date and time, location, collector details, item descriptions, transfer record principles

Tracking: digital tracking e.g. barcode and QR systems; reduced transcription errors and paper handling; objectives e.g. data quality and sustainability.

Forensic reporting outputs:

Purpose: streamlined forensic reports and proportionate communication of findings and limitations; outputs and forms e.g. DNA reports, MG forms, GF111, Streamlined Forensic Reporting (SFR) stages, equivalent reporting formats used in different national and regional legal and procedural contexts, as applicable

Digital production and control: digital production and version control of reporting outputs e.g. secure storage, audit trails, controlled sharing in line with organisational procedures.

Communication to an identified audience and fitness for purpose:

Audience identification: intended audiences e.g. investigating officer, supervisor, case manager or other relevant stakeholder; detail tailored appropriately

Quality and inclusivity: quality e.g. clear, accurate, inclusive, unbiased, complete, fit for purpose

Communication: communication of findings e.g. what was done, what was found; limitations and constraints affecting interpretation e.g. in line with streamlined reporting expectations; digital communication e.g. secure and efficient sharing of outputs, reduced delay and unnecessary printing.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the characteristics and significance of volume crime scenes</td><td rowspan="5">LO1 and LO2

D1 Evaluate the significance of volume crime scene work in supporting forensic and investigative outcomes through decisions made about routine search and recovery.</td></tr>
<tr><td>P1 Describe key characteristics of volume crime scenes.

P2 Explain the significance of volume crime scenes for forensic practice.</td><td>M1 Analyse how volume crime scene characteristics affect evidential opportunities and limitations.</td></tr>
<tr><td colspan="2">LO2 Explore routine search and recovery approaches used at volume crime scenes</td></tr>
<tr><td>P3 Describe routine search approaches used at volume crime scenes.

P4 Explain routine recovery approaches used at volume crime scenes.</td><td>M2 Justify the selection of routine search and recovery approaches used to preserve evidential value and reduce contamination risk at volume crime scenes.</td></tr>
<tr><td colspan="2">LO3 Implement a virtual volume crime scene investigation for an identified scenario</td></tr>
<tr><td>P5 Implement a virtual volume crime scene investigation for an identified scenario.

P6 Review the implementation of the virtual crime scene investigation with identified stakeholders to identify strengths and areas to improve.</td><td>M3 Optimise, using the results of stakeholder feedback, the implementation of the virtual crime scene investigation for an identified scenario.</td><td>LO3 and LO4

D2 Justify the decisions made in the implementation and documentation of the virtual volume crime scene investigation.</td></tr>
<tr><td colspan="2">LO4 Produce crime-scene documentation and streamlined forensic reports from the simulated volume crime scene to communicate findings to an identified audience</td></tr>
<tr><td>P7 Produce crime-scene documentation from a simulated volume crime scene.

P8 Communicate the forensic documentation to an identified audience to obtain feedback.</td><td>M4 Review the clarity, completeness and fitness for purpose of crime-scene documentation for an identified audience.</td></tr>
</table>

Recommended Resources

Textbooks

Bell, S. (2025) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 6th edn. Boca Raton: CRC Press.

Hammer, L. (2019) *Footwear and Tire Track Evidence Collection Manual*. 2nd edn. Boca Raton: CRC Press.

Harris, H.A. and Lee, H.C. (2019) *Introduction to Forensic Science and Criminalistics*. 2nd edn. Boca Raton: CRC Press.

Houck, M.M. and Siegel, J.A. (2015) *Fundamentals of Forensic Science*. 3rd edn. London: Academic Press.

James, S.H., Nordby, J.J. and Bell, S. (2019) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 5th edn. Boca Raton: CRC Press.

Langford, A. (2019) *Practical Skills in Forensic Science*. 3rd edn. Harlow: Pearson.

McCartney, C. (2012) *Forensic Evidence and Criminal Justice*. London: Routledge.

Mozayani, A. and Noziglia, C. (2010) *The Forensic Laboratory Handbook: Procedures and Practice*. 2nd edn. Totowa, NJ: Humana Press.

Mozayani, A. and Parish-Fisher, C. (eds.) (2017) *Forensic Evidence Management: From the Crime Scene to the Courtroom*. Boca Raton: CRC Press.

NicDaeid, N. and White, P.C. (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Pfefferli, P. (2015) *Forensic Evidence Field Guide: A Collection of Best Practices*. Amsterdam: Academic Press.

Robertson, J., Roux, C. and Wiggins, K.G. (2017) *Forensic Examination of Fibres*. 3rd edn. Boca Raton: CRC Press.

Sutton, R., Trueman, K. and Moran, C. (eds.) (2018) *Crime Scene Management: Scene-Specific Methods*. 2nd edn. Chichester: Wiley.

Websites

https://www.ascld.org	American Society of Crime Laboratory Directors Training, education, research and innovation (Professional guidance)

https://www.cps.gov.uk/prosecution-guidance/expert-evidence	CPS Forensic Streamlined Forensic Report (Guidance)
https://www.enfsi.eu	European Network of Forensic Science Institutes Documents and Forensic Glossary (Professional guidance)
https://www.fcn.police.uk/what-we-do/sfr	Forensic Capability Network Streamlined Forensic Reporting (Guidance)
https://www.nist.gov/forensics	National Institute of Standards and Technology Forensic science quality, standards and accreditation research (Research)

Journals and articles

Brown, C., Julian, R. and Howes, L.M. (2024) 'Strands in a cable': effective investigator decision-making using forensic identification evidence in volume crime investigations', *Policing and Society*, 34(5), pp. 417–433. Available at: https://doi.org/10.1080/10439463.2023.2279063.

Goehart, Y.R., *et al*. (2025) 'Determination of relevant sampling locations for burglary investigations', *Forensic Science International*, 377, p. 112615. Available at: https://doi.org/10.1016/j.forsciint.2025.112615.

Tièche, C.C., Dubach, M. and Zieger, M. (2022) 'Efficient DNA Sampling in Burglary Investigations', *Genes*, 13(1), article 26. Available at: https://doi.org/10.3390/genes13010026.

Wüllenweber, S. and Giles, S. (2021) 'The effectiveness of forensic evidence in the investigation of volume crime scenes', *Science and Justice*, 61(5), pp. 542–554. Available at: https://doi.org/10.1016/j.scijus.2021.06.008.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 409: Fundamentals of Forensic Science

Unit 410: Criminal Investigation

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 510: Forensic Evidence Evaluation and Reporting

Unit 511: Applied Forensic Science

Unit 528: Manage Forensic Investigations at Scenes.

Unit 422: Forensic Anthropology and Pathology

Unit code: T/652/3054

Unit level: 4

Credit value: 15

Introduction

Forensic anthropology and forensic pathology are core disciplines within medico–legal death investigation, supporting the recovery, examination and interpretation of human remains and post-mortem findings in criminal, civil and humanitarian contexts. The work sits at the intersection of science, law and public service, requiring careful observation, defensible reasoning and clear communication to stakeholders such as investigators, coronial services, courts and affected communities.

This unit introduces the foundational concepts that underpin forensic anthropology and forensic pathology, including skeletal biology and biological profiling, taphonomic processes and post-mortem change, trauma and injury pattern concepts, and the principles of post-mortem examination. Students will develop an informed understanding of how observations are framed, recorded and interpreted within these disciplines, and how limitations and uncertainty are recognised and communicated.

Students will also explore the processes used in human identification, including comparative approaches such as dental methods, the role of DNA sampling within identification workflows, and the use of facial comparison and reconstruction techniques as supportive tools. Throughout, emphasis is placed on evidential integrity, documentation and secure handling of sensitive information, and on selecting and triangulating approaches that are appropriate to the investigative context.

The unit develops professional awareness of the ethical, legal and procedural frameworks that govern forensic work, including impartiality, dignity, chain of custody, consent, confidentiality and culturally competent practice. By completing the unit, students will be better prepared to interpret and present forensic information to an intended audience using appropriate terminology and structure, and to progress to more specialist study and practice-based units that develop laboratory and analytical capability.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core principles of forensic anthropology

LO2 Describe the basic concepts in forensic pathology

LO3 Review the forensic processes involved in human identification

LO4 Present a review of the ethical, legal and professional frameworks in forensic anthropology and pathology to an intended audience.

Essential Content

LO1 **Explain the core principles of forensic anthropology**

Scope, purpose and role within forensic investigation:

Purpose; interface with crime scene and post-mortem processes e.g. recovery of human remains, triage of commingled remains, mass graves

Scope: advice on what skeletal elements may be present and what they can indicate; contribution to medico–legal investigations; multidisciplinary working with pathology and other forensic specialisms; secure handling of case photographs and notes.

Human osteology and skeletal biology:

Human skeletal anatomy: terminology e.g. axial skeleton, appendicular skeleton; skeletal variation, growth and development principles e.g. adult skeletal change

Trauma versus post-mortem damage: e.g. perimortem fracture characteristics versus dry bone breakage, skeletal landmarks used for identification; careful language when describing human variation; limits of inference.

Biological profiling and limitations:

Biological profiling: biological profile components and purpose e.g. estimation principles and uncertainty, age, sex, stature, ancestry/population affinity, population variation; reference data considerations; reporting language

Limitations: confidence and uncertainty statements e.g. 'consistent with' wording; limitations where reference data are incomplete or unrepresentative e.g. population-based estimation categories, variation across global populations.

Taphonomy, post-mortem change and interpretation factors:

Taphonomy, post-mortem change and interpretation factors: taphonomic processes and timing e.g. decomposition stages

Environmental and contextual factors affecting remains: e.g. animal scavenging, disturbance, weathering, effects of fire and heat on bone; burial effects e.g. surface exposure versus burial

Uncertainty communication: evidence quality and completeness e.g. fragmentation, commingling; bias and cognitive contamination risks; proportionate sampling and packaging choices consistent with evidential requirements.

LO2 **Describe the basic concepts in forensic pathology**

Scope and role of forensic pathology:

Purpose and scope: overview of post-mortem examination pathway; medico–legal death investigation e.g. Home Office post-mortem versus standard post-mortem, jurisdiction-specific post-mortem investigation pathways

Role: relationship to forensic anthropology and other forensic disciplines; secure digital documentation; controlled access to sensitive records and images.

Trauma and injury interpretation:

Trauma: trauma classification principles; injury pattern concepts e.g. blunt force, sharp force, firearm-related, asphyxial, patterned; artefacts, confounders

Injury interpretation: differentiation of injury from post-mortem artefacts e.g. defence-type injuries, patterned bruising; impartial and non-judgemental reporting language.

Post-mortem changes and post-mortem interval estimation:

Post-mortem changes: early and later post-mortem changes e.g. algor mortis, livor mortis, rigor mortis; decomposition processes e.g. environmental effects on post-mortem change, entomological effects

Post-mortem interval (PMI) estimation: limitations and uncertainty in PMI estimation e.g. why PMI is typically a range, effects of different environments on expected post-mortem patterns.

Autopsy principles, cause/manner of death, integration and limitations:

Autopsy principles: e.g. aims and structure of a medico–legal autopsy; external and internal examination principles; sampling rationale; documentation and reporting

Cause and manner of death: reconstruction of events; definitions and distinctions of cause and manner of death; evidential basis for conclusions; confounding factors, differential explanations; corroboration between findings and contextual information

Integration and limitations: uncertainty communication; reliability and limitations when integrating different evidence sources e.g. examples of cause versus manner of death

Waste disposal: appropriate waste streams for personal protective equipment (PPE) and clinical waste.

LO3 **Review the forensic processes involved in human identification**

Identification process overview:

Identification aims and thresholds: presumptive versus positive identification concepts e.g. missing persons investigations, disaster victim identification contexts

Comparison principles: e.g. ante-mortem and post-mortem; case information management; multidisciplinary inputs e.g. records from different jurisdictions.

Comparative and dental methods:

Comparative methods: comparative identification logic; ante-mortem data sources, reconciliation concepts; limitations and access to records e.g. record availability and variation between health systems; exclusions versus inclusions; common pitfalls

Dental methods: forensic odontology role e.g. dental charting and radiograph comparison principles, restorative work and unique features; secure handling of digital radiographs and associated metadata.

DNA sampling and integrity:

DNA sampling: sampling purpose in identification workflows e.g. reference samples versus questioned samples; sample selection principles

Sample integrity: packaging and handling considerations e.g. contamination risks and prevention principles, handling controls; documentation, traceability

Limitations and uncertainty: e.g. data protection and secure recording of identifiers.

Facial methods, selection and suitability:

Selection of facial methods: context-driven method selection e.g. facial approximation versus facial reconstruction; craniofacial superimposition, image-based comparison

Suitability: use cases and limitations e.g. ethical considerations, method limitations and uncertainty, triangulation and corroboration across methods

Requirements: quality and integrity requirements for defensible identification; careful communication of uncertainty in identification contexts.

LO4 **Present a review of the ethical, legal and professional frameworks in forensic anthropology and pathology to an intended audience**

Professional standards and accountability:

Professional standards and accountability: professional roles and responsibilities, competence, scope-of-practice boundaries e.g. escalation routes when outside competence

Professional conduct: e.g. in digital communication; quality culture; reflective practice principles.

Ethical frameworks in forensic contexts:

Ethical frameworks in forensic contexts: autonomy, beneficence, non-maleficence, justice, dignity, respectful handling of the deceased

Conflicts of interest: maintenance of impartiality and objectivity; management of bias; culturally competent practice.

Legal/procedural frameworks and evidential integrity:

Legal and procedural frameworks: evidential continuity and disclosure principles in medico–legal death investigation contexts e.g. handling of sensitive personal data; storage and retention principles

Information-sharing constraints: confidentiality, secure transfer, storage of case material

Evidential integrity: record-keeping requirements e.g. chain of custody and evidence integrity, continuity concepts, documentation points, packaging and labelling principles, exhibit handling, audit trail expectations, data integrity concepts.

Culture and communication to an intended audience:

Culture considerations: faith-related considerations around handling remains, e.g. repatriation considerations, stakeholder communication sensitivity; professional tone, structure and signposting

Communication to an intended audience: audience needs analysis e.g. clarity and accessibility principles; evidence-based justification conventions e.g. of printed versus secure digital dissemination.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core principles of forensic anthropology</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate the reliability and limitations of conclusions drawn from forensic anthropology, forensic pathology and human identification processes by integrating evidence and considering uncertainty and corroboration.</td></tr>
<tr><td>P1 Explain the core principles and purpose of forensic anthropology.

P2 Outline how forensic anthropology contributes to forensic investigation and decision making.</td><td>M1 Analyse factors that influence the interpretation of evidence within forensic anthropology.</td></tr>
<tr><td colspan="2">LO2 Describe the basic concepts in forensic pathology</td></tr>
<tr><td>P3 Describe the basic concepts that underpin forensic pathology.

P4 Explain how forensic pathology supports forensic investigation and decision making.</td><td>M2 Assess factors affecting the interpretation and contribution of forensic pathology within forensic investigation and decision making.</td></tr>
<tr><td colspan="2">LO3 Review the forensic processes involved in human identification</td></tr>
<tr><td>P5 Describe the main stages and approaches used in forensic human identification.

P6 Review quality, integrity and documentation requirements in forensic human identification processes.</td><td>M3 Analyse the suitability of human identification approaches for different investigative contexts.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Present a review of the ethical, legal and professional frameworks in forensic anthropology and pathology to an intended audience		**LO4**
P7 Present a review of the legal and procedural frameworks relevant to forensic anthropology and pathology for an intended audience. **P8** Review audience feedback to identify strengths and areas to improve.	**M4** Analyse, using audience feedback, the effectiveness of the presentation in communicating ethical, legal and professional frameworks to an intended audience.	**D2** Evaluate, using audience feedback, the effectiveness of the presentation in communicating ethical, legal and professional frameworks to an intended audience.

Recommended Resources

Textbooks

Biehler-Gomez, L. and Cattaneo, C. (2020) *Interpreting Bone Lesions and Pathology for Forensic Practice*. London: Academic Press.

Byers, S.N. and Juarez, C.A. (2023) *Introduction to Forensic Anthropology*. 6th edn. London: Routledge.

Christensen, A.M., Passalacqua, N.V. and Bartelink, E.J. (2024) *Forensic Anthropology: Current Methods and Practice*. Revised 3rd edn. San Diego: Cognella Academic Publishing.

Damas, S., Cordón, O. and Ibáñez, O. (2020) *Handbook on Craniofacial Superimposition: The MEPROCS Project*. Cham: Springer.

DiMaio, V.J.M. and Molina, D.K. (2024) *DiMaio's Forensic Pathology*. 3rd edn. Boca Raton: CRC Press.

Lo Re, G., *et al*. (eds.) (2020) *Radiology in Forensic Medicine: From Identification to Post-mortem Imaging*. Cham: Springer.

Nafte, M. (2023) *Flesh and Bone: An Introduction to Forensic Anthropology*. 4th edn. Durham: Carolina Academic Press.

NicDaeid, N. and White, P.C. (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Pokines, J.T., L'Abbé, E.N. and Symes, S.A. (eds.) (2021) *Manual of Forensic Taphonomy*. 2nd edn. Boca Raton: CRC Press.

Prahlow, J.A. and Brooks E.G. (2025) *Forensic Pathology: Principles and Pitfalls*. Northfield: College of American Pathologists.

Squires, K., Errickson, D. and Márquez-Grant, N. (eds.) (2020) *Ethical Approaches to Human Remains: A Global Challenge in Bioarchaeology and Forensic Anthropology*. Cham: Springer.

Websites

https://www.aafs.org/	American Academy of Forensic Sciences Forensic science career resources (Professional body)
https://americananthro.org/	American Anthropological Association (Subject association)

https://nij.ojp.gov/topics/forensics/forensic-anthropology	National Institute of Justice Forensic science career resources (Government resource)
https://therai.org.uk/forensic-anthropology/	Royal Anthropological Institute (Subject association)
https://www.rcpath.org/discover-pathology/careers-in-pathology/careers-in-medicine/become-a-forensic-pathologist.html	Royal College of Pathologists Pathology career resources (Professional body)
https://pathologists.org.uk/specialities/forensic-pathology/	The Association of Clinical Pathologists Description of role (Professional body)

Journals and articles

Franklin, D. and Marks, M.K. (2022) 'The professional practice of forensic anthropology: Contemporary developments and cross-disciplinary applications', *WIREs Forensic Science*, 4(2), e1442. Available at: https://doi.org/10.1002/wfs2.1442.

Goots, A., Hefner, J. and Start, D. (2022) 'Confronting Cognitive Bias in Forensic Anthropology: Michigan's Craigslist Killer Case', *Forensic Anthropology*. Available at: https://doi.org/10.5744/fa.2021.0032.

Jordan, D.J. and Mills, D.M. (2021) 'Past, Present, and Future of DNA Typing for Analyzing Human and Non-Human Forensic Samples', *Frontiers in Ecology and Evolution*, 9. Available at: https://doi.org/10.3389/fevo.2021.646130.

Maier, A.K., *et al*. (2023) 'Wet Bone Characteristics Persist in Buried Bone after 10 Weeks: Implications for Forensic Anthropology', *Forensic Sciences*, 3(3), pp. 491–505. Available at: https://doi.org/10.3390/forensicsci3030034.

Maiese, A., *et al*. (2021) 'MicroRNAs as Useful Tools to Estimate Time Since Death. A Systematic Review of Current Literature', *Diagnostics*, 11(1), 64. Available at: https://doi.org/10.3390/diagnostics11010064.

Miles, K.L., Finaughty, D.A. and Gibbon, V.E. (2020) 'A Review of Experimental Design in Forensic Taphonomy: Moving Towards Forensic Realism', *Forensic Sciences Research*, 5(4), pp. 249–259. Available at: https://doi.org/10.1080/20961790.2020.1792631.

Sutton, L. and Byrd, J. (2020) 'An introduction to postmortem interval estimation in medicolegal death investigations', *WIREs Forensic Science*. Available at: https://doi.org/10.1002/wfs2.1373.

Ubelaker, D.H. (2021) 'Research Integrity in Forensic Anthropology', *Forensic Sciences Research*, 6(4), pp. 285–291. Available at: https://doi.org/10.1080/20961790.2021.1963515

Webber, M.L. and Connor, E.E. (2025) 'Time of Death Estimation in Forensic Pathology: A Brief Assessment of Methods and Reliability', *WIREs Forensic Science*. Available at: https://doi.org/10.1002/wfs2.70005.

Zhang, M. (2022) 'Forensic Imaging: A Powerful Tool in Modern Forensic Investigation', *Forensic Sciences Research*, 7(3), pp. 385–392. Available at: https://doi.org/10.1080/20961790.2021.2008705.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 409: Fundamentals of Forensic Science

Unit 410: Criminal Investigation

Unit 421: Volume Crime Scene Science

Unit 501: Personal and Professional Development for Scientists

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 510: Forensic Evidence Evaluation and Reporting

Unit 511: Applied Forensic Science

Unit 523: Principles of Pharmacology

Unit 527: Clinical Chemistry.

Unit 423: Analytical Chemistry

Unit code: **A/652/3056**

Unit level: **4**

Credit value: **15**

Introduction

Analytical chemistry supports a broad range of applied science disciplines by providing the principles and methods needed to produce reliable chemical data. These methods are used in laboratory, industrial, environmental, clinical and forensic settings, where analytical measurements inform decision making, quality control and problem solving. This unit introduces students to the core concepts of analytical chemistry and shows how they are applied in real-world contexts, preparing them for laboratory-based roles or further study in the applied sciences.

The unit highlights the importance of producing analytical results that are reliable, fit for purpose and of consistent quality. Students explore how calibration, error, sample preparation and variability affect measurements, and how these factors can be controlled to achieve meaningful results. The unit also introduces key aspects of professional laboratory practice, including traceability, the appropriate use of digital tools, and consideration of resource efficiency and sustainability in analytical work.

Students develop an understanding of the theoretical basis of qualitative and quantitative analytical methods and how different approaches generate information about chemical systems. The unit also examines the role of sample preparation in shaping analytical outcomes, including its effects on accuracy, precision and reliability. Through the interpretation of analytical data, students learn to evaluate results using appropriate statistical and validation approaches and to communicate findings clearly to different audiences.

On completion of this unit, students will be able to explain key analytical techniques, interpret analytical information confidently, apply analytical principles to defined problems, and present data in a clear and technically appropriate way. The knowledge and skills developed provide a strong foundation for progression to more advanced analytical techniques, specialist applied science units, or employment in laboratory and technical roles where analytical data informs operational and quality-related decisions.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Review the operation of spectrometric techniques

LO2 Implement quantitative analysis using chromatography and titration techniques

LO3 Explore the analytical processes of quantitative, qualitative and characterisation analysis

LO4 Interpret analytical data from laboratory or real-world data, using appropriate statistical and validation approaches for an identified scenario.

Essential Content

LO1 **Review the operation of spectrometric techniques**

Atomic spectroscopy:

Principle and instrumentation: elemental composition; electronic transitions; free atoms; element-specific source e.g. hollow-cathode lamp or plasma; inductively coupled plasma (ICP); wavelength selector e.g. monochromator; detector e.g. photomultiplier or solid-state detector; analytical outputs: discrete atomic lines, qualitative identification, quantitative determination, calibration curves

Practical considerations: e.g. matrix matching, standard addition, matrix effects, background correction, atomiser selection, sensitivity

Applications: trace metal monitoring in water and soils, clinical elemental assays, industrial quality control.

Molecular spectroscopy – principle and instrumentation:

Vibrational spectroscopy (infrared (IR)): bond vibrations; characteristic group frequencies; fingerprint region; substance identification; instrumentation e.g. IR source, sample accessory e.g. attenuated total reflectance (ATR) crystal, KBr pellet; detector; analytical outputs e.g. IR spectra, functional-group information, fingerprint information, qualitative analysis, characterisation work; practical considerations e.g. solvent effects, path-length effects, baseline correction, stray light correction, sample presentation

Electronic spectroscopy (UV–Vis): electronic transitions; chromophores; instrumentation: deuterium source, tungsten source, monochromators, matched cuvettes, photodetectors; analytical outputs e.g. quantitative data, chromophore presence, λ_{max}; quantitation: Beer–Lambert law; practical considerations e.g. linearity, range, calibration

Applications: organic substance identification, assay of active ingredients, reaction monitoring, polymer analysis.

Mass and magnetic resonance methods:

Mass spectrometry (MS): ionisation, mass-to-charge ratio, fragmentation, isotope patterns; outputs e.g. molecular ion (M^+), fragment peaks, isotope peaks, molecular-weight confirmation, structural clues

Nuclear magnetic resonance (NMR): nuclear spin environments e.g. ^{1}H and ^{13}C; magnetic field; outputs e.g. chemical shifts (δ), multiplicities, spin–spin coupling (J), integrations, relative proton counts, connectivity; analytical outputs e.g. molecular mass, fragment-based structural deduction, internal standards, structural connectivity, purity information, relative quantitation; practical considerations e.g. ionisation choice, analyser choice, sample purity, solvent, fragmentation pathways, internal standards, isotopic standards

Applications e.g. molecular identification, mixture deconvolution, pharmaceutical confirmation, proteomics.

X-ray and scattering methods

Principle and instrumentation: X-ray methods; electron density; crystalline order; X-ray fluorescence (XRF) e.g. elemental composition, characteristic X-ray emission; X-ray diffraction (XRD) e.g. crystalline phases, diffraction patterns

Analytical outputs e.g. elemental screens (XRF), phase identification, unit-cell parameters (XRD), quantitative phase analysis, calibration, Rietveld refinement

Practical considerations: e.g. sample homogeneity, particle size effects, standards, reference materials

Applications e.g. materials characterisation, mineralogy, solid-state quality control.

LO2 **Implement quantitative analysis using chromatography and titration techniques**

Chromatographic techniques for quantitative analysis:

Chromatography techniques: e.g. paper chromatography, thin-layer chromatography, column chromatography, gas chromatography (GC), high-performance liquid chromatography (HPLC), ultra-high-performance liquid chromatography (UHPLC)

Principles: e.g. mobile phase, stationary phase, elution, rate of migration, sample injection, column choice, temperature control, detection methods, qualitative analysis, quantitative analysis, internal standards, standard addition

Chromatographic conditions: sample injection; mobile and stationary phases; sorption mechanisms; column choice; injection temperature; oven temperature; temperature gradients (GC); mobile phase choice; isocratic elution; gradient elution (HPLC/UHPLC)

Detection: detection methods; instrumentation; retention time; peak area; internal standards; standard addition

Applications: applications to sample types relevant to centres e.g. food colourings, pharmaceutical mixtures, environmental samples or fermentation products.

Titration techniques for quantitative analysis:

Titration techniques: purpose and principles of titrimetric analysis; techniques e.g. acid–base, redox, complexation, precipitation, potentiometric, gravimetric; equivalence point; indicator choice; procedural consistency e.g. careful observation, instrumental endpoint detection, concordant results

Equipment e.g. standard solutions, pipettes, burettes, volumetric flasks, balances

Applications: analytical contexts e.g. determining acidity in vinegar, chloride content in water, metal–ion concentration in an industrial sample.

Quality and reliability in quantitative implementation:

Quality and reliability: e.g. accuracy, precision, repeatability, validity, replicate measurements; sample preparation; glassware handling; instrument settings e.g. calibration quality; recording practice e.g. anomalous values

Safe and efficient laboratory practice: solvent, reagent and waste considerations e.g. minimising solvent volumes and segregating chemical waste correctly

Quantitative interpretation of chromatographic data: retention time, peak area, calibration, internal standards, standard addition; chromatographic condition selection for sample types relevant to the programme e.g. food products, pharmaceutical preparations, environmental samples or fermentation products

Practical factors affecting reliability: sample preparation, injection technique, instrument settings, contamination control.

LO3 **Explore the analytical processes of quantitative, qualitative and characterisation analysis**

Quantitative, qualitative and characterisation analysis:

Analytical approaches: quantitative determination, qualitative identification, characterisation analysis; purpose of each analytical approach

Analytical outputs: concentration data, presence or absence of analytes, structural information, compositional information; links between analytical question and analytical approach; single technique or combined techniques for analytical problems e.g. identifying an unknown spill, confirming the active ingredient in a tablet, checking metal content in a water sample.

Applications of analytical methods and the analytical process:

Applications of analytical chemistry: contexts e.g. laboratory, industrial, environmental, pharmaceutical, biological, forensic

Stages of the analytical process: problem definition, method choice, sampling, sample pretreatment, analysis, interpretation, reporting; fitness for purpose

Method selection factors: sample type, matrix, concentration range, required information

Analytical workflow: traceability, procedural consistency, resource use e.g. choice of lower-solvent methods where appropriate.

Statistical treatment of analytical data:

Statistical treatment: central tendency, dispersion, mean, range, standard deviation; repeated measurements; variability in analytical results; links between variability and confidence in reported data; units; significant figures

Digital tools: digital tools for data handling and checking e.g. spreadsheet-based calculation of averages and standard deviations.

LO4 **Interpret analytical data from laboratory or real-world data, using appropriate statistical and validation approaches for an identified scenario**

Interpretation of given analytical data:

Interpretation of given analytical data: tables, chromatograms, titration data, calibration data, spectra; trends, patterns, anomalies; comparison with expected values, specifications or reference materials; retention time, peak area, absorbance, endpoint volume, characteristic spectral features

Inference: in context interpretation of analytical data e.g. whether a water sample meets a stated metal limit, whether a pharmaceutical result falls within specification.

Statistical approaches for interpretation:

Statistical approaches: mean, range and standard deviation of data; data quality judgements; repeat measurements; graphical presentation

Conclusions: data interpretation; confidence in conclusions; spread and consistency in quantitative datasets; calibration graphs; unknown concentration estimation; anomalous or inconsistent results

Digital tools: digital tools for statistical interpretation and visualisation e.g. spreadsheets for plotting calibration lines and calculating summary statistics.

Validation approaches and confidence in conclusions:

Validation approaches: accuracy, precision, repeatability, linearity, working range, selectivity, detection limits, method suitability; blanks, standards, controls, calibration checks; data limitations; sources of uncertainty

Reliability judgements:; analytical evidence; justified conclusion for a stated scenario e.g. interpreting quality-control results for a manufactured product, reviewing contamination evidence from an environmental sample, judging whether an unknown sample has been correctly identified and quantified.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Review the operation of spectrometric techniques</td><td rowspan="6">LO1, LO2 and LO3

D1 Evaluate the suitability of analytical approaches and technique selection for an identified analytical problem, considering data requirements, practical constraints and limitations.</td></tr>
<tr><td>P1 Describe the operation of atomic and X-ray spectrometric techniques.

P2 Explain the operation of molecular spectroscopy, mass spectrometry and magnetic resonance methods.</td><td>M1 Assess the suitability of selected spectrometric techniques for analytical purposes, considering strengths and limitations.</td></tr>
<tr><td colspan="2">LO2 Implement quantitative analysis using chromatography and titration techniques</td></tr>
<tr><td>P3 Implement quantitative analysis using chromatography and titration techniques.

P4 Discuss the implications of quality and reliability in quantitative implementation.</td><td>M2 Assess the quality of quantitative results from chromatography and titration in terms of accuracy, precision and repeatability.</td></tr>
<tr><td colspan="2">LO3 Explore the analytical processes of quantitative, qualitative and characterisation analysis</td></tr>
<tr><td>P5 Describe the differences between quantitative, qualitative and characterisation analysis.

P6 Outline the stages of the analytical process for a defined analytical problem.</td><td>M3 Analyse how sample characteristics and analytical questions influence method selection and workflow design.</td></tr>
<tr><td colspan="2">LO4 Interpret analytical data from laboratory or real-world data, using appropriate statistical and validation approaches for an identified scenario</td><td rowspan="2">LO4

D2 Evaluate the interpretation of analytical data for an identified scenario, considering the suitability of statistical and validation approaches and the reliability of conclusions.</td></tr>
<tr><td>P7 Interpret analytical data from laboratory or real-world data, using appropriate statistical and validation approaches for an identified scenario, to obtain meaningful insights.

P8 Explain how statistical and validation concepts support confidence in analytical conclusions.</td><td>M4 Analyse the effectiveness of the interpretation of analytical data for an identified scenario.</td></tr>
</table>

Recommended Resources

Textbooks

Dean, J.R., *et al.* (2017) *Practical Skills in Chemistry*. 3rd edn. Harlow: Pearson.

Ham, B.M. and MaHam, A. (2024) *Analytical Chemistry: A Toolkit for Scientists and Laboratory Technicians*. 2nd edn. Hoboken: Wiley.

Harris, D.C. and Lucy, C.A. (2020) *Quantitative Chemical Analysis*. 10th edn. New York: W.H. Freeman and Company.

Higson, S.P.J. (2004) *Analytical Chemistry*. Oxford: Oxford University Press.

Meier, P.C. and Zünd, R.E. (2000) *Statistical Methods in Analytical Chemistry*. Hoboken: Wiley.

Miller, J.N., Miller, J.C. and Miller, R.D. (2018) *Statistics and Chemometrics for Analytical Chemistry*. 7th edn. Harlow: Pearson Education.

Mitra, S. (2004) *Sample Preparation Techniques in Analytical Chemistry*. Hoboken: Wiley.

Poole, C.F. (2021) *Gas Chromatography*. 2nd edn. Amsterdam: Elsevier.

Skoog, D.A., *et al.* (2022) *Fundamentals of Analytical Chemistry*. 10th edn. Boston: Cengage Learning.

Soffiantini, V.A. (2021) *Analytical Chemistry: Principles and Practice*. Berlin: De Gruyter.

Websites

https://chem.libretexts.org/Bookshelves/Analytical_Chemistry	Chemistry LibreTexts Analytical chemistry open educational resources (General reference)
https://pubs.acs.org/journal/ancham	American Chemical Society Analytical Chemistry journal resources (Research)
https://www.rsc.org/publishing/journals/analyst	Royal Society of Chemistry Analyst journal resources (Research)
https://www.nist.gov/analytical-chemistry	National Institute of Standards and Technology Standard reference materials and measurement guidance (General reference)

https://www.chromacademy.com/	CHROMacademy Chromatography and mass spectrometry training resources (Training)
https://www.mdpi.com/journal/analytica	MDPI Analytica journal resources (Research)
https://www.sigmaaldrich.com/GB/en/technical-documents/technical-article/analytical-chemistry	Merck (Sigma-Aldrich) Analytical chemistry technical articles (General reference)

Journals and articles

Ren, B. (2025) 'Fundamental and Applied Reviews in Analytical Chemistry 2025', *Analytical Chemistry*, 97(24), pp. 12465–12466. Available at: https://doi.org/10.1021/acs.analchem.5c03181.

Meher, A.K. and Zarouri, A. (2025) 'Green Analytical Chemistry—Recent Innovations', *Analytica*, 6(1), p. 10. Available at: https://doi.org/10.3390/analytica6010010.

Mehta, M., Mehta, D. and Mashru, R. (2024) 'Recent application of green analytical chemistry: eco-friendly approaches for pharmaceutical analysis', *Future Journal of Pharmaceutical Sciences*, 10, Article 83. Available at: https://doi.org/10.1186/s43094-024-00658-6.

Nichols, Z.E. and Geddes, C.D. (2021) 'Sample Preparation and Diagnostic Methods for a Variety of Settings: A Comprehensive Review', *Molecules*, 26(18), Article 5666. Available at: https://doi.org/10.3390/molecules26185666.

Pawar, A., *et al.* (2025) 'Analytical Method Validation: ICH and USP Perspectives', *International Journal of Research and Review*, 12(8). Available at: https://doi.org/10.52403/ijrr.20250809.

Pollard, C. and Rapp-Wright, H. (2026) 'Sustainable analytical chemistry laboratories: the critical role of education', *RSC Sustainability*. Available at: https://doi.org/10.1039/D5SU00921A.

Poojarya, H., *et al.* (2025) 'Current advances in solid-phase microextraction as a green analytical sample preparation approach', *Green Chemistry Letters and Reviews*, 18(1). Available at: https://doi.org/10.1080/17518253.2025.2486135.

Shinde, S.S. and Khulbe, P. (2025) 'Analytical Method Validation: A Comprehensive Review of Current Practices', *South Eastern European Journal of Public Health*, 21, pp. 244–254. Available at: https://doi.org/10.70135/seejph.vi.6516.

Links

This unit links to the following related units:

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 526: Further Analytical Chemistry.

Unit 424: Artificial Intelligence in Applied Science

Unit code: D/652/3057

Unit level: 4

Credit value: 15

Introduction

Artificial intelligence (AI) is increasingly used within applied science settings to support data handling, analysis and decision making across laboratory, research and technical environments. AI-enabled systems are influencing how scientific data is processed, interpreted and communicated, making it important for students to understand what artificial intelligence is and how it is used appropriately within applied science organisations.

The aim of this unit is to introduce students to the fundamental concepts, characteristics and capabilities of AI, with a focus on applied science use rather than technical development. Students will explore how AI systems differ from traditional automated or rule-based approaches and how they can be selected and used to support defined scientific and organisational tasks.

This unit covers key artificial intelligence concepts, including categories of AI systems, their capabilities and limitations, and the benefits and risks associated with their use in applied science contexts. Students will explore the principles of prompt engineering and examine legal, ethical and professional considerations, including data protection, accountability and the importance of human oversight in scientific practice.

On successful completion of this unit, students will be able to describe how AI is used within organisational and applied science contexts, assess its suitability for specific tasks, and communicate effectively with others. These skills will support progression into roles such as AI Support Technician, Data Analysis Assistant, Laboratory Data Officer, Technology Project Assistant or Digital Operations Coordinator, as well as further study where AI-enabled systems form part of everyday professional practice.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Describe the fundamental concepts, characteristics, and capabilities of artificial intelligence

LO2 Explore the concept of prompt engineering within applied science contexts

LO3 Examine the potential benefits and limitations of artificial intelligence in applied science contexts

LO4 Deliver a workshop on the ethical use of artificial Intelligence for an identified applied science scenario.

Essential Content

LO1 **Describe the fundamental concepts, characteristics, and capabilities of artificial intelligence**

Artificial intelligence concepts and terminology:

Definition and scope: artificial intelligence e.g. laboratory data tools, scientific analysis systems; scope e.g. laboratory use, applied research

System distinctions: automation e.g. automated instruments, sample handling; artificial intelligence e.g. adaptive analysis tools, learning systems

Core terms: data e.g. experimental data, measurement data; models e.g. predictive models, analytical models; inference e.g. result interpretation, outcome judgement

Outputs: outputs e.g. analytical results, diagnostic results; organisational contexts e.g. laboratories, research environments.

Artificial intelligence approaches and categories (overview):

Approach types: rule-based systems e.g. quality control rules, decision thresholds; data-driven approaches e.g. pattern learning, dataset analysis

Functional uses: prediction e.g. trend prediction, result forecasting; classification e.g. sample classification, result categorisation; optimisation e.g. process optimisation, resource optimisation

Pattern uses: pattern recognition e.g. imaging patterns, spectroscopy patterns; recommendation e.g. method selection, parameter selection

Language uses: language-based generation e.g. report drafting, documentation support; large language models e.g. report summarisation, procedure explanation.

Capabilities and performance characteristics:

System capabilities: speed e.g. rapid data processing, real-time analysis; consistency e.g. repeatable analysis, standardised outputs

Data interaction: pattern identification e.g. trend detection, anomaly detection; data e.g. sensor data, experimental datasets

Performance sensitivity: input quality e.g. sample quality, data accuracy; output variability e.g. result variation, measurement variation

Operational dependence: defined parameters e.g. calibration settings, control limits; training data e.g. reference datasets, historical results.

Constraints and limitations of capability:

Contextual constraints: contextual understanding e.g. experimental context, procedural context; organisational contexts e.g. laboratory environments, applied science settings

Data dependency: available data e.g. sample availability, dataset completeness; data quality e.g. data accuracy, data integrity

Reasoning limits: trained scope e.g. validated conditions, tested ranges; limitations e.g. system constraints, method constraints

Performance variation: performance variability e.g. instrument variability, sample variability; variability e.g. result variability, procedural variability.

LO2 **Explore the concept of prompt engineering within applied science contexts**

Prompt engineering principles:

Prompt purpose: purpose of prompts e.g. explaining concepts, summarising information; task direction e.g. giving instructions, requesting steps, guiding tasks

User interaction: user–AI interaction e.g. asking questions, submitting prompts, reviewing responses; output guidance e.g. response format, expected detail

Prompt control: contextual instruction e.g. scientific context, applied setting, task background; scope control e.g. topic limits, detail boundaries, focus areas; relevance shaping e.g. subject focus, output relevance, applied use.

Prompt structure and clarity:

Language quality: clear language e.g. plain wording, simple sentences; concise phrasing e.g. short prompts, focused wording, reduced repetition

Task definition: task focus e.g. defined task, specific aim; relevance to purpose e.g. appropriate response, aligned output

Input handling: contextual detail e.g. background information, applied context, scientific setting; input specification e.g. data description, information scope.

Prompt engineering in applied science contexts:

Scientific support: data interpretation support e.g. trend explanation, result meaning, data insight; comparison of results e.g. result differences, outcome comparison, dataset contrast; exploratory questioning e.g. follow-up questions, clarification prompts, investigative queries

Documentation and methods: report drafting assistance e.g. structured reports, summary sections, written explanations; summary generation e.g. result summaries, outcome overviews, concise findings; procedural explanation e.g. step description, process explanation, method outline; method clarification e.g. procedural detail, method understanding, approach explanation; preparation of documentation e.g. lab notes, reports, supporting documents.

Limitations and risks of prompt-based interaction:

Prompt issues: prompt ambiguity e.g. vague wording, unclear intent, broad requests; misunderstood context e.g. missing background, wrong assumptions, incomplete detail; incomplete responses e.g. partial answers, missing steps, limited detail

Output risks: misleading outputs e.g. incorrect explanations, oversimplified results, wrong emphasis; over-generalisation e.g. broad statements, non-specific outputs, generic responses; reliability concerns e.g. inconsistent results, accuracy issues, trust limitations

Responsible use risks: bias reinforcement e.g. repeated assumptions, unbalanced responses, skewed outputs; over-reliance on generated content e.g. reduced checking, dependency risks, excessive use; verification requirements e.g. result checking, source confirmation, human review.

LO3 **Examine the potential benefits and limitations of artificial intelligence in applied science contexts**

Benefits of AI use:

Efficiency benefits: time efficiency e.g. faster data processing, reduced manual analysis; task automation e.g. routine calculations, repetitive data handling

Analytical support: pattern identification e.g. trend detection in results, anomaly identification; data handling e.g. large experimental datasets, complex measurements

Decision support: decision assistance e.g. method selection support, result comparison; information summarisation e.g. concise experimental summaries, key finding extraction.

Limitations of AI use:

Data limitations: data quality e.g. inaccurate sensor readings, poorly labelled experimental data; data availability e.g. limited sample numbers, incomplete datasets

Context limitations: contextual understanding e.g. missing experimental conditions, lack of procedural awareness; applicability limits e.g. unsuitable methods, task mismatch

Performance limitations: reliability e.g. inconsistent analytical outputs, variable system behaviour; output accuracy e.g. incorrect result interpretation, misleading analysis

Model integrity risks: LLM poisoning e.g. compromised training data, manipulated input data; output reliability e.g. distorted responses, untrustworthy generated content.

Legal and regulatory considerations:

Data protection legislation: UK GDPR e.g. lawful processing, data minimisation; Data Protection Act 2018 e.g. research exemptions, data handling duties

Personal data constraints: personal data e.g. clinical samples, identifiable research data; processing limits e.g. purpose limitation, consent requirements

Accountability requirements: accountability e.g. organisational responsibility, compliance evidence; record keeping e.g. processing records, audit trails

Sector regulation: MHRA regulations e.g. medical device data use, clinical evaluation; Human Tissue Act 2004 e.g. use of human samples, consent scope

Organisational compliance: policies and procedures e.g. information governance policies, laboratory standard operating procedures (SOPs); professional standards e.g. ethical guidance, codes of conduct.

LO4 **Deliver a workshop on the ethical use of artificial intelligence for an identified applied science scenario**

Ethical considerations and responsible use:

Fair and inclusive use: fairness e.g. inclusive data interpretation, bias-aware analysis; appropriate application e.g. suitable experimental use, justified task selection; equality of access e.g. accessible outputs, inclusive participation

Professional responsibility: human oversight e.g. result checking, supervisory review; accountability e.g. responsibility for decisions, ownership of outcomes; ethical responsibility e.g. recognising bias, preventing exclusion

Transparency and accessibility: explainability e.g. understandable analytical outputs, clear result reasoning; communication e.g. clear reporting, accurate scientific explanation; accessible formats e.g. plain language summaries, visual support, alternative formats.

Workshop purpose and structure:

Inclusive audience requirements: audience requirements e.g. prior knowledge, technical expectations; audience needs e.g. learning aims, topic relevance, skill alignment; accessibility needs e.g. readable materials, inclusive language, support for different learning preferences

Scope definition: scope definition e.g. session boundaries, core topics; content depth e.g. essential details, technical clarity, appropriate complexity; EDI scope e.g. fairness, accessibility, inclusive AI use

Logical sequencing of content: content sequencing e.g. structured flow, progressive steps; session outlines e.g. segment order, time allocation, topic grouping; inclusive sequencing e.g. clear signposting, recap points, opportunities for questions.

Technical communication:

Technical language: technical language e.g. accurate terminology, domain-specific vocabulary; clarity of explanation e.g. concise descriptions, precise wording, clear definitions

Inclusive audience engagement: audience engagement e.g. interactive prompts, question opportunities; delivery structure e.g. logical transitions, consistent formatting, clear progression; participation strategies e.g. accessible questioning, collaborative discussion, respectful interaction

Inclusive learning materials: learning materials e.g. slide resources, reference notes; delivery resources e.g. demonstration tools, visual aids, supporting documents; accessibility features e.g. readable layouts, captions or transcripts, alternative formats.

Workshop delivery:

Presentation organisation: presentation organisation e.g. structured layout, ordered sections; coherence e.g. consistent narrative, logical emphasis, aligned messaging

Inclusive technical tone: technical tone e.g. appropriate register, professional language; audience-appropriate language e.g. accessible wording, level-matched terminology, clear phrasing; inclusive communication e.g. non-biased language, respectful examples, culturally aware references

Time management and responsive delivery: time management e.g. session pacing, allocated segments; structured responses e.g. orderly answers, relevant clarification, focused explanations; inclusive delivery e.g. processing time, checks for understanding, supportive feedback routes.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Describe the fundamental concepts, characteristics, and capabilities of artificial intelligence</td><td rowspan="8">LO1, LO2 and LO3

D1 Evaluate, using a selection of real-world examples, the benefits and limitations of AI systems and prompt engineering in supporting the advancement of applied scientific research and development.</td></tr>
<tr><td>P1 Describe, using a selection of real-world examples, the fundamental concepts and terminologies associated with AI.

P2 Explain, using a selection of real-world examples, the capabilities, limitations and constraints of AI systems.</td><td>M1 Analyse, using a selection of real-world examples, the suitability of AI systems in identified applied science contexts.</td></tr>
<tr><td colspan="2">LO2 Explore the concept of prompt engineering within applied science contexts</td></tr>
<tr><td>P3 Explore, using a selection of real-world examples, the concept of prompt engineering as used within applied science contexts.

P4 Explain, using a selection of real-world examples, the limitations and risks of prompt engineering within applied science contexts.</td><td>M2 Assess, using a selection of real-world examples, the impact of prompt engineering within identified applied science contexts.</td></tr>
<tr><td colspan="2">LO3 Examine the potential benefits and limitations of artificial intelligence in applied science contexts</td></tr>
<tr><td>P5 Examine, using a selection of real-world examples, the potential benefits and limitations of AI in applied science contexts.

P6 Explain, using a selection of real-world examples, legal and regulatory considerations for the application of AI in applied science contexts.</td><td>M3 Analyse, using a selection of real-world examples, how the benefits, limitations and regulatory considerations affect the application of AI in applied science contexts.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Deliver a workshop on the ethical use of artificial intelligence for an identified applied science scenario		**LO4**
P7 Plan the delivery of a workshop on the ethical use of AI in an identified applied science scenario to an identified audience. **P8** Deliver a workshop on the ethical use of AI in an identified applied science scenario to a technical audience and obtain relevant feedback.	**M4** Analyse the results of the audience feedback on the delivery of the workshop to identify a range of strengths and areas for improvement.	**D2** Evaluate the overall effectiveness of the workshop in communicating the ethical use of AI in an identified applied science scenario to an identified audience.

Recommended Resources

Textbooks

Bhargava, C. and Sharma, P.K. (eds.) (2021) *Artificial Intelligence: Fundamentals and Applications.* Boca Raton: CRC Press.

Boddington, P. (2023) *AI Ethics: A Textbook.* Singapore: Springer.

Marcus, G. and Davis, E. (2021) *Rebooting AI: Building Artificial Intelligence We Can Trust*. London: Penguin.

Nolan, A. (2024) *Artificial Intelligence in Science: Challenges, Opportunities and the Future of Research*. Paris: OECD Publishing.

Phoenix, J. and Taylor, M. (2024) *Prompt Engineering for Generative AI*. Sebastopol, CA: O'Reilly Media.

Websites

https://www.geeksforgeeks.org/artificial-intelligence/what-is-artificial-intelligence-ai/	GeeksforGeeks Definition and core concepts of artificial intelligence, including learning, data use and decision-making (General reference)
https://www.ibm.com/think/topics/artificial-intelligence	IBM High-level explanation of artificial intelligence concepts, system capabilities and limitations (General reference)
https://machinelearningplus.com/gen-ai/prompt-engineering-basics/	Machine Learning Plus Introduction to prompt engineering principles, prompt structure and clarity for AI interaction (Tutorial)
https://www.ibm.com/think/prompt-engineering	IBM Guidance on designing effective prompts to control AI outputs and task direction (General reference)

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https://www.researchtoaction.org/2024/04/ai-in-research-its-uses-and-limitations/	Research to Action Overview of benefits and limitations of artificial intelligence in research and data analysis contexts (Blog)
https://www.turing.ac.uk/research/research-projects/ai-ethics-and-governance-practice	The Alan Turing Institute Practical guidance on ethical, transparent and accountable use of artificial intelligence systems (Resource hub)
https://www.certara.com/blog/best-practices-for-ai-prompt-engineering-in-life-sciences/	Certara Applied guidance on prompt engineering practices within life science and research environments (Article)

Journals and articles

Castillo-Martínez, I.M., *et al.* (2024) 'AI in higher education and scientific research: Benefits, challenges and limitations', *Frontiers in Education*, 9, 1391485. Available at: https://doi.org/10.3389/feduc.2024.1391485.

European Commission (2019) 'Ethics guidelines for trustworthy AI'. Available at: https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai.

Floridi, L., *et al.* (2018) 'AI4People—An Ethical Framework for a Good AI Society: Opportunities, Risks, Principles, and Recommendations', *Minds and Machines*, 28(4), pp. 689–707. Available at: https://doi.org/10.1007/s11023-018-9482-5.

Garzón, J., Patiño, E. and Marulanda, C. (2025) 'Systematic Review of Artificial Intelligence in Education: Trends, Benefits, and Challenges', *Multimodal Technologies and Interaction*, 9(8), 84. Available at: https://doi.org/10.3390/mti9080084.

Haymond, S. and McCudden, C. (2021) 'Rise of the Machines: Artificial Intelligence and the Clinical Laboratory', *The Journal of Applied Laboratory Medicine*, 6(6), pp. 1640–1654. Available at: https://doi.org/10.1093/jalm/jfab075.

Lo, L.S. (2023) 'The Art and Science of Prompt Engineering: A New Literacy in the Information Age', *Internet Reference Services Quarterly*, 27(4), pp. 203–210. Available at: https://doi.org/10.1080/10875301.2023.2227621.

Shneiderman, B. (2020) 'Bridging the Gap Between Ethics and Practice: Guidelines for Reliable, Safe, and Trustworthy Human-centered AI Systems', *ACM Transactions on Interactive Intelligent Systems*, 10(4), pp. 1–31. Available at: https://doi.org/10.1145/3419764.

Links

This unit links to the following related units:

Unit 419: Bioinformatics

Unit 420: Cheminformatics

Unit 525: Genomics and Proteomics.

5.0 Unit descriptors

Unit 501: Personal and Professional Development for Scientists

Unit code: F/652/3058

Unit level: 5

Credit value: 15

Introduction

Professional practice plays a critical role across all areas of scientific work, including laboratory science, research, analytical services, quality assurance and regulatory environments. Scientists are expected to operate to high professional standards, demonstrating accuracy, ethical conduct, accountability and effective communication in increasingly regulated and technologically advanced workplaces. As scientific roles continue to evolve, maintaining professional competence and adapting to sector expectations has become essential for both individual effectiveness and career progression.

The aim of this unit is to develop students' understanding of personal and professional development within scientific contexts. It provides students with the theoretical foundations and practical approaches needed to reflect on their own performance, understand professional expectations and plan structured development activities that align with scientific roles and sector requirements. The unit supports students in taking responsibility for their ongoing professional growth.

The unit content explores key theories of personal and professional development, reflective practice models and professional standards relevant to scientific practice. Students examine how professional behaviours, ethical responsibilities and communication requirements contribute to effective and responsible working environments. The unit also focuses on the use of reflective tools and development planning techniques to identify strengths, address development needs and support long-term career progression within scientific sectors.

On successful completion of this unit, students will be able to evaluate their own professional practice, apply reflective methods to improve performance and develop structured personal or career development plans aligned with sector expectations. These skills support progression into a range of scientific roles, including Laboratory Scientist, Analytical Scientist, Research Technician, Quality Assurance Officer and Regulatory Affairs Assistant, as well as providing a strong foundation for further study and professional development.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss the theories of personal and professional development relevant to scientific practice

LO2 Review the professional behaviours, ethical responsibilities and communication requirements for effective scientific practice

LO3 Apply reflective practice models to analyse personal performance against professional standards

LO4 Develop a structured personal or career development plan aligned with scientific roles and sector requirements.

Essential Content

LO1 **Discuss the theories of personal and professional development relevant to scientific practice**

Theories of personal and professional development:

Development and identity: personal development e.g. self-awareness, skills development; professional development e.g. competence maintenance, career progression; professional identity formation e.g. role socialisation, professional values

Learning and motivation: adult learning theories e.g. experiential learning, self-directed learning, lifelong learning; motivation e.g. intrinsic motivation, extrinsic motivation; self-regulation e.g. goal monitoring, reflective control

Career models: career stage models e.g. entry stage, advancement stage; strengths-based approaches e.g. capability focus, performance optimisation

Adaptability: resilience e.g. coping strategies, professional endurance; adaptability e.g. role flexibility, skills transferability

Continuing professional development: CPD benefits e.g. knowledge currency, skill enhancement, professional recognition; career progression opportunities e.g. promotion pathways, role diversification.

Professional development in scientific contexts:

Professional expectations: professional growth expectations e.g. ongoing learning, performance improvement; scientific roles e.g. laboratory scientist, analytical scientist, research scientist

Competence and accountability: competence e.g. technical accuracy, methodological consistency; accountability e.g. responsibility ownership, compliance adherence

Theory in practice: scientific judgement e.g. evidence evaluation, decision making; accuracy e.g. procedural precision, data integrity

Scientific environments: laboratory environments e.g. controlled settings, safety-regulated spaces; regulatory environments e.g. compliance settings, governance frameworks.

Relevance of development theories to scientific practice:

Contextual relevance: contextual relevance e.g. workplace demands, operational settings; scientific work e.g. experimentation, reporting

Professional standards: standards e.g. sector standards, regulatory standards, professional benchmarks; ethical conduct e.g. integrity, responsibility

Career progression: progression e.g. advancement, specialisation; scientific careers e.g. laboratory careers, regulatory careers

Lifelong learning: lifelong learning e.g. continuous learning, skills updating, professional currency; sector change e.g. technological advancement, regulatory change.

LO2 **Review the professional behaviours, ethical responsibilities and communication requirements for effective scientific practice**

Professional behaviours in scientific practice:

Professional behaviours: responsibility e.g. task ownership, procedural compliance; reliability e.g. consistency, timekeeping; accountability e.g. outcome responsibility, professional judgement; stakeholder expectations e.g. internal users, external clients; expectation management e.g. requirement alignment, communication clarity

Teamwork and professionalism: teamwork e.g. collaborative working, role coordination; professionalism e.g. appropriate conduct, professional attitude; adaptability e.g. role flexibility, continuous improvement; stakeholder collaboration e.g. cross-functional working, communication alignment; escalation e.g. issue reporting, decision support

Inclusive professional practice: inclusive practice principles e.g. equality, diversity, inclusion; professional conduct standards e.g. respectful behaviour, non-discriminatory practice; accessibility requirements e.g. reasonable adjustments, inclusive communication; cultural competence e.g. diversity awareness, inclusive interaction; barriers to inclusion e.g. unconscious bias, communication barriers; fair working practices e.g. equitable treatment, consistent expectations; inclusive workplace behaviour e.g. collaborative inclusion, supportive interaction.

Ethical responsibilities and responsible scientific conduct:

Ethical principles: integrity e.g. honesty, transparency; responsible conduct e.g. ethical decision making, professional responsibility

Data and confidentiality: confidentiality e.g. data protection, information security; data responsibility e.g. accurate recording, data integrity

Consequences of unethical practice: conflicts of interest e.g. personal bias, professional imbalance; consequences e.g. disciplinary action, reputational damage.

Communication requirements for effective practice:

Professional communication: clarity e.g. clear reporting, unambiguous language; accuracy e.g. factual correctness, precise terminology; context e.g. scientific reporting, technical discussions

Communication methods: written communication e.g. reports, documentation; verbal communication e.g. briefings, discussions; formal communications e.g. posters, presentations

Digital communication for agile working: digital communication tools e.g. collaboration platforms, messaging systems; synchronous communication e.g. virtual meetings, real-time discussions; asynchronous communication e.g. email updates, recorded briefings; collaborative working practices e.g. shared documents, version control; information transparency e.g. visible task tracking, open communication channels; communication responsiveness e.g. timely updates, message acknowledgement; remote working communication e.g. distributed teams, virtual coordination

Communication contexts: safety communication e.g. risk information, procedure guidance; quality communication e.g. SOPs, quality reporting; stakeholder communication e.g. team members, external parties.

Working with global teams:

Cross-cultural communication e.g. cultural awareness, communication styles; time zone coordination e.g. scheduling meetings, asynchronous collaboration; language considerations e.g. clear language, simplified terminology; collaborative practices e.g. shared platforms, distributed teamwork; professional etiquette e.g. cultural sensitivity, respectful interaction; coordination challenges e.g. time delays, communication gaps; inclusive global working e.g. equitable participation, diverse perspectives.

LO3 **Apply reflective practice models to analyse personal performance against professional standards**

Reflective practice models and approaches:

Reflective practice: purpose e.g. performance improvement, professional learning; value e.g. self-awareness, informed judgement, professional accountability

Reflective models: experiential learning cycles e.g. Kolb cycle, learning stages; structured reflection models e.g. Gibbs cycle, staged reflection; reflective practice theory e.g. reflection-in-action, reflection-on-action; structured models e.g. Schön reflection, structured reflection frameworks

Reflective selection: model selection e.g. context suitability, role relevance.

Professional standards and performance expectations:

Professional standards: role-based expectations e.g. job responsibilities, competence requirements; organisational standards e.g. workplace policies, quality procedures; sector standards e.g. professional codes, regulatory guidance

Performance evidence: feedback e.g. supervisor feedback, peer feedback; work outputs e.g. reports, experimental results; compliance outcomes e.g. audit results, procedural adherence

Codes and conduct: codes of conduct e.g. ethical guidelines, professional behaviour.

Analysis of personal performance:

Self-evaluation: critical self-evaluation e.g. strengths identification, development needs; evidence-based analysis e.g. documented feedback, work records

Reflective tools: self-assessment tools e.g. SWOT analysis, skills audits; goal-setting tools e.g. SMART goals, performance targets; reflective records e.g. reflective logs, reflective journals

Evidence use: evidence use e.g. performance records, feedback analysis, reflective logs

Reflection in practice: routine reflection e.g. daily review, task reflection; structured reflection e.g. post-incident review, planned reflection sessions

Performance improvement: performance improvement e.g. action planning, skill development.

LO4 **Develop a structured personal or career development plan aligned with scientific roles and sector requirements**

Personal and career development planning:

Development planning: purpose e.g. career direction, professional growth; structure e.g. clear objectives, planned actions

Goal setting: development objectives e.g. short-term goals, long-term goals, SMART goals; prioritisation e.g. skills importance, career relevance

Self-assessment: skills audits e.g. competence review, capability assessment; frameworks e.g. Big Five personality traits, cognitive ability measures; personality trait dimensions e.g. openness, conscientiousness; cognitive ability components e.g. problem solving, reasoning; emotional intelligence tools e.g. self-awareness assessment, interpersonal awareness; self-awareness components e.g. emotional recognition, self-reflection; interpersonal awareness components e.g. empathy, social skills; behavioural assessment methods e.g. 360-degree feedback, competency frameworks.

Development plan construction and review:

Action planning: action steps e.g. defined activities, resource use; resources e.g. training opportunities, professional support; timelines e.g. realistic schedules, milestone planning

Monitoring and review: progress monitoring e.g. milestone tracking, outcome review; feedback e.g. supervisory feedback, peer feedback

Plan adaptation: development adjustments e.g. revised goals, updated actions; reflection e.g. achievement review, improvement focus.

Alignment with scientific roles and sector requirements:

Role alignment: scientific roles e.g. laboratory roles, analytical roles; role requirements e.g. technical competence, professional responsibility

Sector expectations: professional standards e.g. regulatory expectations, quality systems; employability frameworks e.g. transferable skills, career readiness

Career progression: progression pathways e.g. role advancement, responsibility expansion; long-term development e.g. CPD planning, career sustainability.

Communication and evaluation of development plans:

Professional communication: audience awareness e.g. supervisors, assessors; clarity e.g. structured presentation, clear justification

Evaluation: development effectiveness e.g. progress review, outcome evaluation; career progression e.g. future opportunities, professional development.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss the theories of personal and professional development relevant to scientific practice</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the impact of development theories, professional behaviours, responsibilities and communication requirements on effective scientific practice.</td></tr>
<tr><td>P1 Discuss, using a selection of real-world examples, the theories of personal and professional development.

P2 Explore, using a selection of real-world examples, the relevance of personal and professional development theories to scientific practice.</td><td>M1 Analyse, using a selection of real-world examples, how theories of personal and professional development support progression and competence within scientific practice.</td></tr>
<tr><td colspan="2">LO2 Review the professional behaviours, ethical responsibilities and communication requirements for effective scientific practice</td></tr>
<tr><td>P3 Review, using a selection of real-world examples, the professional behaviours and ethical responsibilities expected within scientific practice.

P4 Explain, using a selection of real-world examples, the communication requirements for effective scientific practice.</td><td>M2 Analyse the effectiveness of professional behaviours, ethical responsibilities, and communication requirements in supporting effective scientific practice.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Apply reflective practice models to analyse personal performance against professional standards		**LO3**
P5 Explain, using a selection of real-world examples, the concepts of reflective practice and their significance for scientific practice. **P6** Apply a selection of appropriate reflective practice models to analyse personal performance against identified professional standards.	**M3** Justify the selection of reflective practice models used to analyse personal performance against identified professional standards.	**D2** Critically evaluate the effectiveness of reflective practice models in improving personal performance against professional standards.
LO4 Develop a structured personal or career development plan aligned with scientific roles and sector requirements		**LO4**
P7 Develop a structured personal or career development plan that aligns individual goals with identified scientific roles and sector requirements. **P8** Deliver a professional presentation on the structured personal or career development plan to a target audience of identified stakeholders to obtain feedback.	**M4** Optimise, using the feedback obtained, the structured personal or career development plan to more closely align individual goals with identified scientific roles and sector requirements.	**D3** Justify the decisions made in the development of the personal or career development plan in meeting sector requirements and supporting long-term professional development and career progression within scientific sectors.

Recommended Resources

Textbooks

Bassot, B. (2023) *The Reflective Practice Guide: An Interdisciplinary Approach to Critical Reflection*. London: Routledge.

Bassot, B. (2024) *The Reflective Journal.* London: Bloomsbury Publishing.

Dennis, C. and Abbott, S. (2025) *Excelling at University: Academic Literacies and the Development of Graduate Identity.* London: Routledge.

Hopkins, D. and Reid, T. (2024) *The Academic Skills Handbook: Your Guide to Success in Writing, Thinking and Communicating at University*. 2nd edn. London: Sage.

McMorrow, M. (2024) *The Student's Guide to Reflective Writing.* London: Bloomsbury Academic.

Thompson, C. (2021) *Reflective Practice for Professional Development: A Guide for Teachers*. London: Routledge.

Travers, C.J. (2022) *Reflective Goal Setting: An Applied Approach to Personal and Leadership Development*. Cham: Palgrave Macmillan.

Websites

https://sciencecouncil.org	Science Council Professional standards, registration, and CPD expectations for scientists (Standards)
https://www.hse.gov.uk	Health and Safety Executive Health and safety culture and professional responsibilities (General reference)
https://www.cpduk.co.uk	CPD Standards Office Continuing professional development principles and frameworks (General reference)
https://www.gov.uk/career-skills-and-training	UK Government Career skills, training, and employability guidance (General reference)

https://www.prospects.ac.uk	Prospects Scientific career pathways and labour market information (General reference)
https://www.tandfonline.com/doi/pdf/10.11120/beej.2012.19000004	Taylor and Francis Online Reflective practice in bioscience laboratories (PDF Download)
https://documents.ahcs.ac.uk/docs/292/-023-Good-Scientific-Practice-v1.7-January-2025.pdf	Academy for Healthcare Science Good Scientific Practice (2025) (PDF Download)
https://www.ibms.org/resource/ibms-good-professional-practice-in-biomedical-science.html	Institute of Biomedical Science Good Professional Practice in Biomedical Science (PDF Download)
https://myidp.sciencecareers.org/	myIDP Science Careers Individual Development Plan (IDP) for scientists (General reference)
https://help.open.ac.uk/developing-your-career/personal-development-plan	Open University Personal development plan (PDP) (General reference)

Journals and articles

Eraut, M. (2004) 'Informal learning in the workplace', *Studies in Continuing Education*, 26(2), pp. 247–273. Available at: https://doi.org/10.1080/158037042000225245.

Jackson, D. (2016) 'Re-conceptualising graduate employability: the importance of pre-professional identity', *Higher Education Research & Development*, 35(5), pp. 925–939. Available at: https://doi.org/10.1080/07294360.2016.1139551.

Mann, K., Gordon, J. and MacLeod, A. (2009) 'Reflection and reflective practice in health professions education: a systematic review', *Advances in Health Sciences Education*, 14(4), pp. 595–621. Available at: https://doi.org/10.1007/s10459-007-9090-2.

Trede, F., Macklin, R. and Bridges, D. (2012) 'Professional identity development: a review of the higher education literature', *Studies in Higher Education*, 37(3), pp. 365–384. Available at: https://doi.org/10.1080/03075079.2010.521237.

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Links

This unit links to the following related units:

Unit 416: Work-based Learning

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 519: Science Laboratory Management.

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit code: H/652/3059

Unit level: 5

Credit value: 30

Introduction

This unit is a Pearson-set unit. The applied science research project brief will be set by the centre, based on a theme released by Pearson that changes annually. The theme provides a common framework while allowing students to explore an area of applied science relevant to their subject pathway, ensuring that the project reflects current scientific, technical or sector-based priorities.

The purpose of this unit is to enable students to plan and carry out an independently managed applied science research project that mirrors professional scientific practice. Through engagement with a Pearson-set theme, students are able to investigate a clearly defined problem or question, apply appropriate scientific methods and work within ethical, safe and regulatory constraints that are characteristic of real-world research environments.

The aim of the unit is to develop students' ability to design, implement and review a small-scale applied science research project, from proposal through to final communication of outcomes. Students are expected to demonstrate informed decision making in relation to methodology, data handling and analysis, while producing conclusions that are supported by evidence and aligned to the original project aims.

On successful completion of the unit, students will be able to undertake small-scale scientific research, analyse experimental or secondary data, and communicate findings to an intended audience using appropriate scientific conventions. The knowledge and skills developed support progression into roles such as Laboratory Technician, Scientific Research Assistant, Quality Control Analyst, Clinical Research Support Officer and Environmental Science Technician.

***Please refer to the accompanying Pearson-set Assignment Guide and the Theme Release document for further support and guidance on the delivery of the Pearson-set unit.**

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Develop a structured and ethically compliant research proposal for an identified project, citing appropriate literature where relevant

LO2 Implement appropriate experimental methodologies to collect accurate data using correct lab techniques and safe working practices

LO3 Review the experimental research data using appropriate statistical, computational or interpretative techniques

LO4 Communicate effectively the experimental findings and conclusions to an external audience.

Essential Content

LO1 **Develop a structured and ethically compliant research proposal for an identified project, citing appropriate literature where relevant**

Project scoping and proposal structure:

Research focus: research aims e.g. project purpose, scientific intent; research objectives e.g. measurable outcomes, investigation targets; research questions e.g. testable queries, focused prompts; hypotheses e.g. predicted relationships, expected outcomes, theoretical assumptions

Variables and scope: variables e.g. independent variables, dependent variables; project scope e.g. investigation boundaries, defined limits; feasibility considerations e.g. resources, timescales, access

Proposal structure: abstract e.g. project summary, concise overview; rationale e.g. scientific justification, contextual relevance; methodology overview e.g. approach summary, method outline; references e.g. source attribution, citation list.

Ethical and regulatory compliance:

Ethical approval: ethical approval requirements e.g. institutional ethics approval, NHS Research Ethics Committee approval; ethical approval routes e.g. Health Research Authority review, university ethics panels

Consent and data protection: informed consent principles e.g. voluntary participation, informed agreement; confidentiality e.g. controlled access, restricted disclosure; data protection considerations e.g. UK GDPR, Data Protection Act 2018

Research integrity: research integrity e.g. avoidance of fabrication, avoidance of falsification; authorship e.g. contributor recognition, authorship criteria; acknowledgement e.g. funding disclosure, collaborator recognition

Risk management: risk assessment principles e.g. hazard identification, risk mitigation; laboratory projects e.g. Control of Substances Hazardous to Health Regulations (COSHH) 2002, Health and Safety at Work etc. Act 1974; secondary-source projects e.g. data licensing, data provenance.

Scientific literature and justification:

Literature use: scientific literature searching e.g. database use, keyword strategies; selection criteria e.g. relevance thresholds, quality standards; referencing conventions e.g. citation style, consistency rules

Justification and appraisal: literature rationale e.g. theoretical grounding, contextual framing; critical appraisal e.g. relevance, quality, limitations

Alignment: Pearson-set theme alignment e.g. theme relevance, contextual fit; project choice alignment e.g. methodological coherence, aim consistency.

LO2 **Implement appropriate experimental methodologies to collect accurate data using correct lab techniques and safe working practices**

Methodological approach (practical-based and/or secondary-source):

Method selection and justification: method selection e.g. aim alignment, data suitability; experimental methodologies e.g. controlled experiments, laboratory investigations, field studies; analytical methodologies e.g. instrumental analysis, sample testing; investigative methodologies e.g. observational studies, secondary analysis

Sampling and data sources: sampling approaches e.g. representative sampling, controlled selection; data-source selection e.g. primary data, secondary data, existing datasets; inclusion criteria e.g. relevance thresholds, quality standards; exclusion criteria e.g. data limitations, relevance constraints

Procedural control and transparency: procedural controls e.g. standardised procedures, controlled conditions; variable management e.g. independent variables, dependent variables; data parameters e.g. measurement ranges, calibration settings; reproducibility expectations e.g. repeatability, documentation.

Data generation/data handling and technique application:

Technique application: practical techniques e.g. measurement techniques, observational techniques; analytical techniques e.g. instrumental techniques, computational handling, data processing; data collection tools e.g. laboratory measurements, digital instruments, existing datasets

Data quality management: reliability e.g. consistency checks, repeatability; validity e.g. method suitability, data accuracy; data uncertainty e.g. missing data, outliers; methodological limitations e.g. measurement constraints, sampling constraints.

Safe working practices and ethics in implementation:

Laboratory and field safety: safety practices e.g. safe equipment use, contamination control; standard operating procedure (SOP) awareness e.g. procedural guidance, risk controls; accurate equipment use e.g. calibration compliance, operational limits

Ethical and responsible practice: e.g. responsible practice, compliance awareness

Legislation awareness: legislation awareness e.g. COSHH Regulations 2002, Health and Safety at Work etc. Act 1974; regulatory awareness e.g. institutional safety policies, laboratory governance.

Sustainability considerations in experimental design:

Resource efficiency: material optimisation e.g. reduced reagent volumes, batch preparation, scaled experiments; energy efficiency e.g. low-energy equipment, shutdown protocols, efficient run scheduling

Consumable management: consumable reduction e.g. reusable glassware, durable materials; consumable selection e.g. low-impact materials, biodegradable options

Waste minimisation: waste reduction e.g. process optimisation, minimal by-products; waste segregation e.g. chemical separation, biological categorisation

Regulatory sustainability compliance: compliance awareness e.g. institutional sustainability policies, environmental regulations; reporting requirements e.g. waste logs, sustainability records.

LO3 **Review the experimental research data using appropriate statistical, computational or interpretative techniques**

Analytical techniques and processing:

Technique selection: statistical techniques e.g. descriptive statistics, inferential statistics; computational techniques e.g. data modelling, algorithmic processing, simulation tools; interpretative techniques e.g. thematic analysis, qualitative coding; artificial intelligence e.g. machine learning models, pattern recognition, classification systems, predictive analysis

Data processing: data preparation e.g. data cleaning, data organisation; data transformation e.g. normalisation, categorisation; data visualisation principles e.g. graphical representation, trend display; digital systems e.g. data platforms, laboratory software; adaptability e.g. system updates, workflow changes

Uncertainty and assumptions: assumptions e.g. model assumptions, methodological assumptions; constraints e.g. data limitations, methodological constraints; sources of uncertainty e.g. measurement error, sampling variability.

Interpretation in relation to aims, limitations and context:

Alignment to aims: research aims alignment e.g. objective comparison, hypothesis testing; hypotheses alignment e.g. support evaluation, rejection decisions

Scientific context: scientific context framing e.g. literature comparison, theoretical context; relevant literature e.g. previous studies, reference findings

Limitations and confidence: methodological limitations e.g. design constraints, sampling limits; validity implications e.g. measurement accuracy, construct validity; reliability implications e.g. consistency, repeatability.

Justified conclusions and evaluative judgement:

Conclusion development: conclusion logic e.g. evidence linkage, analytical coherence; justification of conclusions e.g. data support, contextual justification

Evaluation of significance: scientific significance e.g. contribution value, knowledge relevance; applied significance e.g. practical relevance, sector implications

Implications and recommendations: implications for practice e.g. methodological insight, applied improvements; further investigation within scope e.g. refinement opportunities, methodological adjustment; recommendations e.g. method evaluation, analysis improvement.

LO4 **Communicate effectively the experimental findings and conclusions to an external audience**

Scientific communication to audience:

Audience identification: stakeholder identification e.g. scientific peers, technical supervisors; audience needs e.g. information depth, technical detail

Communication methods: communication methods e.g. written reports, oral presentations, posters; communication media e.g. digital formats, visual formats; knowledge sharing e.g. team briefings, summary reports

Reporting conventions: reporting conventions e.g. scientific structure, formal language; clarity and accuracy e.g. precise terminology, factual correctness; evidence traceability e.g. data linkage, source referencing

Uncertainty and limitations: presentation of uncertainty e.g. error margins, confidence levels; communication of limitations e.g. methodological constraints, data boundaries.

Reflective practice and process review:

Reflective approaches: reflective models e.g. evaluative reflection, structured reflection; reflective principles e.g. critical self-review, improvement focus

Process evaluation: methodological decisions e.g. method selection, procedural choices; analysis approach e.g. technique selection, data handling; project outcomes e.g. result effectiveness, conclusion strength

Improvement and professionalism: improvement logic e.g. justified changes, evidence-based refinement; professional behaviours e.g. planning awareness, time management, risk awareness

Responsible reflection: sustainability reflection e.g. environmental impact, ethical consideration.

Sustainability and responsible practice in outcomes communication:

Sustainability communication: sustainability aspects e.g. resource use, waste minimisation; decision influence e.g. material choice, process selection

Responsible data practice: data minimisation e.g. limited data collection, relevance control; data retention e.g. storage duration, disposal decisions.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Develop a structured and ethically compliant research proposal for an identified project, citing appropriate literature where relevant		**LO1**
P1 Develop a structured and ethically compliant research proposal for an identified project, citing appropriate literature where relevant. **P2** Review the structured and ethically compliant research proposal with identified internal stakeholders to identify strengths and areas for improvement.	**M1** Optimise, using the results of the internal stakeholder feedback and literature review, the design and ethical approach of the applied science project proposal.	**D1** Justify, using the results of the internal stakeholder feedback and literature review, the decisions made in the design of a feasible and ethically compliant scientific research proposal.

Pass	Merit	Distinction
LO2 Implement appropriate experimental methodologies to collect accurate data using correct lab techniques and safe working practices		**LO2 and LO3** **D2** Justify the decisions made in the implementation and safe, sustainable and ethically compliant scientific research proposal and the selection of appropriate statistical, computational, or interpretative techniques in relation to project aims and limitations.
P3 Implement appropriate experimental methodologies to collect accurate data using correct lab techniques. **P4** Demonstrate, using a range of data recording and observation techniques, the use of safe working practices, ethical and sustainability considerations in the implementation of experimental methodologies.	**M2** Evaluate the effectiveness of the chosen scientific methodologies used to collect accurate data, considering the use of safe working practices, ethical and sustainability considerations.	
LO3 Review the experimental research data using appropriate statistical, computational or interpretative techniques		
P5 Review the experimental research data using appropriate statistical, computational, or interpretative techniques to produce conclusions in relation to project aims and limitations. **P6** Discuss, with internal stakeholders, the results of the ethically compliant scientific research in relation to the identified project aims and objectives to identify strengths and areas for improvement.	**M3** Evaluate, using internal stakeholder feedback and project findings, the effectiveness of the conclusions of the ethically compliant scientific research proposal.	
LO4 Communicate effectively the experimental findings and conclusions to an external audience		**LO4** **D3** Evaluate, using the results of internal stakeholder feedback, external audience feedback and self-reflection, the overall effectiveness of the scientific research project in relation to the initial proposal.
P7 Communicate effectively the experimental findings and conclusions to an external audience to obtain feedback. **P8** Review the effectiveness of the research proposal using a range of identified reflective practices.	**M4** Analyse, using the results of the self-reflection and the audience feedback, the strengths and limitations of the scientific project.	

Recommended Resources

Textbooks

Booth, W.C., *et al*. (2024) *The Craft of Research*. 5th edn. Chicago: University of Chicago Press.

Cohen, L., Manion, L. and Morrison, K. (2024) *Research Methods in Education*. 9th edn. London: Routledge.

Creswell, J.W. and Creswell, J.D. (2023) *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches*. 6th edn. Thousand Oaks: SAGE.

Day, R.A. and Gastel, B. (2022) *How to Write and Publish a Scientific Paper*. 9th edn. Cambridge: Cambridge University Press.

Field, A., Miles, J. and Field, Z. (2024) *Discovering Statistics Using IBM SPSS Statistics*. 6th edn. London: SAGE.

Hart, C. (2023) *Doing a Literature Review: Releasing the Research Imagination*. 3rd edn. London: SAGE.

Knaflic, S.N. (2020) *Storytelling with Data: Let's Practice!* Hoboken: Wiley.

Montgomery, D.C. and Runger, G.C. (2021) *Applied Statistics and Probability for Engineers*. 7th edn. Hoboken: Wiley.

Sapsford, R. and Jupp, V. (2024) *Data Collection and Analysis*. 4th edn. London: SAGE.

Saunders, M., Lewis, P. and Thornhill, A. (2023) *Research Methods for Business Students*. 9th edn. Harlow: Pearson Education.

Websites

https://www.scribbr.com/methodology/research-ethics/	Scribbr Ethical considerations in scientific research design, consent and data protection (Article)
https://studyinghq.com/how-to/research-proposal-ethics-statement-example/	Studying HQ Ethics statements and ethical approval considerations for research proposals (Tutorial)
https://researchmethod.net/sampling-methods/	Research Method Sampling strategies and methodological choices in experimental research (General reference)

https://towardsdatascience.com/a-guide-to-analyzing-experimental-data-7b05eea7e70c/	towards data science Practical guidance on analysing and interpreting experimental research data (Tutorial)
https://researchmethod.net/data-interpretation/	Research Method Data interpretation techniques and linking results to research aims and limitations (Research)
https://in-mind.org/article/a-step-by-step-guide-to-writing-science-communication-articles	University of New England Structure, reporting conventions and presentation of scientific investigations (Article)
https://www.hse.gov.uk/coshh/	Health and Safety Executive (HSE) Control of Substances Hazardous to Health (COSHH) (Standards/Regulatory guidance)
https://www.legislation.gov.uk/uksi/1999/3106/contents	UK Government Legislation Good Laboratory Practice (GLP) Regulations 1999 (Standards/Regulatory guidance)
https://www.initial.co.uk/blog/lab-waste-disposal-uk-guidelines/	Initial UK Laboratory waste disposal legislation including HTM 07-01 and Controlled Waste Regulations (Article)

Journals and articles

Fanelli, D. (2021) 'Opinion: Is science really facing a reproducibility crisis, and do we need it to?', *Proceedings of the National Academy of Sciences*, 115(11), pp. 2628–2631. Available at: https://doi.org/10.1073/pnas.1708272114.

Ioannidis, J.P.A. (2021) 'Meta-research: Why research on research matters', *PLOS Biology*, 16(3), e2005468. Available at: https://doi.org/10.1371/journal.pbio.2005468.

Munafò, M.R., *et al*. (2020) 'A manifesto for reproducible science', *Nature Human Behaviour*, 1(1), pp. 0021. Available at: https://doi.org/10.1038/s41562-016-0021.

Poldrack, R.A., Huckins, G. and Varoquaux, G. (2020) 'Establishment of Best Practices for Evidence for Prediction: A Review', *JAMA Psychiatry*, 77(5), pp. 534–540. Available at: https://doi.org/10.1001/jamapsychiatry.2019.3671.

Wilkinson, M.D., *et al*. (2016) 'The FAIR Guiding Principles for scientific data management and stewardship', *Scientific Data*, 3, 160018. Available at: https://doi.org/10.1038/sdata.2016.18.

Links

This unit links to the following related units:

Unit 501: Personal and Professional Development for Scientists

Unit 519: Science Laboratory Management.

Unit 503: Applied Molecular Biology

Unit code: **M/652/3061**

Unit level: **5**

Credit value: **15**

Introduction

Molecular biology plays a central role in modern applied science, underpinning work across biotechnology, medical diagnostics, environmental monitoring, genetics-based investigation and laboratory research. In applied science settings, practitioners are increasingly required not only to generate molecular data but also to interpret laboratory outputs using computational tools and analytical approaches. This unit is situated within that applied context, building on foundational biological knowledge and focusing on the practical and analytical capabilities required in contemporary laboratory and data-driven environments.

The unit emphasises professional practice in molecular biology, including the selection and use of appropriate analytical approaches, consideration of data quality, and interpretation of results within defined scenarios. Students will engage with laboratory-based and case-study contexts that reflect real-world constraints, such as methodological limitations, sources of error and fitness for purpose, while developing reliable and defensible scientific decision making.

Key areas of study include the analysis of nucleic acids using integrated laboratory and computational approaches, the generation and quantification of gene expression data, and the interpretation of molecular biological datasets using quantitative and qualitative methods. Students are also encouraged to engage with contemporary debates around genetic technologies, including gene therapy, genetically modified organisms and the regulation of human genome editing, developing their capacity for reasoned, ethically informed argument.

On completion of this unit, students will be able to apply molecular biology approaches in a critical and informed manner, using data to support interpretation and decision making in applied science contexts. They will be confident in the principles, techniques and applications that underpin applied molecular biology, supporting progression to higher-level study or roles within molecular genetics, biomedical science and biotechnology.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Investigate how nucleic acids are analysed using integrated laboratory and computational approaches

LO2 Explore how gene expression data are generated and quantified

LO3 Review how quantitative and qualitative approaches are applied to molecular biological data to generate informed decisions

LO4 Discuss, using real-world case studies, the suitability of molecular biology approaches for applied science contexts.

Essential Content

LO1 **Investigate how nucleic acids are analysed using integrated laboratory and computational approaches**

Integrated nucleic acid analysis workflows:

Laboratory components: analytical objectives, method selection, laboratory outputs

Computational components: downstream computational processing, data suitable for digital analysis, integration points, wet-lab outputs, bioinformatic tools.

Laboratory-based nucleic acid analysis approaches:

Nucleic acid extraction and purification principles: sample preparation and analysis; sample quality indicators; quantification approaches e.g. spectrophotometric and fluorometric measurement; amplification outputs e.g. polymerase chain reaction (PCR)-derived products; PCR variants e.g. qPCR, RT-PCR, multiplex; primer design; restriction enzymes; vector design; molecular cloning strategies; bacterial transformation and selection

Data; data formats generated by laboratory methods, sources of technical variability, quality control

Sequencing and genome editing: Sanger sequencing, next-generation sequencing platforms, CRISPR-Cas9; alternative genome editing approaches; recombinant protein expression and purification principles.

Computational analysis and data quality considerations:

Computational tools: sequence data handling e.g. alignment; basic annotation concepts, artefact recognition, controls, basic next generation sequencing (NGS) read analysis

Data quality: comparison against reference standards; comparators; bioinformatics e.g. BLAST, multiple sequence alignment, NCBI/Ensembl databases

Limitations: e.g. sources of error, output quality, signal strength, background noise, reliability, interpretability of integrated outputs.

LO2 **Explore how gene expression data are generated and quantified**

Gene expression data generation:

Data generation: sources of gene expression data, expression outputs, data type produced, replicates, controls

Experimental design: experimental contexts for expression measurement; laboratory-based techniques e.g. reverse transcription followed by quantitative analysis or sequencing-based approaches.

Quantification approaches for gene expression data:

Quantification: relative quantification approaches e.g. comparative C_T ($\Delta\Delta C_T$) models; absolute quantification models; threshold-based and comparative quantification principles; data normalisation concepts; reference or housekeeping genes

Selection: selection of appropriate quantification approaches; experimental context; accuracy; comparability; constraints e.g. dynamic range, sensitivity, reference selection.

LO3 **Review how quantitative and qualitative approaches are applied to molecular biological data to generate informed decisions**

Quantitative and qualitative data analysis approaches:

Quantitative measures: trends; patterns; variation within molecular biological datasets e.g. concentration values, expression fold-change data, read counts

Qualitative assessment of outputs: e.g. banding patterns, signal presence or absence, comparative profiles; triangulation of multiple data types; strengthened interpretation.

Data interpretation, limitations and uncertainty:

Limitations and uncertainty: anomalies e.g. inconsistencies within datasets; limitations arising from methodology, sample quality, analytical approach

Uncertainty: impact on interpretation; statistically observable trends; biologically meaningful conclusions; technical and biological sources of variation.

Decision making based on molecular biological data:

Analysed data: scientific or applied decisions; identified scenario; interpretive conclusions

Data quality: limitations; alternative interpretations; ambiguous or constrained data.

LO4 **Discuss, using real-world case studies, the suitability of molecular biology approaches for applied science contexts.**

Applied science contexts for molecular biology:

Applied science contexts: molecular biology within applied settings e.g. biotechnology, medical diagnostics, environmental monitoring, genetics-based investigation

Purpose: analytical approaches; applied objectives; stakeholder needs.

Suitability and fitness for purpose:

Suitability: suitability criteria e.g. sensitivity, specificity, scalability, turnaround time, robustness

Constraints: implementation constraints e.g. resource availability, technical expertise, regulatory requirements, ethical considerations.

Evaluation and recommendation of approaches:

Evaluation: selected methods; comparative assessment; alternative molecular biology approaches; case study context

Recommended approaches: evidence; limitations; risk; recommendations appropriate to the applied science setting.

Applications and ethics:

Applications: molecular diagnostics e.g. infectious disease, oncology, inherited disorders; pharmacogenomics and personalised medicine; gene therapy; recombinant therapeutic proteins; genetically modified organisms e.g. agriculture, industrial biotechnology; forensic DNA profiling; ancestry analysis

Ethics: ethical, legal and social issues e.g. heritable genome editing, biosecurity, data privacy, intellectual property, regulatory frameworks.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Investigate how nucleic acids are analysed using integrated laboratory and computational approaches</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate the suitability and limitations of integrated laboratory and computational approaches used to generate, quantify and interpret molecular biological data for the identified scenario.</td></tr>
<tr><td>P1 Investigate laboratory methods used to generate nucleic acid data for an identified context.

P2 Examine computational processing of nucleic acid data, including data quality and limitations.</td><td>M1 Critically analyse how integration of laboratory and computational approaches influences the quality and interpretability of nucleic acid analysis outputs for the identified context.</td></tr>
<tr><td colspan="2">LO2 Explore how gene expression data are generated and quantified</td></tr>
<tr><td>P3 Explore how gene expression data are generated for an identified context.

P4 Explain how gene expression data are quantified using appropriate approaches.</td><td>M2 Critically analyse the appropriateness of quantification approaches used for gene expression data in relation to the identified context and data quality constraints.</td></tr>
<tr><td colspan="2">LO3 Review how quantitative and qualitative approaches are applied to molecular biological data to generate informed decisions</td></tr>
<tr><td>P5 Analyse molecular biological data using appropriate quantitative and qualitative approaches.

P6 Assess the impact of limitations and uncertainty on data interpretation.</td><td>M3 Analyse molecular biological data to determine the significance of trends, anomalies and limitations in relation to the identified scenario.</td></tr>
<tr><td colspan="2">LO4 Discuss, using real-world case studies, the suitability of molecular biology approaches for applied science contexts.</td><td rowspan="2">LO4

D2 Critically evaluate, using real-world case studies, the suitability of molecular biology approaches in the applied science contexts, including ethical, legal and social considerations.</td></tr>
<tr><td>P7 Discuss, using real-world case studies, the suitability of molecular biology approaches for applied science contexts.

P8 Examine, using real-world case studies, constraints affecting the use of molecular biology approaches in applied science contexts.</td><td>M4 Analyse, using real-world case studies, how constraints affect the suitability of molecular biology approaches in applied science contexts.</td></tr>
</table>

Recommended Resources

Textbooks

Alberts, B., *et al.* (2022) *Molecular Biology of the Cell*. 7th edn. New York: W.W. Norton.

Brown, T.A. (2025) *Gene Cloning and DNA Analysis: An Introduction*. 9th edn. Hoboken: Wiley.

Doudna, J.A. and Sternberg, S.H. (2017) *A Crack in Creation: Gene Editing and the Unthinkable Power to Control Evolution*. Boston: Houghton Mifflin Harcourt.

Elliott, D. and Ladomery, M. (2016) *Molecular Biology of RNA*. 2nd edn. Oxford: Oxford University Press.

Green, M.R. and Sambrook, J. (2012) *Molecular Cloning: A Laboratory Manual*. 4th edn. Cold Spring Harbor: Cold Spring Harbor Laboratory Press.

Kappelmann-Fenzl, M. (ed.) (2021) *Next Generation Sequencing and Data Analysis*. Cham: Springer.

Klug, W.S., *et al.* (2022) *Concepts of Genetics*. 13th edn. Harlow: Pearson.

Lesk, A.M. (2019) *Introduction to Bioinformatics*. 5th edn. Oxford: Oxford University Press.

Pevsner, J. (2015) *Bioinformatics and Functional Genomics*. 3rd edn. Hoboken: Wiley-Blackwell.

Primrose, S.B. and Twyman, R.M. (2006) *Principles of Gene Manipulation and Genomics*. 7th edn. Oxford: Blackwell.

Strachan, T. and Read, A. (2018) *Human Molecular Genetics*. 5th edn. Boca Raton: Garland Science.

Watson, J.D., *et al.* (2013) *Molecular Biology of the Gene*. 7th edn. Cold Spring Harbor: Cold Spring Harbor Laboratory Press.

Websites

https://www.addgene.org/educational-resources/	Addgene Plasmid resources and gene expression tools (General reference)
https://www.bio-rad.com	Bio-Rad Laboratories PCR, qPCR and electrophoresis technologies (General reference)

https://www.ebi.ac.uk	European Bioinformatics Institute (EMBL-EBI) Bioinformatics tools, sequence databases and analysis platforms (General reference)
https://www.ensembl.org	Ensembl Genome Browser Genome annotation and comparative genomics tools (General reference)
https://www.genome.gov	National Human Genome Research Institute Genomics and applied molecular biology contexts (General reference)
https://www.nature.com/collections	Nature Research Molecular biology and genomics article collections (Research)
https://www.ncbi.nlm.nih.gov	National Center for Biotechnology Information (NCBI) Molecular biology databases and sequence analysis resources (General reference)
https://www.qiagen.com/gb	QIAGEN Sample preparation and nucleic acid analysis technologies (General reference)
https://www.thermofisher.com	Thermo Fisher Scientific Molecular biology techniques and applications (General reference)

Journals and articles

Bustin, S.A., *et al.* (2009) 'The MIQE guidelines: Minimum information for publication of quantitative real-time PCR experiments', *Clinical Chemistry*, 55(4), pp. 611–622. Available at: https://doi.org/10.1373/clinchem.2008.112797.

Bustin, S.A. and Huggett, J.F. (2017) 'qPCR primer design revisited', *Biomolecular Detection and Quantification*, 14, pp. 19–28. Available at: https://doi.org/10.1016/j.bdq.2017.11.001.

Conesa, A., *et al.* (2016) 'A survey of best practices for RNA-seq data analysis', *Genome Biology*, 17, Article 13. Available at: https://doi.org/10.1186/s13059-016-0881-8.

Garibyan, L. and Avashia, N. (2013) 'Polymerase chain reaction', *Journal of Investigative Dermatology*, 133(3), pp. 1–4. Available at: https://doi.org/10.1038/jid.2013.1.

Goodwin, S., McPherson, J.D. and McCombie, W.R. (2016) 'Coming of age: Ten years of next-generation sequencing technologies', *Nature Reviews Genetics*, 17(6), pp. 333–351. Available at: https://doi.org/10.1038/nrg.2016.49.

Love, M.I., Huber, W. and Anders, S. (2014) 'Moderated estimation of fold change and dispersion for RNA-seq data with DESeq2', *Genome Biology*, 15(12), Article 550. Available at: https://doi.org/10.1186/s13059-014-0550-8.

Marx, V. (2021) 'Method of the year: Spatially resolved transcriptomics', *Nature Methods*, 18(1), pp. 9–14. Available at: https://doi.org/10.1038/s41592-020-01033-y.

Nurk, S., *et al.* (2022) 'The complete sequence of a human genome', *Science*, 376(6588), pp. 44–53. Available at: https://doi.org/10.1126/science.abj6987.

Quince, C., *et al.* (2017) 'Shotgun metagenomics, from sampling to analysis', *Nature Biotechnology*, 35(9), pp. 833–844. Available at: https://doi.org/10.1038/nbt.3935.

Stark, R., Grzelak, M. and Hadfield, J. (2019) 'RNA sequencing: The teenage years', *Nature Reviews Genetics*, 20(11), pp. 631–656. Available at: https://doi.org/10.1038/s41576-019-0150-2.

Svensson, V., Vento-Tormo, R. and Teichmann, S.A. (2018) 'Exponential scaling of single-cell RNA-seq in the past decade', *Nature Protocols*, 13(4), pp. 599–604. Available at: https://doi.org/10.1038/nprot.2017.149.

Van den Berge, K., *et al.* (2019) 'RNA sequencing data: Hitchhiker's guide to expression analysis', *Annual Review of Biomedical Data Science*, 2, pp. 139–173. Available at: https://doi.org/10.1146/annurev-biodatasci-072018-021255.

Wang, Z., Gerstein, M. and Snyder, M. (2009) 'RNA-Seq: A revolutionary tool for transcriptomics', *Nature Reviews Genetics*, 10(1), pp. 57–63. Available at: https://doi.org/10.1038/nrg2484.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 419: Bioinformatics

Unit 525: Genomics and Proteomics.

Unit 504: Industrial Microbiology

Unit code: **R/652/3062**

Unit level: **5**

Credit value: **15**

Introduction

Industrial microbiology plays an important role in sectors including pharmaceuticals, food and beverage production, environmental biotechnology, biomanufacturing and industrial biotechnology. Microorganisms are used to produce valuable products and support industrial processes, including enzymes, antibiotics, organic acids, biofuels, recombinant proteins, wastewater treatment and bioremediation. As these applications continue to develop, scientists and technicians need to understand how microbial characteristics, process conditions, product recovery, quality systems and sustainability considerations affect industrial performance.

The aim of this unit is to develop students' understanding of the principles and applications of industrial microbiology. Students will explore how microorganisms are selected, cultivated, developed and controlled for industrial use, and how microbial structure, growth, metabolism and strain characteristics influence productivity, robustness, process suitability and product yield.

The unit content explores fundamental microbiological principles in industrial contexts, including microbial structure and function, growth kinetics, metabolism, organism selection, strain development, culture maintenance and biosafety. Students examine microbial cultivation and fermentation systems, including batch, fed-batch, continuous, solid-state, immobilised cell, aerobic, anaerobic, open and closed systems. They also consider process monitoring and control, scale-up, digital tools and AI in optimisation. The unit further explores microbial product recovery and downstream processing, including primary separation, clarification, cell disruption, purification and concentration methods.

On successful completion of this unit, students will be able to explain industrial microbiology principles, assess microbial fermentation systems, explore product recovery and downstream processing, and review regulatory, quality and sustainability requirements for an intended audience. These skills support progression into roles in industrial laboratories, biotechnology, bioprocessing, quality assurance, regulatory compliance, pharmaceutical production, food and beverage manufacturing and environmental biotechnology, as well as further study in microbiology, biotechnology and bioprocess science.

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Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core principles of industrial microbiology

LO2 Assess microbial fermentation systems and processes used in industrial microbiology

LO3 Explore, using real-world case studies or laboratory-based investigation, the techniques of microbial product recovery and downstream processing

LO4 Present a review of the regulatory, quality and sustainability considerations of industrial microbiology to an intended audience.

Essential Content

LO1 **Explain the core principles of industrial microbiology**

Fundamental microbiological principles in industrial contexts:

Microbiological principles: microbial cell structure and function e.g. differences between prokaryotic and eukaryotic microorganisms; yeast organelles supporting secretion of recombinant proteins; spore-formers in enzyme production e.g. *Bacillus* spp.; filamentous fungi e.g. *Aspergillus* spp.; morphology effects on viscosity and oxygen transfer e.g. pellets versus filaments

Industrial context: relevance of cellular structures and physiological characteristics to industrial productivity, robustness and process suitability e.g. Gram-negative outer membrane affecting solvent tolerance and contamination control;

Links: links between microbial form, function and industrial application e.g. *Escherichia coli* for recombinant protein expression; *Saccharomyces cerevisiae* for ethanol and food production; *Streptomyces* spp. for antibiotics; lactic acid bacteria for dairy processes.

Microbial growth, reproduction and metabolism in industrial systems:

Microbial growth: microbial growth phases e.g. lag, exponential, stationary and decline; relevance in industrial microbiology e.g. inoculum preparation to reduce lag phase, timing of harvest to optimise biomass or product yield; use of recognised models e.g. growth kinetics and Monod kinetics to describe and predict microbial behaviour

Influencing factors: factors influencing growth and population behaviour e.g. temperature, pH, oxygen availability, substrate concentration, inhibitory by-products, shear stress

Industrial contexts: microbial metabolism in industrial contexts e.g. carbon and nitrogen utilisation, energy generation, primary and secondary metabolism; relationship between metabolic activity and product formation e.g. ethanol, organic acids, enzymes, antibiotics, biomass.

Selection, application and development of microorganisms in industry:

Selection: criteria used to select microorganisms for industrial processes e.g. growth rate, metabolic capability, tolerance to process conditions, genetic stability, safety

Application: application across industrial sectors e.g. pharmaceuticals, food and beverage production, environmental biotechnology, biomanufacturing; use of microbial systems beyond controlled fermentation e.g. wastewater treatment, anaerobic digestion, bioremediation, biomining, industrial catalysis; use of specialised microorganisms e.g. extremophiles supporting high-temperature, high-salinity or low-pH processes; application of microbial consortia e.g. mixed cultures in environmental and industrial systems, interactions influencing stability, productivity, resilience

Development: strain development and maintenance strategies e.g. directed evolution, recombinant modification, preservation techniques; biosafety and culture management e.g. containment, traceability, maintenance of strain integrity

Links: links between microbial characteristics, process efficiency and industrial performance e.g. robustness reducing contamination risk, secretion reducing downstream processing requirements, tolerance enabling higher product yields.

LO2 **Assess microbial fermentation systems and processes used in industrial microbiology**

Industrial microbiology systems and cultivation approaches:

Cultivation systems: microbial cultivation systems used in industrial microbiology: application of fermentation alongside alternative production systems e.g. batch, fed-batch and continuous systems, solid-state systems for enzyme and food production, immobilised cell systems using carriers or matrices, biofilm-based processes

Cultivation approaches: aerobic and anaerobic processes; open versus closed systems e.g. closed bioreactors supporting asepsis in pharmaceutical production, open and semi-controlled systems in food and environmental applications; selection of systems based on organism characteristics and product type e.g. filamentous fungi in solid-state systems, immobilised enzymes for repeated or continuous use.

Process parameters, monitoring and control:

Parameters: environmental and operational parameters affecting microbial process performance e.g. temperature, pH, oxygen availability, agitation, nutrient supply; role of reactor design and operation in maintaining suitable growth conditions and supporting productivity e.g. vessel design influencing mixing and heat transfer, aeration systems improving oxygen transfer

Monitoring and control: monitoring and control strategies used in industrial microbiology e.g. pH monitoring, dissolved oxygen measurement, optical density or turbidity, feedback control systems, foam sensing, sterile sampling; automated control systems e.g. acid or base addition for pH regulation, cascade control of agitation and airflow to maintain oxygen levels.

Performance, efficiency and industrial application:

Performance: evaluation of microbial systems e.g. productivity, yield, robustness, consistency; contamination risk and control in industrial microbiology systems e.g. differences between high-value sterile processes and less controlled environmental systems; comparison of laboratory-scale, pilot-scale and industrial-scale systems e.g. challenges in scalability, oxygen transfer, mixing efficiency and heat removal

Industrial application: selection of systems for different industrial contexts e.g. high-control systems for biopharmaceutical production versus lower-cost systems for bulk products or environmental applications

Optimisation: trade-offs in industrial decision making e.g. control versus cost, scalability versus precision

Digital tools: role of digital tools and AI e.g. process monitoring, optimisation, design of industrial microbiology systems.

LO3 **Explore, using real-world case studies or laboratory-based investigation, the techniques of microbial product recovery and downstream processing**

Processes and industrial context:

Processes: industrial microbiology e.g. microbial product recovery, downstream processing, relationship between upstream production and downstream requirements

Industrial contexts: integration of unit operations within industrial workflows e.g. linking fermentation outputs to recovery and purification stages, alignment of process conditions with product stability

Developments: developments in industrial processing e.g. continuous bioprocessing, process intensification, integration of upstream and downstream operations, automation and real-time monitoring; influence of process design on yield, product quality, scalability and cost efficiency.

Product recovery and downstream techniques:

Product recovery: primary recovery approaches for biomass and product separation e.g. filtration, centrifugation, sedimentation, flocculation; clarification of process streams e.g. depth filtration, microfiltration; cell disruption methods for intracellular products e.g. high-pressure homogenisation, bead milling, enzymatic lysis

Downstream techniques: downstream purification and concentration techniques e.g. precipitation, solvent extraction, adsorption, chromatography, membrane-based processes such as ultrafiltration and diafiltration; application to different product types e.g. protein purification using ion-exchange and affinity chromatography, enzyme concentration, recovery of organic acids

Technique selection: selection of techniques based on product characteristics e.g. extracellular versus intracellular location, molecular size, charge, hydrophobicity, solubility, stability.

Performance, optimisation and industrial application:

Performance: evaluation and optimisation of recovery and downstream processing strategies; relationship between processing stages and yield, purity and product quality e.g. product loss across unit operations, impact of shear and foaming on biomolecules

Optimisation: trade-offs between purity, cost and processing time; comparison of laboratory-scale and industrial-scale processing e.g. scalability constraints, equipment limitations, process robustness; operational challenges e.g. filter fouling, solvent handling, chromatography resin cost and regeneration

Industrial applications: suitability of approaches for different industrial contexts e.g. low-cost bulk products such as bioethanol requiring minimal purification versus high-value biopharmaceuticals requiring multi-stage purification and tight quality control; application across industrial microbiology sectors e.g. food production, environmental biotechnology, biomanufacturing

Digital tools: role of digital tools and AI in process optimisation, data-driven decision-making and 'labs of the future'.

LO4 **Present a review of the regulatory, quality and sustainability considerations of industrial microbiology to an intended audience**

Regulation, risk and biosafety:

Regulation: regulatory frameworks governing industrial microbiology across sectors: legal and procedural requirements e.g. health and safety legislation, environmental regulation, product compliance in food and pharmaceutical manufacture; role of regulatory bodies and inspection systems e.g. good manufacturing practice (GMP) and good laboratory practice (GLP) frameworks, environmental compliance and discharge regulation

Risk and biosafety: risk assessment and control measures e.g. biological hazards, chemical risks, process safety; biosafety and containment principles e.g. safe handling of microorganisms, containment levels, prevention of organism escape; biosecurity considerations e.g. controlled access, secure storage, risk of misuse; global regulatory variation across industrial contexts.

Quality systems and industrial control:

Quality systems: quality frameworks and standards e.g. GMP, GLP, ISO systems; implementation of quality systems e.g. controlled documentation, training and competence, equipment calibration, deviation reporting, corrective and preventive actions (CAPA)

Control systems: contamination control and validation e.g. sterilisation validation, cleaning validation, environmental monitoring, in-process testing and release testing

Documentation: documentation and traceability e.g. batch records, logbooks, sample tracking, audit trails, change control systems; role of quality systems in ensuring consistency, compliance and product safety.

Sustainability, professional communication and digital practice:

Economic sustainability: resource efficiency and waste management in industrial microbiology e.g. reducing water and energy use, solvent recycling, effluent treatment; waste valorisation and circular bioeconomy approaches e.g. reuse of process residues

Environmental sustainability: environmental impact of industrial microbiology processes and mitigation strategies e.g. use of renewable feedstocks such as molasses or whey permeate

Communication: communication of technical information to different audiences e.g. summaries of batch performance, contamination trends, process deviations, recommendations

Digital tools: use of digital tools for data presentation e.g. dashboards, data visualisation, process monitoring; ethical and regulatory considerations in digital practice e.g. AI in research and manufacturing, data integrity, responsible use of digital systems.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Explain the core principles of industrial microbiology		**LO1, LO2 and LO3** **D1** Justify an integrated microbial production and downstream processing strategy for a specified product, with reference to microbiological principles, trade-offs and limitations.
P1 Discuss the relationship between microbial structure, function and industrial application. **P2** Explain how microbial growth, metabolism and organism selection influence industrial process performance.	**M1** Analyse how core microbiological principles influence industrial process performance.	
LO2 Assess microbial fermentation systems and processes used in industrial microbiology		
P3 Discuss microbial cultivation and fermentation systems used in industrial microbiology. **P4** Explore process parameters, monitoring and control methods used to support microbial process performance.	**M2** Assess the performance of different microbial production systems for a specified product in relation to efficiency and process control.	
LO3 Explore, using real-world case studies or laboratory-based investigation, the techniques of microbial product recovery and downstream processing		
P5 Investigate microbial product recovery techniques used in industrial microbiology. **P6** Explore downstream processing techniques used to support product yield, purity and quality.	**M3** Analyse the suitability of recovery and downstream processing strategies for a specified microbial product.	

Pass	Merit	Distinction
LO4 Present a review of the regulatory, quality and sustainability considerations of industrial microbiology to an intended audience		**LO4**
P7 Present a review of regulatory, quality and sustainability considerations in industrial microbiology to an intended audience. **P8** Discuss the effectiveness of regulatory, quality and sustainability considerations in supporting responsible industrial microbiology practice.	**M4** Assess the effectiveness of regulatory, quality and sustainability considerations in supporting responsible industrial microbiology practice.	**D2** Critically evaluate regulatory, quality and sustainability considerations in relation to compliance risk, product quality and sustainable industrial practice.

Recommended Resources

Textbooks

Agrawal, R. (2024) *Textbook of Industrial Microbiology*. Cham: Springer Nature.

Beschkov, V.N. and Yankov, D. (2021) *Downstream Processing in Biotechnology*. Berlin: De Gruyter.

Crueger, W., Crueger, A. and Aneja, K.R. (2017) *Crueger's Biotechnology: A Textbook of Industrial Microbiology*. 3rd edn. New Delhi: Medtech.

El-Mansi, E.M.T., *et al.* (eds.) (2019) *Fermentation Microbiology and Biotechnology*. 4th edn. Boca Raton: CRC Press.

Najafpour, G.D. (2024) *Biochemical Engineering and Biotechnology*. 3rd edn. Amsterdam: Elsevier.

Shuler, M.L., Kargi, F. and DeLisa, M.P. (2017) *Bioprocess Engineering: Basic Concepts*. 3rd edn. Upper Saddle River: Prentice Hall.

Soetaert, W. and Vandamme, E.J. (eds.) (2010) *Industrial Biotechnology: Sustainable Growth and Economic Success*. Weinheim: Wiley-VCH.

Stanbury, P.F., Whitaker, A. and Hall, S.J. (2024) *Principles of Fermentation Technology*. 4th edn. Oxford: Butterworth-Heinemann.

Websites

https://www.fda.gov	U.S. Food and Drug Administration Current Good Manufacturing Practice (CGMP) regulations and guidance (Regulatory guidance)
https://www.ecfr.gov	Electronic Code of Federal Regulations 21 CFR Part 211 - Current Good Manufacturing Practice for Finished Pharmaceuticals (Regulatory guidance)
https://www.ema.europa.eu	European Medicines Agency Guidelines on GMP and biological medicinal products (Regulatory guidance)

https://www.who.int	World Health Organization WHO Technical Report Series - GMP for biological products (Regulatory guidance)
https://www.microbiologynotes.org	Microbiology Notes Downstream processing methods and unit operations (General reference)
https://www.frontiersin.org	Frontiers Journals Industrial microbiology, bioprocessing and sustainability research (Research)
https://biomanufacturing.org/curriculum-resources/program-units/downstream-processing	Northeast Biomanufacturing Center Bioprocessing and downstream processing educational resources (Training)
https://www.pharmacopoeia.com/	British Pharmacopoeia Quality standards for pharmaceutical microbiology (Standards)
https://www.iso.org	International Organization for Standardization ISO standards related to quality, environment and biotechnology (Standards)
https://www.statista.com	Statista Industrial biotechnology and bioprocess market data (Datasets)

Journals and articles

Agarwal, A., *et al.* (2021) 'Downstream Processing; Applications and Recent Updates', in Srivastava, N., Srivastava, *et al.* (eds.) *Bioprocessing for Biofuel Production: Strategies to Improve Process Parameters*. Singapore: Springer, pp. 29–55. Available at: https://doi.org/10.1007/978-981-15-7070-4_2.

Buarque, F.S., Lemes, A.C. and Coelho, M.A.Z. (2025) 'Advances in Industrial Biotechnology: Bioprocess and Bioseparation', *Processes*, 13(4), 1101. Available at: https://doi.org/10.3390/pr13041101.

Choi, K.R., *et al.* (2019) 'Systems metabolic engineering strategies: Integrating systems and synthetic biology with metabolic engineering', *Trends in Biotechnology*, 37(8), pp. 817–837. Available at: https://doi.org/10.1016/j.tibtech.2019.01.003.

Mandeep and Shukla, P. (2020) 'Microbial nanotechnology for bioremediation of industrial wastewater', *Frontiers in Microbiology*, 11, 590631. Available at: https://doi.org/10.3389/fmicb.2020.590631.

Nielsen, J. and Keasling, J.D. (2016) 'Engineering cellular metabolism', *Cell*, 164(6), pp. 1185–1197. Available at: https://doi.org/10.1016/j.cell.2016.02.004.

Sharma, N., *et al.* (2025) 'Microbial enzymes in industrial biotechnology: Sources, production, and significant applications of lipases', *Journal of Industrial Microbiology and Biotechnology*, 52, kuaf010. Available at: https://doi.org/10.1093/jimb/kuaf010.

Straathof, A.J.J. (2014) 'Transformation of biomass into commodity chemicals using enzymes or cells', *Chemical Reviews*, 114(3), pp. 1871–1908. Available at: https://doi.org/10.1021/cr400309c.

Vees, C.A., Neuendorf, C.S. and Pflügl, S. (2020) 'Towards continuous industrial bioprocessing with solventogenic and acetogenic clostridia: Challenges, progress and perspectives', *Journal of Industrial Microbiology and Biotechnology*, 47(9-10), pp. 753–787. Available at: https://doi.org/10.1007/s10295-020-02296-2.

Walsh, G. and Walsh, E. (2022) 'Biopharmaceutical benchmarks 2022', *Nature Biotechnology*, 40(12), pp. 1722–1760. Available at: https://doi.org/10.1038/s41587-022-01582-x.

Wang, Y., (2021) 'Microbial cell factories for green production of vitamins', *Frontiers in Bioengineering and Biotechnology*, 9, 661562. Available at: https://doi.org/10.3389/fbioe.2021.661562.

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 503: Applied Molecular Biology

Unit 505: Ethics and Biotechnology

Unit 506: Medical Microbiology

Unit 521: Infectious Disease Epidemiology and Control.

Unit 505: Ethics and Biotechnology

Unit code: **T/652/3063**

Unit level: **5**

Credit value: **15**

Introduction

Biotechnology is reshaping applied science through developments in gene editing, synthetic biology, stem-cell technologies, gene and cell therapies, AI-enabled genomics, genetically modified organisms and environmental biotechnology. These advances create new possibilities in healthcare, agriculture, industry and sustainability, but also raise complex ethical questions about risk, benefit, consent, justice, public trust and professional responsibility.

This unit enables students to examine ethical theories and decision-making frameworks that support responsible judgement in biotechnology. Students will consider how principles such as autonomy, beneficence, non-maleficence, justice, rights, consequences and professional integrity can be applied to real-world contexts, including clinical research, genomic data use, environmental release, commercial development and emerging therapeutic applications.

The unit also explores the regulatory landscape governing biotechnology across national and international settings. Students will consider the role of regulatory bodies, governance systems, ethical approval, compliance requirements, data protection, documentation, risk management and post-deployment monitoring. They will analyse how regulation shapes research design, innovation, clinical use, environmental application and commercial deployment, including the challenges created by differing requirements across global markets.

On completion of this unit, students will be able to analyse ethical and regulatory issues in biotechnology and develop coherent, ethically justified responses to real-world scenarios. They will be prepared to evaluate uncertainty, competing stakeholder interests, societal impact and potential unintended consequences. This unit supports progression to further study in applied sciences, biotechnology, bioethics, regulatory science or related disciplines, and to roles in laboratory science, research, quality, regulatory affairs, healthcare innovation and responsible biotechnology development.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss the core ethical theories and frameworks relevant to biotechnology

LO2 Review the regulatory landscape governing biotechnological research and applications

LO3 Explore the implications of emerging biotechnologies on society

LO4 Develop ethically justified responses to an identified real-world biotechnology scenario.

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Essential Content

LO1 **Discuss the core ethical theories and frameworks relevant to biotechnology**

Ethical theories and moral frameworks:

Ethical theories: normative ethical theories e.g. utilitarianism, deontology, virtue ethics; rights-based approaches e.g. autonomy, beneficence, non-maleficence, justice, moral duty, consequences, character, rights; ethical tension in biotechnology decision making

Moral frameworks: population-level benefit versus risk e.g. in gene-drive mosquitoes; informed consent in first-in-human gene therapy; privacy and control of genomic data in biobanks; researcher honesty; uncertainty and safety reporting.

Ethical decision-making frameworks in biotechnology:

Ethical decision-making frameworks: issue identification e.g. evaluation of options; research design, innovation and development e.g. incidental findings from whole-genome sequencing, animal models versus organoids in preclinical testing; stakeholder consideration e.g. CRISPR crop trial stakeholders; justification of decisions e.g. values, duties, consequences, professional judgement; clinical use; environmental release; commercial application; AI-assisted diagnostic tools in genomics, bias in training datasets.

Ethics in professional biotechnological contexts:

Professional ethical responsibilities: e.g. professional standards, ethical guidelines, codes of conduct, accountability, transparency, integrity, research governance; balancing innovation, public benefit, sustainability and potential harm

Managing uncertainty and risk: preregistering outcomes; reporting negative results e.g. responding to contamination events; managing conflicts of interest; balancing commercial timelines with patient safety; precaution in environmental biotechnology.

LO2 **Review the regulatory landscape governing biotechnological research and applications**

Regulatory frameworks and oversight:

Regulatory frameworks and oversight: e.g. national and international regulatory systems; approval, licensing and monitoring processes e.g. research, development, clinical use, environmental use, commercial deployment, preclinical laboratory studies, first-in-human gene therapy trials, biomarker assays, genetically modified organism (GMO) field trials

Ethics approval: clinical trial authorisation; marketing authorisation; post-market surveillance e.g. HFEA, HTA, MHRA, EMA, FDA, PMDA, NMPA, CBD, Cartagena Protocol, WHO frameworks, regulatory disparities across global markets.

Compliance requirements and standards:

Compliance requirements: quality standards e.g. legal, ethical and quality requirements, research governance, ethical approval, informed consent, risk definition, risk classification and risk management

Data protection standards: digital data governance e.g. GDPR provisions on genetic data, security, data integrity; documentation and record keeping; traceable laboratory records; deviation reporting, instrument-generated results; bioinformatics pipelines, clinical-use materials.

Regulation in practice:

Regulation in practice: regulatory constraints and enablers e.g. influence of regulatory requirements on research design, innovation and application; ethical responsibility; risk management, sustainability, public trust, consequences of non-compliance, study protocol redesign

Compliance across jurisdictions: product labelling and claims across countries e.g. gene-edited organisms across jurisdictions, inadequate consent, weak data security, incomplete batch records, cultural and religious considerations, global governance, biosecurity challenges.

LO3 **Explore the implications of emerging biotechnologies on society**

Emerging biotechnologies:

Emerging biotechnologies: e.g. CRISPR-Cas systems, human germline and somatic genome editing, He Jiankui case, heritable genome modification, synthetic biology, organoids, gene drives, microbiome interventions, AI-enabled genomics, stem–cell research, embryonic stem cells, induced pluripotent stem cells, therapeutic and reproductive cloning, mitochondrial replacement therapy, preimplantation genetic testing, whole-genome sequencing, direct-to-consumer genetic testing, forensic and ancestry DNA databases, gene and cell therapies, Luxturna, Zolgensma, Casgevy, chimeric antigen receptor T-cell (CAR-T), advanced therapy medicinal products (ATMP) regulation, GM crops, precision breeding, engineered microbes for biofuels, bioremediation, bio-manufactured pharmaceuticals, dual-use research of concern, gain-of-function research

Regulation: EU and post-Brexit UK divergence; biosecurity governance.

Societal and ethical implications:

Societal and ethical implications: societal values e.g. risk–benefit analysis, proportionality, uncertainty, public perception, acceptance and concern, disparities in risk exposure and benefit access between high- and lower-income nations

Ethical implications: ethical debates e.g. distribution of benefits, risks and burdens, equity, access, justice, environmental and societal sustainability, germline editing and designer traits, unequal access to advanced gene therapies, genetic surveillance and discrimination, food security and environmental concerns, cultural views on modifying organisms.

Stakeholders and impact:

Stakeholders: e.g. patients, clinicians, health systems, insurers, regulators, advocacy groups, researchers, commercial organisations, investors, communities, environmental groups

Impact: e.g. stakeholder roles, interests and responsibilities, competing interests, ethical tension, risk, benefit and harm, public trust, transparency, legitimacy, short-term and long-term societal consequences, affordability, patient safety, ecological spillover, health inequalities.

LO4 **Develop ethically justified responses to an identified real-world biotechnology scenario**

Ethical analysis of biotechnology scenarios:

Ethical analysis of biotechnology scenarios: identification of ethical issues e.g. real-world biotechnology contexts, stage of technological development, strength of evidence base, methodological uncertainty, digital data use, automation, algorithmic decision making

Ethical theories and frameworks: regulatory, legal and compliance considerations e.g. whole-genome sequencing in hospitals, consent, incidental findings, privacy, algorithmic interpretation, environmental release proposals, reversibility, harm pathways, monitoring, limited evidence, small trials, short follow-up.

Development of an ethically justified response:

Ethically justified responses: justification of ethical choices and decisions e.g. coherent ethical response, ethical frameworks, regulatory requirements, competing stakeholder interests, balancing benefits, risks, sustainability, potential harms

Uncertainty: ethical disagreement e.g. stronger consent models, restricted data access, independent oversight, phased trials, post-deployment monitoring, precaution where harms may be widespread or irreversible, public benefit and individual rights in data sharing.

Evaluation and reflection:

Evaluation and reflection: risk–benefit considerations e.g. wider societal implications; limitations, risks, potential unintended consequences; alternative ethical approaches; public trust following adverse events; ecological effects; rights-based and utilitarian responses; sustainability and Net Zero; stem cell technologies e.g. moral status of the embryo; induced pluripotent stem cells; commercialisation pressures

Case study examples: biotechnology research and industrial applications e.g. CRISPR-Cas9 genome editing, therapeutic applications, germline modification, 2018 He Jiankui case, genetically modified organisms, synthetic biology, novel organisms

Regulation: regulatory divergence between the EU and US intellectual property, compulsory licensing; MIT Registry, DIY bio, open-source life; policy and practice implications

Access to technology: inequitable access food sovereignty in the Global South; biopharmaceuticals and access, COVID-19 vaccine inequality.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss the core ethical theories and frameworks relevant to biotechnology</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate how ethical frameworks and regulatory and compliance requirements interact to shape responsible decision making in biotechnological research and applications, using a real-world scenario.</td></tr>
<tr><td>P1 Discuss ethical theories and principles relevant to biotechnology.

P2 Review how ethics and ethical decision-making frameworks are applied to biotechnology contexts.</td><td>M1 Analyse the effectiveness of ethical theories and frameworks in applied biotechnology contexts.</td></tr>
<tr><td colspan="2">LO2 Review the regulatory landscape governing biotechnological research and applications</td></tr>
<tr><td>P3 Review regulatory frameworks and oversight relevant to biotechnological research and applications.

P4 Discuss how compliance requirements are applied to biotechnological research and applications.</td><td>M2 Assess the impact of regulatory and compliance requirements on the development and use of biotechnological research and applications.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Explore the implications of emerging biotechnologies on society		**LO3 and LO4** **D2** Critically evaluate the ethical response developed for the identified real-world biotechnology scenario in relation to wider societal implications, limitations and potential unintended consequences.
P5 Discuss key features, applications and associated uncertainty of emerging biotechnologies. **P6** Explore societal, ethical and stakeholder implications of emerging biotechnologies.	**M3** Analyse the implications of emerging biotechnologies for society in relation to risk, benefit, ethical tension and stakeholder impact.	
LO4 Develop ethically justified responses to an identified real-world biotechnology scenario		
P7 Develop an ethical response to an identified real-world biotechnology scenario using ethical frameworks and regulatory considerations. **P8** Review the effectiveness of the developed ethical response to an identified real-world biotechnology scenario using ethical frameworks and regulatory considerations.	**M4** Justify the decisions made in the development of an ethical response to an identified real-world biotechnology scenario, considering alternatives.	

Recommended Resources

Textbooks

Barrett, D.H., *et al.* (eds.) (2016) *Public Health Ethics: Cases Spanning the Globe*. Cham: Springer.

Beauchamp, T.L. and Childress, J.F. (2024) *Principles of Biomedical Ethics*. 9th edn. New York: Oxford University Press.

Bennett, G. (ed.) (2017) *The Ethics of Biotechnology*. Abingdon: Routledge.

Chadwick, R.F. and Schüklenk, U. (2020) *This is Bioethics: An Introduction*. Hoboken, NJ: Wiley-Blackwell.

Harris, J. (2016) *How to Be Good: The Possibility of Moral Enhancement*. Oxford: Oxford University Press.

Jasanoff, S. (2016) *The Ethics of Invention: Technology and the Human Future*. New York: W.W. Norton.

Websites

https://www.fda.gov/vaccines-blood-biologics/cellular-gene-therapy-products	Food and Drug Administration (FDA) Regulation of biotechnology products, including gene therapies, GM organisms and biologics (General reference)
https://www.gov.uk/government/collections/genetically-modified-organisms-applications-and-consents	UK Government Genetically modified organisms and biotechnology regulation (General reference)
https://www.nuffieldbioethics.org/publication/emerging-biotechnologies-technology-choice-and-the-public-good/	Nuffield Council on Bioethics Ethics of emerging biotechnologies and life sciences (Research)

https://www.oecd.org/en/publications/anticipatory-governance-for-responsible-innovation-in-synthetic-biology_864dd003-en.html	Organisation for Economic Co-operation and Development (OECD) Biotechnology policy, governance and ethics (General reference)
https://phrma.org/about/ethics-codes-guidelines	Pharmaceutical Research and Manufacturers of America (PhRMA) Ethics codes and compliance frameworks in biotechnology and pharmaceuticals (General reference)
https://www.springernature.com/gp/editors/editor-courses/course-research-ethics	Springer Nature Ethics in biotechnology and life sciences research (Training)
www.unesco.org	United Nations Educational, Scientific and Cultural Organization (UNESCO) (General reference)
https://usbiotechnologyregulation.mrp.usda.gov/biotechnologygov/home	United States Department of Agriculture (USDA) Unified framework for biotechnology regulation (General reference)
https://www.who.int/teams/health-ethics-governance/emerging-technologies/human-genome-editing	World Health Organization (WHO) Ethics, governance and biotechnology in global health (General reference)

www.wma.net	World Medical Association (WMA) Ethical standards and declarations relevant to biomedical practice (General reference)
www.thehastingscenter.org	The Hastings Center for Bioethics Resources on bioethics relevant to the latest technological developments (General reference)
www.nationalacademies.org	National Academies Artificial intelligence code of conduct for health and medicine (Report)

Journals and articles

Abushal, L.T., *et al.* (2021) 'Agricultural biotechnology: Revealing insights about ethical concerns', *Journal of Biosciences*, 46, Article 81. Available at: https://doi.org/10.1007/s12038-021-00203-0.

Juengst, E.T. (2021) '"Prevention" and human gene editing governance', *AMA Journal of Ethics*, 23(1), pp. E49–E54. Available at: https://doi.org/10.1001/amajethics.2021.49.

Juengst, E.T., *et al.* (2024) 'Preventive human genome editing and enhancement: Candidate criteria for governance', *Hastings Center Report*, 54(5), pp. 14–23. Available at: https://doi.org/10.1002/hast.4913.

Levidow, L. and Raman, S. (2020) 'Sociotechnical imaginaries of low-carbon waste-energy futures: UK techno-market fixes displacing public accountability', *Social Studies of Science*, 50(4), pp. 609–641. Available at: https://doi.org/10.1177/0306312720905084.

Marchant, G.E. (2021) 'Global governance of human genome editing: What are the rules?', *Annual Review of Genomics and Human Genetics*, 22, pp. 385–405. Available at: https://doi.org/10.1146/annurev-genom-111320-091930.

Maurya, P. (2024) 'Biotechnology ethics and regulatory frameworks', *The Spectrum of Discovery*, 15, pp. 1–15. Available at: https://www.academia.edu/143647368/Biotechnology_Ethics_and_Regulatory_Frameworks.

Schneider, M., Vayena, E. and Blasimme, A. (2023) 'Digital bioethics: Introducing new methods for the study of bioethical issues', *Journal of Medical Ethics*, 49(11), pp. 783–790. Available at: https://doi.org/10.1136/medethics-2021-107387.

Taylor, K. and Woods, S. (2020) 'Reflections on the practice of responsible (research and) innovation in synthetic biology', *New Genetics and Society*, 39(2), pp. 127–147. Available at: https://doi.org/10.1080/14636778.2019.1709431.

Vayena, E., Blasimme, A. and Cohen, I.G. (2018) 'Machine learning in medicine: Addressing ethical challenges', *PLOS Medicine*, 15(11), e1002689. Available at: https://doi.org/10.1371/journal.pmed.1002689.

Links

This unit links to the following related units:

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 503: Applied Molecular Biology

Unit 504: Industrial Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 520: Stem Cell Biology

Unit 521: Infectious Disease Epidemiology and Control

Unit 523: Principles of Pharmacology

Unit 524: Immunology

Unit 525: Genomics and Proteomics.

Unit 506: Medical Microbiology

Unit code: **Y/652/3064**

Unit level: **5**

Credit value: **15**

Introduction

Medical microbiology is central to understanding, investigating and managing infectious disease in healthcare, diagnostic and applied science settings. It brings together knowledge of medically relevant microorganisms, host responses, laboratory investigation and antimicrobial treatment. This unit supports students preparing for progression in biomedical science, microbiology, infection science, healthcare science and related laboratory-based sectors.

Students will examine the taxonomy, structure and physiology of microorganisms that are significant to human health, including bacteria, viruses, fungi, protozoa and helminths. They will consider how classification, cellular organisation, growth requirements and physiological adaptations influence identification, survival, transmission and clinical significance. This provides the biological foundation needed to understand how microorganisms behave in different clinical and environmental contexts.

The unit also explores microbial pathogenicity, host–pathogen interactions and antimicrobial resistance. Students will consider mechanisms such as colonisation, invasion, toxin production, immune evasion and biofilm formation, as well as the immune responses that influence infection outcomes. They will examine the principles of antimicrobial action, the development and spread of resistance, and the role of antimicrobial stewardship in supporting evidence-based treatment and protecting public health.

On completion of this unit, students will be able to apply microbiological knowledge to the analysis of infectious processes, laboratory findings and case-based investigations. They will be able to evaluate the suitability, validity and limitations of methods used to identify and analyse microorganisms, including culture-based, immunological, molecular and susceptibility testing approaches. The knowledge and skills developed support progression to further study or employment in biomedical science, microbiology, diagnostics, infection control, healthcare support, quality assurance and related applied science roles.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the taxonomy, structure and physiology of medically relevant microorganisms

LO2 Describe the mechanisms of microbial pathogenicity and host–pathogen interactions

LO3 Discuss the principles of antimicrobial agents and the development of antimicrobial resistance

LO4 Explore, using either real-world case studies or laboratory-based investigation, the laboratory methods used in the identification and analysis of microorganisms.

Essential Content

LO1 **Explain the taxonomy, structure and physiology of medically relevant microorganisms**

Microbial taxonomy and classification:

Taxonomy: principles of microbial taxonomy and classification: three-domain classification of cellular life e.g. Bacteria, Archaea, Eukarya; medically relevant infectious groups e.g. bacteria, viruses, fungi, protozoa, helminths; viruses as acellular infectious agents classified separately; hierarchical classification e.g. domain, kingdom, phylum, class, order, family, genus, species, strain

Nomenclature: binomial nomenclature and clinical naming conventions e.g. *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus* (MRSA)

Classification: phenotypic, genotypic and molecular classification e.g. morphology, staining reactions, biochemical profiles, polymerase chain reaction (PCR), 16S rRNA sequencing, whole-genome sequencing, phylogenetic analysis; distinction between normal microbiota, opportunists and pathogens

Clinical relevance: clinical relevance to identification, transmission, disease association and management e.g. Gram reaction guiding empirical therapy, enveloped viruses showing susceptibility to detergents and alcohol-based hand rubs, Enterobacterales association with urinary tract infections.

Cellular structure and organisation:

Structure: structural features of medically relevant bacteria, viruses, fungi and protozoa; prokaryotic and eukaryotic organisation e.g. nucleoid, nucleus, 70S and 80S ribosomes, membrane-bound organelles; bacterial cell envelopes e.g. peptidoglycan, teichoic acids, outer membrane, lipopolysaccharide

Identification: staining and identification features e.g. Gram-positive bacteria, Gram-negative bacteria, acid-fast organisms with mycolic acids

Survival: survival and virulence structures e.g. capsules, pili, flagella, spores; viral structure e.g. capsid, genome type, envelope, attachment proteins; fungal and protozoal structures e.g. chitin cell walls, ergosterol membranes, yeasts, moulds, trophozoites, cysts

Organisation: relationships between structure, survival, transmission and pathogenicity e.g. capsule in *Streptococcus pneumoniae*, lipopolysaccharide as endotoxin, pili in uropathogenic *Escherichia coli*, non-enveloped viruses persisting on surfaces.

Microbial physiology and growth requirements:

Microbial physiology: microbial metabolism and energy generation e.g. aerobic respiration, anaerobic respiration, fermentation

Requirements: nutritional and environmental growth requirements e.g. oxygen, temperature, pH, water activity, enriched media

Growth: growth kinetics and measurement e.g. lag phase, log phase, stationary phase, colony-forming units, turbidity; survival adaptations e.g. endospores, capsules, biofilms; regulation of microbial behaviour e.g. quorum sensing, virulence gene expression, environmental triggers

Organisation: relationship between physiology, infection control and treatment e.g. biofilms reducing antimicrobial penetration, anaerobes growing in low-oxygen tissues, spore-forming organisms requiring enhanced decontamination; applied contexts e.g. catheter-associated infection, culture conditions, device-associated biofilms.

LO2 **Describe the mechanisms of microbial pathogenicity and host–pathogen interactions**

Mechanisms of microbial pathogenicity:

Mechanisms: pathogenicity, virulence and infectious dose; colonisation, carriage and infection; routes of entry and exit e.g. respiratory tract, gastrointestinal tract, urogenital tract, skin and wounds, blood

Adhesion and tropism: e.g. pili and adhesins in uropathogenic *Escherichia coli*; invasion and dissemination e.g. local tissue invasion, bloodstream spread, tissue tropism; toxin-mediated disease e.g. exotoxins, endotoxin, A-B toxins, superantigens

Immune evasion: e.g. capsules, antigenic variation, intracellular survival, biofilm formation; regulation of virulence e.g. quorum sensing, iron limitation, environmental signalling; opportunistic and healthcare-associated infection e.g. device-associated biofilms, infections in immunocompromised hosts.

Host immune responses and interactions:

Host immune responses: innate immune defences e.g. physical barriers, antimicrobial peptides, complement, phagocytosis, inflammation

Recognition: pathogen recognition and signalling e.g. pattern recognition receptors, pathogen-associated molecular patterns, Toll-like receptor recognition of lipopolysaccharide

Adaptive immune responses: e.g. antigen presentation, clonal selection, antibody-mediated immunity, cell-mediated immunity; immune modulation and immunopathology e.g. excessive inflammation, tissue damage, immune suppression

Interactions: host factors influencing susceptibility e.g. age, vaccination status, comorbidities, immunosuppression, microbiome disruption after antibiotics

Outcomes: interaction outcomes e.g. clearance, asymptomatic carriage, acute disease, latency, chronic infection, reinfection; immune escape e.g. antigenic drift in influenza viruses.

Disease progression and clinical outcomes:

Stages of infection and incubation: localised and systemic infection; determinants of disease severity e.g. virulence factors, microbial load, site of infection, immune competence; acute, chronic and opportunistic infection patterns

Clinical outcomes: relationship between pathogenesis, clinical presentation and diagnostic findings e.g. toxin-mediated disease producing severe symptoms with low organism burden, intracellular pathogens requiring cell-mediated immunity

Complications: complications and sequelae e.g. post-infectious inflammatory complications; prevention and control linked to chain of infection e.g. reservoir, transmission route, susceptible host, hand hygiene, contact precautions, vaccination.

LO3 **Discuss the principles of antimicrobial agents and the development of antimicrobial resistance**

Principles of antimicrobial action:

Antimicrobial action: antimicrobial classes and spectrum of activity e.g. narrow-spectrum and broad-spectrum agents; bactericidal and bacteriostatic action; selective toxicity and therapeutic index; cellular and molecular targets e.g. cell wall synthesis, protein synthesis, nucleic acid synthesis, metabolic pathways, membrane integrity

Dynamics: pharmacodynamics e.g. time-dependent killing, concentration-dependent killing, post-antibiotic effect

Clinical outcomes: factors affecting clinical effectiveness e.g. tissue penetration, inoculum effect, biofilm tolerance, host immune status, adherence to dosing; adverse effects e.g. microbiome disruption, antibiotic-associated diarrhoea, *Clostridioides difficile* infection risk; combination therapy e.g. synergy, antagonism, broad empirical cover, reduced emergence of resistance.

Development and spread of antimicrobial resistance:

Intrinsic and acquired resistance: selective pressure and fitness cost; mutation-driven resistance and adaptive responses; horizontal gene transfer e.g. conjugation, transduction, transformation; mobile genetic elements e.g. plasmids, transposons, integrons; resistance mechanisms e.g. enzymatic inactivation, β-lactamases, target modification, altered penicillin-binding proteins, reduced permeability, porin loss, efflux pumps, target protection, metabolic bypass

Causes of resistance: e.g. biofilms and persister cells contributing to tolerance and treatment failure; cross-resistance and co-selection

Examples: clinical examples e.g. extended-spectrum β-lactamase-producing Enterobacterales, methicillin-resistant *Staphylococcus aureus* (MRSA), carbapenemase-producing organisms.

Detection, stewardship and sustainability considerations:

Detection: laboratory susceptibility testing and interpretation e.g. minimum inhibitory concentration, breakpoints, susceptible, intermediate and resistant categories, local antibiograms; evidence-based antimicrobial use e.g. right drug, dose, route and duration, de-escalation, intravenous-to-oral switch

Stewardship: stewardship strategies e.g. prescribing guidelines, formulary restriction, audit and feedback, prescribing review; infection prevention and control e.g. screening, isolation, hand hygiene, device care bundles; surveillance and reporting e.g. local and national antimicrobial resistance datasets, outbreak signals

Sustainability: sustainability and global health impacts of antimicrobial resistance; evaluation of antimicrobial use in relation to patient outcomes, population-level consequences and preservation of antimicrobial effectiveness.

LO4 **Explore, using either real-world case studies or laboratory-based investigation, the laboratory methods used in the identification and analysis of microorganisms**

Laboratory identification methods:

Limitations: pre-analytical factors affecting validity e.g. specimen selection, aseptic collection, labelling, transport time and temperature, contamination risk; incubation requirements e.g. aerobic, anaerobic, carbon dioxide-enriched conditions, temperature, duration

Methods: microscopy and staining e.g. Gram stain, acid-fast stain, wet mount, rapid presumptive identification; culture-based methods e.g. enrichment, selective media, differential media, colony morphology, haemolysis; phenotypic identification e.g. biochemical tests, enzyme tests, commercial identification panels; immunological, antigen detection and molecular methods e.g. lateral flow assays, enzyme immunoassays, PCR, nucleic acid amplification tests, gene targets, sequencing, syndromic panels; antimicrobial susceptibility testing e.g. disc diffusion, minimum inhibitory concentration, automated susceptibility testing.

Analysis and interpretation of laboratory findings:

Interpretation: interpretation of microscopy, culture, immunological and molecular outputs in relation to specimen type and clinical context; differentiation between colonisation, contamination and infection e.g. skin flora in blood culture, significant bacteriuria, mixed growth

Quantitative and semi-quantitative interpretation: e.g. colony counts, threshold values, organism burden; triangulation of findings across methods e.g. stain, culture, antigen test, molecular result

Quality control: quality control and assurance e.g. positive controls, negative controls, internal controls, repeat testing triggers; method selection for diagnostic purpose e.g. screening, confirmation, outbreak investigation, monitoring treatment response; communication of clinically significant results e.g. urgent reporting, critical values, clear reporting conventions.

Validity, limitations, suitability and digital considerations:

Validity: analytical performance and uncertainty e.g. sensitivity, specificity, predictive values, false positives, false negatives

Limitations and suitability: limitations and sources of error e.g. sampling error, prior antimicrobial use, mixed cultures, inhibitory substances in molecular testing; suitability of methods in different contexts e.g. speed, accuracy, cost, biosafety, laboratory capacity, clinical urgency; comparison of methods e.g. culture enabling antimicrobial susceptibility testing, nucleic acid amplification tests enabling rapid detection, sequencing supporting outbreak investigation

Safety: biosafety and risk assessment e.g. containment level, personal protective equipment, decontamination, waste disposal; sustainability and laboratory stewardship e.g. consumables, reagent use, energy use, targeted testing, waste management

Digital considerations: digital microbiology and data governance e.g. laboratory information management systems, barcoding, audit trails, automated identification and susceptibility platforms, digital microscopy, database-supported interpretation, cybersecurity, data integrity, interoperability, system downtime, turnaround time.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the taxonomy, structure and physiology of medically relevant microorganisms</td><td rowspan="7">LO1, LO2 and LO3

D1 Critically evaluate how microbial structure, pathogenicity and antimicrobial agents influence host–pathogen interactions and clinical outcomes.</td></tr>
<tr><td>P1 Explain the classification, structure and physiological characteristics of medically relevant microorganisms.

P2 Discuss how microbial taxonomy, structure and physiology influence identification, survival, transmission and clinical significance.</td><td>M1 Analyse the relationships between microbial classification, structural features and physiological adaptations in different clinical or environmental contexts.</td></tr>
<tr><td colspan="2">LO2 Describe the mechanisms of microbial pathogenicity and host–pathogen interactions</td></tr>
<tr><td>P3 Discuss key mechanisms of microbial pathogenicity.

P4 Explain how host immune responses interact with microorganisms during infection.</td><td>M2 Analyse host–pathogen interactions in relation to disease progression, clinical presentation and infection outcomes.</td></tr>
<tr><td colspan="2">LO3 Discuss the principles of antimicrobial agents and the development of antimicrobial resistance</td></tr>
<tr><td>P5 Discuss the principles of antimicrobial action.

P6 Explain how antimicrobial resistance develops and spreads among microorganisms.</td><td>M3 Analyse mechanisms of antimicrobial resistance in relation to antimicrobial use and clinical effectiveness.</td></tr>
<tr><td colspan="2">LO4 Explore, using either real-world case studies or laboratory-based investigation, the laboratory methods used in the identification and analysis of microorganisms</td><td rowspan="2">LO4

D2 Critically evaluate, using either real-world case studies or laboratory methods, the effectiveness of the laboratory methods used in the identification and analysis of microorganisms.</td></tr>
<tr><td>P7 Explore laboratory methods used for the identification of microorganisms.

P8 Review how laboratory findings are analysed and interpreted to support the identification of microorganisms.</td><td>M4 Analyse, using either real-world case studies or laboratory-based investigation, the effectiveness and appropriateness of laboratory methods for the identification of different microorganisms.</td></tr>
</table>

Recommended Resources

Textbooks

Brown, A.E. and Smith, H. (2021) *Benson's Microbiological Applications: Laboratory Manual in General Microbiology*. 15th edn. New York: McGraw-Hill.

Cowan, M.K. and Smith, H. (2024) *Microbiology: A Systems Approach*. 7th edn. New York: McGraw-Hill.

Goering, R.V., *et al*. (2024) *Mims' Medical Microbiology and Immunology*. 7th edn. Edinburgh: Elsevier.

Madigan, M.T., *et al*. (2022) *Brock Biology of Microorganisms*. 16th edn. Harlow: Pearson.

Murray, P.R., Rosenthal, K.S. and Pfaller, M.A. (2023) *Medical Microbiology*. 10th edn. Philadelphia: Elsevier.

OpenStax (2016) *Microbiology*. Houston, TX: OpenStax, Rice University.

Tille, P.M. (2024) *Bailey & Scott's Diagnostic Microbiology*. 16th edn. St Louis: Elsevier.

Tortora, G.J., Funke, B.R. and Case, C.L. (2023) *Microbiology: An Introduction*. 14th edn. Hoboken, NJ: Pearson.

Willey, J.M., Sandman, K.M. and Wood, D.H. (2023) *Prescott's Microbiology*. 12th edn. New York: McGraw-Hill.

Winn, W., *et al*. (2017) *Koneman's Color Atlas and Textbook of Diagnostic Microbiology*. 7th edn. Philadelphia: Wolters Kluwer.

Websites

https://www.cdc.gov	Centers for Disease Control and Prevention Laboratory training and infectious disease sections (Training)
https://www.msdmanuals.com	MSD Manuals Laboratory diagnosis of infectious diseases (General reference)
https://www.microbenotes.com	Microbe Notes Microbiology laboratory techniques and explanations (Tutorials)

https://www.who.int	World Health Organization Antimicrobial resistance and stewardship resources (Report)
https://bsac.org.uk/education/	British Society for Antimicrobial Chemotherapy Antimicrobial stewardship and resistance (Training)
https://www.rcpath.org	Royal College of Pathologists Laboratory practice and quality guidance (Standards)
https://www.nature.com/subjects/clinical-microbiology	Nature Medical microbiology research collection (Research)

Journals and articles

Antimicrobial Resistance Collaborators (2022) 'Global burden of bacterial antimicrobial resistance in 2019: a systematic analysis', *The Lancet*, 399(10325), pp. 629–655. Available at: https://doi.org/10.1016/S0140-6736(21)02724-0.

Clancy, C.J. and Nguyen, M.H. (2018) 'Diagnosing Invasive Candidiasis', *Journal of Clinical Microbiology*, 56(5), e01909-17. Available at: https://doi.org/10.1128/JCM.01909-17.

Ho, C.S., Wong, C.T.H., Aung, T.T., Lakshminarayanan, R., Mehta, J.S., Rauz, S., *et al*. (2025) 'Antimicrobial resistance: A concise update', *The Lancet Microbe*, 6(1), 100947. Available at: https://doi.org/10.1016/j.lanmic.2024.07.010.

Hou, T-Y., *et al.* (2019) 'Current status of MALDI-TOF mass spectrometry in clinical microbiology', *Journal of Food and Drug Analysis*, 27(2), pp. 404–414. Available at: https://doi.org/10.1016/j.jfda.2019.01.001.

Köser, C.U., Ellington, M.J. and Peacock, S.J. (2014) 'Whole-genome sequencing to control antimicrobial resistance', *Trends in Genetics*, 30(9), pp. 401–407. Available at: https://doi.org/10.1016/j.tig.2014.07.003.

Laxminarayan, R., *et al.* (2013) 'Antibiotic resistance – the need for global solutions', *The Lancet Infectious Diseases*, 13(12), pp. 1057–1098. Available at: https://doi.org/10.1016/S1473-3099(13)70318-9.

Miller, J.M., *et al.* (2018) 'A guide to utilization of the microbiology laboratory for diagnosis of infectious diseases: 2018 update by the Infectious Diseases Society of America and the American Society for Microbiology', *Clinical Infectious Diseases*, 67(6), pp. e1–e94. Available at: https://doi.org/10.1093/cid/ciy381.

Oliveira, M., *et al.* (2024) 'An overview of the recent advances in antimicrobial resistance', *Microorganisms*, 12(9), 1920. Available at: https://doi.org/10.3390/microorganisms12091920.

Tang, Y.W., *et al.* (2020) 'Laboratory diagnosis of COVID-19: Current issues and challenges', *Journal of Clinical Microbiology*, 58(6), e00512–20. Available at: https://doi.org/10.1128/JCM.00512-20.

Vandenberg, O., *et al.* (2020) 'Consolidation of clinical microbiology laboratories and introduction of transformative technologies', *Clinical Microbiology Reviews*, 33(2), e00057–19. Available at: https://doi.org/10.1128/CMR.00057-19.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 419: Bioinformatics

Unit 504: Industrial Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 521: Infectious Disease Epidemiology and Control

Unit 524: Immunology

Unit 527: Clinical Chemistry.

Unit 507: Pathophysiology and Applied Diagnostics

Unit code: A/652/3065

Unit level: 5

Credit value: 15

Introduction

Pathophysiology examines the functional changes that occur in the human body as a consequence of disease, injury or abnormal physiological states. It underpins understanding of how normal physiological processes become altered in disease and is fundamental to applied science roles across healthcare, biomedical, laboratory and allied scientific sectors.

This unit provides students with a structured exploration of disease processes as they affect cells, tissues, organs and body systems. Students will explore cellular injury, adaptation and death, alongside inflammatory, immune, genetic, molecular and metabolic mechanisms that contribute to disease development and progression.

The unit also considers how disruption to normal body system function leads to physiological alteration, compensatory responses and loss of homeostatic control. Students will examine patterns of disease progression, clinical manifestations and prognosis, alongside how findings from case studies or laboratory-based investigation can be interpreted in relation to underlying pathophysiological mechanisms and used to inform intervention decisions.

On completion of this unit, students will be able to apply analytical reasoning to disease mechanisms, assess physiological alterations across body systems, and interpret patterns of disease progression, clinical presentation and pathophysiological evidence. The unit supports progression to higher-level study in biomedical science, applied biomedical science, human biology, health sciences and related bioscience programmes. It also supports progression into laboratory, diagnostic and healthcare roles, including Biomedical Science Assistant, Pathology Laboratory Technician, Associate Practitioner and Healthcare Science Assistant.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explore the fundamental mechanisms of disease processes

LO2 Assess the physiological alterations associated with major body systems

LO3 Examine the progression and clinical manifestations of a range of common disorders

LO4 Explore, using either real-world case studies or laboratory-based investigation, the diagnostic approaches and interventions used in pathophysiology.

Essential Content

LO1 **Explore the fundamental mechanisms of disease processes**

Cellular injury, adaptation and death:

Cellular injury mechanisms: physical injury e.g. trauma, temperature extremes; chemical injury e.g. toxins, drugs; infectious causes; immunological causes; reversible cell injury, irreversible cell injury e.g. disruption of membrane integrity, impaired energy production, altered ion balance

Cellular adaptation responses: e.g. hypertrophy, hyperplasia, atrophy, metaplasia; stress responses, survival mechanisms, limits of adaptation; progression from adaptation to pathology e.g. cardiac hypertrophy progressing to functional impairment

Cell death pathways: e.g. apoptosis, necrosis, molecular triggers, signalling cascades, inflammation, fibrosis; loss of organ function e.g. hepatocyte necrosis contributing to liver dysfunction.

Inflammation, immunity and host response:

Inflammatory responses: e.g. acute inflammation, chronic inflammation, protective responses, pathological responses, cytokines, chemokines, prostaglandins, complement, vascular change, leukocyte recruitment, tissue injury

Immune responses: e.g. innate immunity, adaptive immunity, barrier defences, phagocytosis, antigen presentation, antibody production, cell-mediated immunity, immune regulation, hypersensitivity reactions, autoimmunity, immunodeficiency

Host–pathogen interaction: e.g. invasion, immune evasion, persistence, systemic inflammatory response, fever, sepsis, chronic inflammatory disease.

Genetic, molecular and metabolic mechanisms:

Genetic mechanisms: e.g. genetic mutations, inheritance patterns, single-gene conditions, multifactorial conditions, gene–environment interactions, genetic susceptibility combined with environmental exposure

Molecular mechanisms: e.g. dysregulated cell growth, altered apoptosis, inflammatory signalling, altered receptor function, disrupted intracellular messenger pathways

Metabolic mechanisms: e.g. energy imbalance, enzyme dysfunction, disrupted biochemical pathways, integration of genetic, molecular and metabolic changes, cellular and tissue pathology; disease progression e.g. insulin resistance contributing to multi-system effects.

LO2 **Assess the physiological alterations associated with major body systems**

Cardiorespiratory and circulatory alterations:

Cardiovascular functional parameters: e.g. cardiac output (CO = HR × SV), mean arterial pressure (MAP = CO × SVR), stroke volume (SV), systemic vascular resistance (SVR), Frank–Starling relationship, baroreceptor reflexes, renin-angiotensin-aldosterone system (RAAS), sympathetic tone

Cardiovascular alterations: e.g. reduced stroke volume, altered cardiac output, compensatory tachycardia, sodium and water retention, elevated filling pressures, ventricular remodelling, reduced coronary flow reserve, cardiac hypertrophy

Respiratory functional parameters: e.g. alveolar ventilation, ventilation-perfusion (V/Q) matching, diffusion capacity, pulmonary blood flow, airway resistance, lung compliance, arterial blood gases (PaO_2, $PaCO_2$, pH, HCO_3^-)

Respiratory alterations and compensation: e.g. airflow obstruction, bronchoconstriction, hyperinflation, V/Q mismatch, hypoxic pulmonary vasoconstriction, Type II respiratory failure, intrapulmonary shunt, hypoxaemia, hypercapnia, increased work of breathing.

Renal, endocrine and metabolic alterations:

Renal regulation and function: e.g. glomerular filtration rate (GFR), renal autoregulation, myogenic reflex, tubuloglomerular feedback, angiotensin II, nephron filtration, reabsorption and secretion, fluid balance, electrolyte regulation, acid–base homeostasis

Renal alterations: e.g. reduced GFR, prerenal dysfunction, tubular injury, impaired excretion, hyperkalaemia, metabolic acidosis, sodium and water retention, uraemia, renal anaemia, renal osteodystrophy

Endocrine and metabolic regulation: e.g. hormone synthesis, secretion, transport, receptor responsiveness, negative feedback, glucose regulation, lipid metabolism, stress responses, cardiovascular regulation, renal–endocrine interdependence

Endocrine and metabolic alterations: e.g. insulin resistance, beta-cell dysfunction or failure, hyperglycaemia, dyslipidaemia, microvascular complications of diabetes, impaired immune function in diabetes, reduced cardiac output in hypothyroidism, atrial fibrillation in hyperthyroidism, adrenal insufficiency.

Neurological, musculoskeletal and integumentary alterations:

Neurological function and dysfunction: e.g. neuronal integrity, neurotransmission, sensory processing, motor control, cognition, autonomic regulation, blood–brain barrier function, dependence on oxygen and glucose, ischaemic depolarisation, excitotoxicity, demyelination, axonal degeneration, encephalopathy

Musculoskeletal alterations: e.g. bone remodelling, bone resorption, reduced trabecular microarchitecture, synovial inflammation, pannus formation, periarticular bone erosion, secondary osteoporosis, muscle breakdown, weakness, reduced mobility, rhabdomyolysis

Integumentary alterations: e.g. impaired wound healing, reduced tissue integrity, skin as a reflector of systemic pathology, jaundice, central cyanosis, non-blanching purpura, altered perfusion, inflammatory skin change

Functional consequences: e.g. impaired coordination, altered sensation, pain, reduced mobility, impaired tissue repair, pressure damage, systemic signs of vascular, metabolic, hepatic or haematological disease.

Immune, haematological and gastrointestinal alterations:

Immune and inflammatory alterations: e.g. innate immunity, adaptive immunity, cytokine signalling, immune regulation, inflammatory response, host defence, systemic inflammatory response, cytokine storm, distributive shock, immunoparalysis, autoimmunity, chronic inflammation

Haematological alterations: e.g. oxygen transport, haemoglobin concentration, red cell turnover, coagulation, platelet function, vascular haemostasis, anaemia, haemolysis, impaired oxygen delivery, microvascular thrombosis, consumptive coagulopathy, bleeding risk, tissue hypoxia

Gastrointestinal and hepatic function: e.g. intestinal barrier function, tight junctions, secretory IgA, gut-associated lymphoid tissue (GALT), digestion, absorption, portal circulation, hepatic protein synthesis, bilirubin conjugation, detoxification, bile production

Gastrointestinal and hepatic alterations: e.g. epithelial barrier failure, malabsorption, portal hypertension, splanchnic vasodilation, ascites formation, coagulopathy, jaundice, hepatic encephalopathy, hepatorenal syndrome

Systemic interdependence: e.g. cardiorenal axis, gut–liver axis, neuro–immune crosstalk, metabolic–inflammatory coupling, systemic inflammatory response syndrome, metabolic syndrome, multi-system dysfunction, organ strain, loss of homeostatic control.

LO3 **Examine the progression and clinical manifestations of a range of common disorders**

Disease progression, trajectory and staging:

Disease localisation and aetiology: e.g. tissue, organ or single body system involvement, focal or diffuse disease, infectious, neoplastic, autoimmune, metabolic or degenerative causes, influence of aetiology on disease onset, rate of progression, severity, complications and prognosis

Disease processes and dysfunction: e.g. inflammation, ischaemia, hypoxia, neoplasia, metabolic dysregulation, local tissue damage, regional spread, systemic effects, disruption of interconnected physiological networks, manifestation in major body systems

Acute and chronic disease progression: e.g. initiation, progression, resolution, deterioration, latency, exacerbation, remission, relapse, transition from acute to chronic disease states

Disease trajectory: e.g. underlying pathophysiology, host adaptive capacity, environmental or lifestyle influences, stable disease, progressive decline, episodic deterioration, functional impairment, long-term healthcare demand

Compensation and decompensation: e.g. physiological adaptation, compensatory responses, maladaptive change, limits of compensation, functional decline, long-term impairment, early disease recognition, prevention of progression.

Clinical manifestations and symptom presentation:

Clinical signs and symptoms: observable consequences of underlying pathophysiological change e.g. symptom clusters, syndromes associated with specific disorders, variation in clinical presentation between individuals and populations

Factors influencing presentation: e.g. age, genetics, comorbidities, immune status, environmental factors, lifestyle factors, host adaptive capacity

System-specific symptom expression: e.g. systemic inflammation presenting with fever, fatigue and malaise; reduced cardiac output presenting with breathlessness and exercise intolerance; respiratory dysfunction presenting with hypoxia, dyspnoea and reduced exercise tolerance

Interpretation of clinical manifestations: e.g. relationship between affected body systems and symptom expression, disease impact, disease severity, earlier intervention, limitation of disease progression, reduction of longer-term system burden.

Risk profiling, prognosis and disease monitoring:

Risk and protective factors: e.g. modifiable and non-modifiable risk factors, lifestyle influences, environmental exposure, genetic susceptibility, comorbidities, immune status, protective behaviours

Disease monitoring: e.g. physiological indicators, biomarkers, clinical observations, longitudinal data, disease stability, deterioration, response to management, progression markers

Prognosis and outcomes: e.g. disease stage, symptom burden, predicted outcomes, complication risk, quality of life, long-term condition management

Healthcare impact and intervention planning: e.g. acute episodic care, chronic disease trajectories, healthcare resource use, healthcare sustainability, anticipation of complications, rationalisation of therapeutic interventions.

LO4 **Explore, using either real-world case studies or laboratory-based investigation, the diagnostic approaches and interventions used in pathophysiology**

Diagnostic approaches in pathophysiology:

Diagnostic approaches: e.g. clinical observation, physiological assessment, laboratory investigation, imaging, histology, functional assessment, case study data

Links between diagnostic findings and disease mechanisms: AI-supported diagnostic systems and data interpretation, with human oversight e.g. abnormal blood gases indicating respiratory acidosis in chronic obstructive pulmonary disease; raised troponin indicating myocardial cell injury following infarction; reduced estimated glomerular filtration rate (eGFR) and raised creatinine indicating impaired renal filtration; elevated C-reactive protein (CRP), lactate and white cell count indicating systemic inflammatory response in sepsis.

Pathophysiological evidence and interpretation:

Pathophysiological evidence: e.g. cellular injury, tissue damage, inflammation, impaired perfusion, altered oxygen transport, endocrine dysfunction, metabolic dysregulation, immune-mediated damage, organ dysfunction, homeostatic imbalance

Interpretation: interpretation of abnormal findings in relation to disease stage, severity, progression and likely complications e.g. insulin resistance contributing to hyperglycaemia and vascular damage in type 2 diabetes; plaque rupture causing coronary thrombosis and myocardial ischaemia; glomerular damage leading to proteinuria and oedema; hepatocyte injury causing jaundice, coagulopathy and altered metabolism.

Case study or laboratory-based investigation:

Real-world case studies e.g. anonymised laboratory datasets, simulated patient results, biomarker trends, physiological data, microscopy or histology images

Comparison of evidence sources: recognition of patterns indicating compensation, decompensation, acute deterioration, chronic progression or multi-system involvement e.g. worsening hypoxaemia and rising $PaCO_2$ indicating respiratory decompensation; declining haemoglobin and raised reticulocytes indicating haemolytic anaemia; rising HbA1c and microalbuminuria indicating progression of diabetic complications; increasing creatinine and potassium indicating worsening renal failure.

Interventions and response to treatment:

Interventions: relationship between disease mechanism, physiological disruption and intervention choice; restoration of oxygenation, improvement of perfusion, reduction of inflammation, correction of fluid, electrolyte or acid-base imbalance, hormone or enzyme replacement

Response to treatment: infection control, limitation of tissue damage, prevention of complications; monitoring response e.g. bronchodilators improving airflow obstruction in asthma or chronic obstructive pulmonary disease (COPD); insulin correcting hyperglycaemia and ketosis in diabetes; antibiotics and fluid resuscitation addressing infection, hypoperfusion and lactic acidosis in sepsis; dialysis correcting uraemia, hyperkalaemia and fluid overload in renal failure.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explore the fundamental mechanisms of disease processes</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate how disease mechanisms influence physiological alteration, disease progression and clinical manifestation across body systems, using integrated pathophysiological reasoning.</td></tr>
<tr><td>P1 Explore mechanisms of cellular injury, adaptation and cell death in disease.

P2 Explain the roles of inflammatory, immune, genetic, molecular and metabolic mechanisms in disease development.</td><td>M1 Analyse the relationships between disease mechanisms and their effects on cellular, tissue or system function.</td></tr>
<tr><td colspan="2">LO2 Assess the physiological alterations associated with major body systems</td></tr>
<tr><td>P3 Assess physiological alterations affecting major body systems in disease.

P4 Explain compensatory physiological responses, systemic interdependence and their limits in disease.</td><td>M2 Assess the interrelationships between physiological alterations and functional consequences across major body systems.</td></tr>
<tr><td colspan="2">LO3 Examine the progression and clinical manifestations of a range of common disorders</td></tr>
<tr><td>P5 Examine patterns of disease progression in acute and chronic disorders.

P6 Interpret clinical manifestations in relation to underlying disease processes and likely prognosis.</td><td>M3 Analyse the relationship between disease progression and the development of clinical manifestations in common disorders.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Explore, using either real-world case studies or laboratory-based investigation, the diagnostic approaches and interventions used in pathophysiology		**LO4**
P7 Explore diagnostic approaches used to investigate pathophysiological change in disease contexts. **P8** Explain how diagnostic findings inform intervention decisions.	**M4** Analyse the effectiveness and limitations of diagnostic approaches and associated interventions in different pathophysiological contexts.	**D2** Critically evaluate how diagnostic and intervention evidence supports pathophysiological reasoning in specific disease contexts, considering disease mechanisms, progression and limitations of interpretation.

Recommended Resources

Textbooks

Abbas, A.K., Lichtman, A.H. and Pillai, S. (2024) *Cellular and Molecular Immunology*. 11th edn. Philadelphia: Elsevier.

Banasik, J.L. (2024) *Pathophysiology*. 8th edn. St Louis: Elsevier.

Capriotti, T. (2023) *Davis Advantage for Pathophysiology: Introductory Concepts and Clinical Perspectives*. 3rd edn. Philadelphia: F.A. Davis.

Huether, S.E. and McCance, K.L. (2020) *Understanding Pathophysiology*. 7th edn. St Louis: Elsevier.

Norris, T.L. and Lalchandani Tuan, R. (2020) *Porth's Essentials of Pathophysiology*. 5th edn. Philadelphia: Wolters Kluwer.

Rogers, J. (2023) *McCance & Huether's Pathophysiology: The Biologic Basis for Disease in Adults and Children*. 9th edn. St Louis: Elsevier.

Rogers, J. (2023) *Study Guide for McCance & Huether's Pathophysiology*. 9th edn. St Louis: Elsevier.

Tkacs, N.C., Herrmann, L.L. and Johnson, P.L. (2024) *Advanced Physiology and Pathophysiology: Essentials for Clinical Practice*. 2nd edn. New York: Springer Publishing Company.

VanMeter, K.C. and Hubert, R.J. (2022) *Gould's Pathophysiology for the Health Professions*. 7th edn. St Louis: Elsevier.

Willis, L.M. (2020) *Professional Guide to Pathophysiology*. 4th edn. Philadelphia: Wolters Kluwer.

Websites

https://www.cdc.gov/	Centers for Disease Control and Prevention Diseases, conditions and public health data (General reference)
https://www.frontiersin.org	Frontiers in Physiology Pathophysiology and disease mechanisms (Research)

https://www.nhs.uk	National Health Service Conditions, diagnostics and patient pathways (General reference)
https://www.nice.org.uk	National Institute for Health and Care Excellence Diagnostics, screening and clinical guidance (Standards)
https://www.pathologyatlas.ro/index.php	Pathology Atlas Histopathology and diagnostic imaging resources (General reference)

Journals and articles

Barichello, T., *et al.* (2022) 'Biomarkers for sepsis: More than just fever and leukocytosis – a narrative review', *Critical Care*, 26, 14. Available at: https://doi.org/10.1186/s13054-021-03862-5.

Biasucci, L.M., *et al.* (2021) 'Novel Biomarkers in Heart Failure: New Insight in Pathophysiology and Clinical Perspective', *Journal of Clinical Medicine*, 10(13), 2771. Available at: https://doi.org/10.3390/jcm10132771.

Castiglione, V., *et al.* (2022) 'Biomarkers for the diagnosis and management of heart failure', *Heart Failure Reviews*, 27(2), pp. 625–643. Available at: https://doi.org/10.1007/s10741-021-10105-w.

Desiere, F., *et al.* (2021) 'Digital Diagnostics and Mobile Health in Laboratory Medicine: An International Federation of Clinical Chemistry and Laboratory Medicine Survey on Current Practice and Future Perspectives', *The Journal of Applied Laboratory Medicine*, 6(4), pp. 969–979. Available at: https://doi.org/10.1093/jalm/jfab026.

Gopcevic, K.R., *et al.* (2021) 'Pathophysiology of Circulating Biomarkers and Relationship With Vascular Aging: A Review of the Literature From VascAgeNet Group on Circulating Biomarkers, European Cooperation in Science and Technology Action 18216', *Frontiers in Physiology*, 12, 789690. Available at: https://doi.org/10.3389/fphys.2021.789690.

Okwor, I.A., *et al.* (2024) 'Digital Technologies Impact on Healthcare Delivery: A Systematic Review of Artificial Intelligence (AI) and Machine-Learning (ML) Adoption, Challenges, and Opportunities', *AI*, 5(4), pp. 1918–1941. Available at: https://doi.org/10.3390/ai5040095.

Padget, M., *et al.* (2024) 'Measuring environmentally sustainable health care: a scoping review', *The Lancet Planetary Health*, 8(9), pp. e675–e683. Available at: https://doi.org/10.1016/S2542-5196(24)00162-1.

Wettersten, N. (2021) 'Biomarkers in Acute Heart Failure: Diagnosis, Prognosis, and Treatment', *International Journal of Heart Failure*, 3(2), pp. 81–105. Available at: https://doi.org/10.36628/ijhf.2020.0036.

World Health Organization (2023) *Strengthening diagnostics capacity (Resolution WHA76.5)*. Geneva: World Health Organization. Available at: https://www.who.int/activities/strengthening-diagnostics-capacity.

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 408: Human Anatomy and Physiology

Unit 419: Bioinformatics

Unit 504: Industrial Microbiology

Unit 508: Diagnostics for the Biomedical Sciences

Unit 522: Histology and Haematology

Unit 524: Immunology

Unit 527: Clinical Chemistry.

Unit 508: Diagnostics for the Biomedical Sciences

Unit code: F/652/3067

Unit level: 5

Credit value: 15

Introduction

Diagnostics for the Biomedical Sciences introduces students to the scientific principles, methods and technologies used to generate diagnostic evidence in biomedical science. Diagnostic practice supports the detection, confirmation and monitoring of disease, and informs disease management across clinical, laboratory and community settings. This unit focuses on diagnostics as a distinct scientific discipline, with emphasis on diagnostic reasoning, methodological intent, analytical and clinical validity, and the interpretation of diagnostic outputs.

Students will explore how diagnostic methodologies and analytical instruments are selected and used to generate reliable diagnostic information. They will consider how sample type, test purpose, instrument performance, quality control, analytical performance and methodological limitations affect the accuracy, reliability and interpretation of results. The unit also introduces digital systems used in diagnostic workflows, data processing, result flagging, automated interpretation and population-level monitoring.

The unit develops students' ability to analyse diagnostic data using established biomedical analytical frameworks. Students will consider reference intervals, diagnostic thresholds, trend analysis, predictive values, uncertainty and contextual factors when drawing conclusions from diagnostic evidence. They will also explore how population diversity, representativeness of reference datasets and bias within diagnostic thresholds or digitally supported interpretation can affect the validity and fairness of diagnostic conclusions.

On completion of the unit, students will be able to apply scientific, analytical and professional judgement to diagnostic systems, data and outputs. They will understand how international and national regulatory contexts, in vitro diagnostic requirements, data protection, ethical principles, quality management and sustainability considerations shape safe and responsible diagnostic practice. These skills support progression to further study or employment in biomedical science, laboratory diagnostics, healthcare science, quality assurance and compliance, diagnostic technology and related applied biomedical roles.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the theoretical principles of biomedical diagnostic science

LO2 Describe the principles underpinning analytical instruments used in biomedical diagnostics, using either real-world case studies or laboratory practice

LO3 Review diagnostic data using established biomedical analytical frameworks for an identified scenario

LO4 Present a review of the regulatory, ethical, and quality frameworks governing biomedical diagnostics.

Essential Content

LO1 **Explain the theoretical principles of biomedical diagnostic science**

Diagnostic methodologies and diagnostic reasoning:

Diagnostic purpose and methodological intent: e.g. screening, detection, confirmation and monitoring; relationships between diagnostic questions, sample type, methodology selection and interpretation pathways

Diagnostic approaches: laboratory-based and near-patient diagnostic approaches e.g. point-of-care testing; qualitative, quantitative and semi-quantitative diagnostic methodologies used in biomedical science

Diagnostic reasoning concepts: hypothesis-led testing, pre-test probability, test selection trade-offs and interpretation logic; contextual constraints on method selection: turnaround time, throughput, biosafety, resource availability and patient pathway requirements e.g. urgent blood gas testing versus routine laboratory chemistry.

Analytical and clinical validity concepts:

Analytical performance characteristics: accuracy, precision, analytical sensitivity, analytical specificity, selectivity, linearity, limits of detection and quantitation, measurement uncertainty; gold standards in diagnostics e.g. confirmation or comparison of assay results against the most accurate or accepted test

Method comparability concepts: bias, imprecision, traceability and standardisation; clinical validity and clinical utility concepts e.g. reference intervals, diagnostic thresholds, predictive values and prevalence effects

Classification risk concepts: false positive and false negative outcomes and their implications for diagnostic decision making and follow-on testing e.g. the effect of low prevalence on positive predictive value in screening contexts.

Diagnostic evidence and outputs:

Forms of diagnostic output: numerical results, categorical outcomes, qualitative patterns and interpretive reports; sources of diagnostic evidence e.g. biomarker-based, molecular, morphological and functional evidence

Constraints: constraints on interpretation imposed by methodological principles and limitations e.g. interferences, matrix effects, carryover, inhibition, contamination risk; observer variability and decision-limit uncertainty e.g. hook effect in immunoassays, polymerase chain reaction (PCR) inhibition, variation in microscopy pattern recognition

Evidence triangulation concepts: repeat testing, orthogonal confirmation methods and correlation with clinical context e.g. immunoassay screening with confirmatory mass spectrometry or confirmatory PCR where appropriate; digital tools for processing diagnostic outputs.

LO2 **Describe the principles underpinning analytical instruments used in biomedical diagnostics, using either real-world case studies or laboratory practice**

Analytical instrumentation principles:

Measurement system concepts: e.g. signal generation, signal detection, analogue and digital signal processing, sources of noise and interference

Instrumentation platforms: operating principles of core diagnostic instrumentation platforms e.g. spectrophotometry using Beer–Lambert relationships; fluorimetry using excitation/emission and quenching effects; chromatography using partition and retention mechanisms; electrophoresis using charge-to-mass migration; mass spectrometry using ionisation, mass analysis and detection; PCR systems using thermal cycling, amplification kinetics and fluorescence thresholding; microscopy and imaging technologies using contrast mechanisms and resolution limits

Instrument-to-method fit concepts: how theoretical principles constrain what an instrument can reliably measure in a given matrix e.g. haemolysis, lipaemia and icterus effects on photometric measurements.

Instrument components, digital systems and performance characteristics:

Instrument system components: reagents and consumables, optics, detectors, fluidics, temperature control systems and software interfaces

Digital systems: digitally controlled processes for workflow support, data acquisition, calibration, quality control monitoring, result flagging and system alerts

Performance: relationships between instrument design choices and performance characteristics e.g. optical path length and photometric linearity; detector saturation and dynamic range; carryover linked to fluidics design; thermal uniformity linked to PCR reproducibility

Performance verification concepts: calibration models, control rules and traceability expectations e.g. internal standards in mass spectrometry; calibration curves and control charts in automated clinical chemistry; digital tools combined with diagnostic tests and population-level monitoring during pandemics.

Limitations, suitability and sustainability considerations:

Instrument-specific limitations: e.g. matrix effects, cross-reactivity, carryover, contamination risk, reagent stability, environmental influences and operator influences

Contextual suitability factors: e.g. throughput, turnaround time, analytical range, sample volume requirements, biosafety constraints and resource availability

Instrument governance and reliability concepts: e.g. preventive maintenance, downtime risk, software updates and validation burden; gold standard principles in instrument calibration and results verification

Sustainability considerations linked to instrumentation choices: e.g. consumable and plastic use, reagent waste, energy demands; repeat testing frequency and impacts on laboratory efficiency e.g. repeat PCR due to inhibition; repeat chemistry due to sample haemolysis flags increasing reagent and waste burden.

LO3 **Review diagnostic data using established biomedical analytical frameworks for an identified scenario**

Diagnostic data types and contextual structure:

Types of diagnostic datasets: e.g. single-analyte results, multi-analyte panels, time-series monitoring data, categorical outputs, semi-quantitative scoring systems

Context: contextual information required for interpretation: e.g. reference intervals, comparator baselines, sampling timepoints, sample metadata method notes; analyser flags e.g. haemolysis index flags affecting potassium interpretation; uncertainty indicators; quality markers e.g. delta checks for electrolytes; semi-quantitative urine dipstick outputs and their constraints.

Analytical and digitally supported interpretive frameworks:

Established analytical frameworks for diagnostic interpretation: e.g. reference interval application, diagnostic threshold logic, delta checking, trend analysis, panel pattern recognition

Approach selection based on scenario demands: e.g. rule-in/rule-out logic and risk-based interpretation

Digitally supported interpretive systems: e.g. laboratory information system (LIS) configuration, middleware rules, auto-validation checks, reflex testing logic, algorithm-assisted pattern recognition

Integration of analytical performance characteristics into interpretation: sensitivity, specificity, predictive values, pre-test probability considerations, prevalence effects e.g. interpreting a 'detected' molecular result in a low prevalence population; interpreting troponin change over time using decision thresholds and assay precision at low concentrations; AI-assisted interpretation of diagnostic data, with human verification.

Validity of conclusions and strength of inference:

Criteria for evaluating validity of conclusions: e.g. alignment between observed data patterns and the selected framework, internal consistency across related markers, coherence with quality indicators and plausibility checks

Constraints: e.g. constraints on inference linked to uncertainty, interferences, pre-analytical variability, digitally generated outputs, population diversity, representativeness of reference datasets and risk of bias in diagnostic thresholds or digitally supported interpretation

Strength of inference: evaluation of confidence and limitation statements appropriate to output type e.g. borderline results at decision limits; contradictory panel findings prompting verification; reliance on auto-validation where flags are absent but clinical context suggests discordance.

LO4 **Present a review of regulatory, ethical, and quality frameworks governing biomedical diagnostics.**

Regulatory and accreditation frameworks:

Regulatory frameworks: regulatory oversight concepts affecting biomedical diagnostics; international and national regulatory contexts affecting diagnostic practice across different healthcare systems; in vitro diagnostic regulation, medical device regulation and data protection requirements; laboratory accreditation principles and standards e.g. ISO 15189 expectations for competence, method verification/validation, document control and continual improvement

Governance of digital diagnostic systems: data integrity, audit trails, system validation, access control and cybersecurity awareness; documentation, traceability

Auditability and incident reporting requirements: non-conformance handling and implications for patient safety and diagnostic reliability e.g. investigation of a QC failure leading to result review; audit trail review following unauthorised result amendment.

Ethical and professional governance principles:

Ethical frameworks relevant to diagnostic practice: confidentiality, data protection, informed consent where applicable, equity, bias and fairness in testing and interpretation; equitable access to diagnostics; cultural and population-based considerations; under-representation in validation datasets; algorithmic bias and racially aware interpretation of diagnostic outputs

Professional governance: professional accountability e.g. scope of practice, duty of candour and responsible communication of uncertainty and limitations; governance of diagnostic decision making; appropriate escalation routes and clarity of interpretive commenting e.g. communicating limitations of point-of-care results; managing incidental findings within agreed governance.

Quality management, assurance and sustainability systems:

Quality management system structures: SOP governance, document control, training and competence records, equipment management and change control

Quality assurance mechanisms: internal quality control, external quality assessment, audit cycles, corrective and preventive action (CAPA) and risk management

Quality indicators across the testing pathway: pre-analytical, analytical and post-analytical indicators; quality indicators linked to equity of service access, sample rejection patterns, turnaround time variation and differential impact across patient groups e.g. specimen rejection rates; turnaround time breaches; external quality assurance (EQA) performance trends

Sustainability considerations within quality systems: efficient test utilisation, reduction of unnecessary repeat testing, waste management, equipment life cycle management and alignment with organisational sustainability objectives e.g. rationalising repeat testing through agreed criteria; reducing sample transport and energy demand through workflow redesign without compromising quality.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the theoretical principles of biomedical diagnostic science</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the selection and use of diagnostic methodologies and analytical instruments for an identified context, considering principles, purpose and limitations affecting accuracy and reliability.</td></tr>
<tr><td>P1 Explain diagnostic methodologies and reasoning used in biomedical science.

P2 Investigate the influence of analytical and clinical validity on diagnostic interpretation.</td><td>M1 Analyse how diagnostic methodologies are applied to generate reliable diagnostic information, considering methodological intent, validity and interpretation constraints.</td></tr>
<tr><td colspan="2">LO2 Describe the principles underpinning analytical instruments used in biomedical diagnostics, using either real-world case studies or laboratory practice</td></tr>
<tr><td>P3 Describe, using either real-world case studies or laboratory practice, the operating principles of analytical instruments used in biomedical diagnostics.

P4 Discuss, using either real-world case studies or laboratory practice, how instrument performance and limitations affect diagnostic outputs.</td><td>M2 Analyse, using either real-world case studies or laboratory practice, the suitability of analytical instruments for generating valid diagnostic outputs in different contexts, considering performance characteristics and limitations.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Review diagnostic data using established biomedical analytical frameworks for an identified scenario		**LO3 and LO4** **D2** Critically evaluate the validity of conclusions drawn from diagnostic data analysis for the identified scenario, considering the influence of regulatory, ethical and quality frameworks on diagnostic outputs.
P5 Review diagnostic data for the identified scenario using established analytical frameworks to obtain meaningful insights and conclusions. **P6** Discuss the validity of the conclusions and the strength of inference of the generated insights.	**M3** Assess the effectiveness of the analytical frameworks used in the identified scenario, including how uncertainty and contextual factors may affect conclusions.	
LO4 Present a review of the regulatory, ethical, and quality frameworks governing biomedical diagnostics		
P7 Present a review of the regulatory, ethical and quality frameworks governing biomedical diagnostics. **P8** Review audience feedback to identify strengths and areas to improve.	**M4** Analyse, using audience feedback, the effectiveness of the presentation in communicating the influence of regulatory, ethical and quality frameworks on diagnostic outputs, safe practice and data integrity.	

Recommended Resources

Textbooks

Bishop, M.L., *et al.* (eds.) (2023) *Clinical Chemistry: Principles, Techniques, and Correlations*. 9th edn. Burlington, MA: Jones & Bartlett Learning.

Crook, M.A. (2021) *Clinical Biochemistry and Metabolic Medicine*. 8th edn. Boca Raton, FL: CRC Press.

Marshall, W.J., *et al.* (eds.) (2021) *Clinical Chemistry*. 9th edn. Edinburgh: Elsevier.

Procop, G.W., *et al.* (eds.) (2024) *Clinical Laboratory Management*. 3rd edn. Washington, DC: ASM Press/Hoboken, NJ: Wiley.

Khandpur, R.S. (2020) *Handbook of Biomedical Instrumentation*. 3rd edn. Chennai: McGraw-Hill Education (India).

Laposata, M. (ed.) (2023) *Laposata's Laboratory Medicine: The Diagnosis of Disease in the Clinical Laboratory*. 4th edn. New York: McGraw-Hill.

McPherson, R.A. and Pincus, M.R. (eds.) (2022) *Henry's Clinical Diagnosis and Management by Laboratory Methods*. 24th edn. Philadelphia: Elsevier.

Price, C.P., St John, A. and Kricka, L.J. (eds.) (2010) *Point-of-Care Testing: Needs, Opportunity, and Innovation*. 3rd edn. Washington, DC: AACC Press.

Rifai, N. (ed.) (2023) *Tietz Fundamentals of Clinical Chemistry and Molecular Diagnostics*. 9th edn. St Louis: Elsevier.

Rifai, N., *et al.* (eds.) (2022) *Tietz Textbook of Laboratory Medicine*. 7th edn. St Louis: Elsevier.

Sahin, M., Fidel, H. and Perez-Castillejos, R. (2021) *Instrumentation Handbook for Biomedical Engineers*. Boca Raton, FL: CRC Press.

World Health Organization (2011) *Manual for the Laboratory Diagnosis and Virological Surveillance of Influenza*. Geneva: World Health Organization.

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Websites

https://www.ibms.org	Institute of Biomedical Science Professional standards and guidance for biomedical diagnostic practice (Professional body)
https://www.iso.org	International Organization for Standardization International standards relevant to biomedical diagnostics (e.g. ISO 15189) (Standards)
https://www.nice.org.uk	National Institute for Health and Care Excellence Diagnostics, screening and evidence-based clinical guidance (Standards)
https://www.rcpath.org	Royal College of Pathologists Laboratory quality, governance and professional practice guidance (Professional guidance)
https://www.scispot.com	Scispot Laboratory information systems and digital diagnostics integration (General reference)
https://www.ukas.com	United Kingdom Accreditation Service Laboratory accreditation and quality assurance frameworks (Regulatory guidance)

Journals and articles

Bossuyt, P.M., *et al.* (2015) 'STARD 2015: an updated list of essential items for reporting diagnostic accuracy studies', *BMJ*, 351, h5527. Available at: doi.org/10.1136/bmj.h5527.

Desiere, F., *et al.* (2021) 'Digital Diagnostics and Mobile Health in Laboratory Medicine: An International Federation of Clinical Chemistry and Laboratory Medicine Survey on Current Practice and Future Perspectives', *The Journal of Applied Laboratory Medicine*, 6(4), pp. 969–979. Available at: doi.org/10.1093/jalm/jfab026.

McAlister, S., *et al.* (2022) 'The carbon footprint of hospital diagnostic imaging in Australia', *The Lancet Regional Health - Western Pacific*, 24, 100459. Available at: doi.org/10.1016/j.lanwpc.2022.100459.

Plebani, M., *et al.* (2014) 'Quality indicators to detect pre-analytical errors in laboratory testing', *Clinical Biochemistry*, 47(4-5), pp. 344–346. Available at: doi.org/10.1016/j.clinbiochem.2013.08.024.

Sacks, D.B., *et al.* (2023) 'Guidelines and Recommendations for Laboratory Analysis in the Diagnosis and Management of Diabetes Mellitus', *Clinical Chemistry*, 69(8), pp. 777–784. Available at: doi.org/10.1093/clinchem/hvad080.

Schwen, L.O., *et al.* (2023) 'Digitization of Pathology Labs: A Review of Lessons Learned', *Laboratory Investigation*, 103(11), 100244. Available at: doi.org/10.1016/j.labinv.2023.100244.

Sciacovelli, L., *et al.* (2023) 'Quality indicators in laboratory medicine: state-of-the-art, quality specifications and future strategies', *Clinical Chemistry and Laboratory Medicine*, 61(4), pp. 688–695. Available at: doi.org/10.1515/cclm-2022-1143.

World Health Assembly (2023) *Strengthening diagnostics capacity (Resolution WHA76.5)*. Geneva: World Health Organization. Available at: www.who.int/activities/strengthening-diagnostics-capacity.

World Health Organization (2023) *The selection and use of essential in vitro diagnostics: report of the fourth meeting of the WHO Strategic Advisory Group of Experts on In Vitro Diagnostics, 2022 (including the fourth WHO model list of essential in vitro diagnostics)*. Geneva: World Health Organization. Available at: www.who.int/publications/i/item/9789240081093.

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Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 404: Mathematics and Statistics for the Applied Sciences

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 506: Medical Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 522: Histology and Haematology

Unit 524: Immunology

Unit 527: Clinical Chemistry.

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit code: H/652/3068

Unit level: 5

Credit value: 15

Introduction

Forensic evidence collection at scenes is a critical stage within the forensic science process, as decisions made at this point directly affect the integrity, reliability and usability of evidential material throughout an investigation. This unit is designed for students progressing within applied science and forensic pathways who need a structured understanding of how evidence is recognised, recovered, preserved and documented at crime scenes. It reflects professional practice across forensic contexts, including law enforcement, regulatory and investigative settings, and supports preparation for roles where scene-based forensic activity forms part of wider criminal justice or scientific workflows.

The unit emphasises professional expectations at crime scenes, including regulatory compliance, health and safety, accurate documentation and continuity of evidence. Students explore how crime scene conditions, environmental factors and operational constraints influence evidence handling, and how proportionate and responsible approaches support evidential integrity and sustainable practice. Digital tools for scene recording and evidence tracking are considered, reflecting contemporary forensic environments where auditable records are essential.

Students study methods used for the recognition and collection of biological, chemical and physical evidence at crime scenes, considering the characteristics, risks and preservation requirements associated with different evidence types. The unit addresses contamination prevention, safe handling of hazardous materials and techniques used to maintain fragile or transient evidence. Students also consider how collection methods are selected and adapted to differing scene contexts, balancing recovery priorities with safety, integrity and resource considerations.

On successful completion of this unit, students will be able to design a coherent, regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence within a simulated crime scene. The unit supports progression to further study in forensic science, crime scene investigation, forensic biology, forensic chemistry, policing, criminal investigation and evidence evaluation. It also provides a foundation for roles such as Forensic Technician, Crime Scene

Investigator, Forensic Laboratory Assistant, Evidence Recovery Officer, Police Staff Investigator and related scientific or investigative roles where accurate evidence handling, preservation and documentation are essential.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explore methods used for the recognition and collection of biological evidence at crime scenes

LO2 Examine methods used for the recognition and collection of chemical evidence at crime scenes

LO3 Review methods used for the recognition and collection of physical evidence at crime scenes

LO4 Develop a regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence for a simulated crime scene.

Essential Content

LO1 **Explore methods used for the recognition and collection of biological evidence at crime scenes**

Biological evidence types and recognition:

Biological evidence types: e.g. blood, saliva, semen, vaginal fluid, urine, faeces, vomit, sweat, tissue, bone, teeth, hair with root material, skin cells, cellular material

DNA evidence: e.g. touch DNA, low-template DNA, mixed biological material, degraded biological material

Recognition methods: visual assessment, contextual interpretation, search strategy, search patterns, evidence location; biological screening e.g. presumptive testing for blood, saliva or semen; bloodstain pattern recognition, digital scene records, photography, scene sketches, accurate recording, minimal disturbance

Transfer and deposition: primary transfer, secondary transfer, passive transfer, contact transfer, activity level interpretation; deposition patterns e.g. staining, smearing, dilution, cleaning, movement of individuals or objects

Substrate and environmental factors: surface type e.g. porous surfaces, non-porous surfaces, absorbent materials, textured surfaces; environmental exposure e.g. heat, moisture, ultraviolet light, microbial activity, weather exposure; time since deposition, visibility, recoverability, degradation

Evidential value: relevance, probative value, evidential priority, sample quality, sample quantity, contamination risk, persistence, background DNA, potential for interpretation, review of evidence locations; item contexts e.g. door handles, mobile phones, steering wheels, weapons, clothing fastenings, reusable bottles, gloves, bedding, vehicle interiors, discarded tissues or ligatures.

Collection methods for biological evidence:

Collection methods: e.g. sterile swabbing, wet swabbing, dry swabbing, double swabbing, taping, scraping, cutting, excision, lifting, whole-item recovery; sampling approaches e.g. targeted sampling, sequential sampling, duplicate sampling

Sample selection: sample location, sample concentration, sample distribution, biological load, visible staining, latent material; sample condition e.g. low-quantity samples, mixed samples, degraded samples, fragile deposits, transient evidence

Surface and item considerations: surface type e.g. absorbent surfaces, non-absorbent surfaces, porous materials, non-porous materials;

item contexts e.g. clothing, bedding, weapons, containers, packaging, glassware, vehicles, flooring, furniture, personal items

Controls and comparison samples: substrate controls, control samples, reference samples, elimination samples, negative controls; sample management e.g. sample labelling, exhibit numbering, continuity records, substrate controls from unstained areas

Preservation and packaging: degradation control, moisture control, air drying, packaging choice, storage conditions, laboratory submission requirements; packaging materials e.g. paper packaging, breathable packaging, tamper-evident sealing

Method selection: evidence characteristics, surface type, scene conditions, contamination risk, proportionality, evidential need, preservation requirements, available resources, sustainable use of consumables, avoidance of unnecessary recovery; adapted recovery e.g. fragile, wet, degraded or low-quantity samples.

Contamination risk, control and scene constraints:

Contamination risks: contamination, cross-contamination, cross-transfer, DNA transfer, adventitious transfer, background DNA, operator DNA, mixed DNA profiles; activity-related risks e.g. contamination from emergency responders, suspect or victim movement, scene examiner activity

Control measures: scene zoning, common approach path, controlled entry, controlled exit, scene log, clean working areas; personal protective equipment e.g. gloves, masks, overshoes, coveralls; contamination controls e.g. sterile equipment, single-use consumables, glove changing, equipment changing

Evidence handling controls: evidence segregation, exhibit separation, packaging separation, separate storage, contamination logs, continuity recording, digital logging systems, decision logs; wet and dry item management e.g. separating wet biological items from dry exhibits

Scene constraints: scene type e.g. outdoor scenes, vehicles, confined spaces, public access, multi-occupancy scenes; evidence condition e.g. fragile evidence, transient evidence, decomposition; environmental conditions e.g. weather, rain, wind, heat, humidity, insects, animals, cleaning activity; operational constraints e.g. time pressures, access limitations

Risk and prioritisation: health and safety risk assessment, biohazard risk, blood-borne pathogens, sharps risk, prioritisation, proportionality, justified recovery decisions, adapted procedures, professional judgement; specialist support e.g. decomposition, sharps, biological hazards or confined spaces.

LO2 **Examine methods used for the recognition and collection of chemical evidence at crime scenes**

Chemical evidence types and recognition:

Chemical evidence types: e.g. powders, tablets, capsules, liquids, residues, stains, vapours, gases, controlled substances, toxic substances, corrosives, solvents, ignitable liquids, accelerants, fire debris, drug paraphernalia, clandestine laboratory materials

Recognition indicators: e.g. odour, colour, container type, labelling, burn patterns, residue distribution, damaged packaging, chemical warning symbols

Recognition methods: e.g. visual assessment, contextual interpretation, scene information, hazard awareness, minimal handling, digital scene records, photography, evidence mapping, presumptive screening, field detection, prioritisation; screening tools e.g. pH paper, colour tests, presumptive drug tests, hydrocarbon detectors, portable spectroscopy where authorised

Chemical behaviour and evidential value: e.g. volatility, solubility, reactivity, toxicity, flammability, persistence, degradation, evaporation, contamination risk, sample stability, probative value, evidential priority; scene contexts e.g. fire scenes, suspected drug production, poisoning incidents, spillages, vehicles, containers, surfaces or clothing.

Collection methods for chemical evidence:

Collection methods: e.g. containment, sealing, absorption, scraping, swabbing, scooping, whole-item recovery, debris recovery, liquid sampling, air or vapour sampling where appropriate; collection strategy e.g. representative sampling, control samples, comparison samples, duplicate samples, avoidance of unnecessary recovery

Packaging and preservation: e.g. substance properties, chemically compatible packaging, airtight containers, vapour-tight packaging, leak-proof containers, sealed bags, tamper-evident seals, labelling, segregation, temperature control, light protection, evaporation reduction, degradation control; packaging examples e.g. nylon bags with swan-neck sealing for suspected accelerants, glass containers for volatile liquids, separate packaging for contaminated items

Method selection: e.g. evidence characteristics, surface type, quantity, concentration, volatility, contamination risk, safety risk, scene conditions, laboratory requirements, transport requirements, proportionality, sustainability, waste reduction, environmentally responsible handling.

Safety risks, preservation requirements and scene constraints:

Safety risks: e.g. inhalation, ingestion, skin contact, eye contact, corrosive exposure, toxicity, flammability, explosion risk, oxidising agents, unknown substances, pressurised containers, contaminated sharps

Scene control: control measures e.g. exclusion zones, ventilation, PPE, respiratory protection, specialist attendance, delayed collection where risk cannot be controlled

Preservation and scene constraints: e.g. evaporation reduction, degradation prevention, cross-contamination control, compatibility of packaging and substance, transport risk management, regulatory requirements, ISO 21043 recognition, collection, transport and storage principles, access limitations, fire-damaged scenes, confined spaces, poor ventilation, environmental conditions, modified approaches; safety information e.g. container labels, hazard symbols, safety data, fire service information or specialist chemical advice.

LO3 **Review methods used for the recognition and collection of physical evidence at crime scenes**

Physical evidence types and recognition:

Physical evidence types: e.g. fingerprints, palm prints, footwear marks, tyre marks, tool marks, weapons, firearms-related evidence, impressions, glass, paint, fibres, soil, fragments, documents, packaging, broken items, trace materials; evidence condition e.g. fragile evidence, transient evidence, partial marks, overlapped marks, contaminated surfaces, weathered impressions

Recognition methods: e.g. systematic search, visual examination, oblique lighting, magnification, alternative light sources, photography, scaled photography, 3D scanning, scene sketches, evidence markers, contextual interpretation, prioritisation; pattern evidence e.g. friction ridge detail, tread patterns, striations, indentation marks, fracture patterns, transfer patterns

Evidential value: e.g. relevance, uniqueness, class characteristics, individual characteristics, comparison potential, persistence, fragility, recoverability, probative value, contamination risk, context of deposition; scene contexts e.g. entry points, footwear routes, vehicle contact points, handled surfaces, damaged locks, broken glass or seating areas

Collection methods for physical evidence:

Collection methods: e.g. lifting, casting, gel lifting, electrostatic lifting, tape lifting, powdering, chemical enhancement, hand picking, tweezers, scraping, cutting, whole-item recovery, securing items, rigid packaging; recovery examples e.g. casting 3D footwear impressions, lifting latent prints from smooth surfaces, packaging weapons to protect surfaces and points

Method selection: e.g. evidence type, surface condition, substrate, mark visibility, stability, fragility, contamination risk, sequence of recovery, preservation needs, comparison requirements, proportionality, duplication avoidance, damage prevention, laboratory requirements

Packaging and documentation: e.g. protective packaging, rigid containers, bindles, paper folds, bags, boxes, exhibit labels, seals, orientation marks, scale use, continuity records, digital records, ISO 21043 recognition, collection, transport and storage principles; item protection e.g. immobilising sharp weapons, protecting impression casts, separating trace material from bulk items.

Evidence condition, integrity and scene constraints:

Evidence condition and integrity: e.g. handling, movement, packaging, disturbance, loss, contamination, degradation, surface damage, mark distortion, environmental exposure, integrity preservation, continuity recording, scene complexity; environmental protection e.g. shielding impressions from rain, covering fragile marks, restricting movement through evidence routes

Scene constraints: e.g. weather, lighting, access restrictions, high-traffic locations, multi-occupancy scenes, confined spaces, unstable surfaces, public areas, time pressures, competing recovery priorities; adapted approaches e.g. photographing before lifting, recovering original items where possible, sequencing fragile evidence before intrusive recovery.

LO4 **Develop a regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence for a simulated crime scene**

Regulatory and professional frameworks:

Regulatory and professional frameworks: forensic science codes of practice, authorised professional practice, quality standards, competence, accountability, legal requirements, ethical requirements, health and safety, risk assessment, evidence integrity, reliability, admissibility, proportionality, sustainability; compliance considerations e.g. ISO 21043 forensic sciences, ISO/IEC 17020 for forensic inspection activities, ISO/IEC 17025 for testing activities, Forensic Science Regulator Code of Practice, recognised forensic standards, local procedures, statutory requirements, laboratory submission requirements

Global and regulatory standards: ISO 21043 series e.g. ISO 21043-1 vocabulary, ISO 21043-2 recognition, recording, collecting, transport and storage of items, ISO 21043-5 reporting; accreditation and quality standards e.g. ISO/IEC 17020 for inspection, ISO/IEC 17025 for testing, jurisdictional requirements, international good practice, cross-border evidence handling, auditability, quality assurance, competence, impartiality, traceability

Professional responsibilities: role boundaries, competence, objectivity, impartiality, transparency, accountability, contamination prevention, secure handling, justified decision making, escalation routes; professional practice e.g. consulting specialist support for hazardous chemicals, firearms, complex scenes or biological hazards

Ethical and inclusive practice: e.g. impartiality, objectivity, bias awareness, cognitive bias, contextual bias, dignity, privacy, confidentiality, cultural sensitivity, trauma-informed communication, accessibility needs, respectful handling of personal items, proportionality, non-discriminatory practice, avoidance of assumptions, transparent decision making.

Methodology structure and sequencing:

Methodology structure: e.g. scene assessment, initial briefing, risk assessment, scene preservation, controlled access, common approach path, evidence recognition, evidence prioritisation, recovery sequence, contamination prevention, preservation planning, documentation planning, resource allocation, communication, contingency planning

Sequencing and decision making: e.g. logical sequencing, fragile evidence first, transient evidence first, hazardous evidence control, least intrusive methods, avoidance of cross-contamination, proportionality, auditability, efficiency, professional judgement; sequencing examples e.g. photographing before recovery, collecting volatile chemicals before evaporation, preserving impressions before movement through the scene

Methodology presentation: e.g. clear rationale, step-by-step process, evidence type justification, control measures, equipment selection, packaging selection, documentation requirements, communication plan, review points; simulated scene application e.g. biological, chemical and physical evidence recovery within one coherent collection plan.

Preservation, continuity, documentation, and review:

Preservation and continuity: preservation requirements e.g. continuity of evidence, chain of custody, exhibit numbering, labelling, sealing, secure handling, secure storage, traceability, scene-to-submission process, transport requirements, laboratory submission, evidence transfer records; standards alignment e.g. ISO 21043 recognition, recording, collecting, transport and storage of items, ISO/IEC 17020 inspection activity requirements, ISO/IEC 17025 testing activity requirements

Documentation and review: e.g. contemporaneous notes, scene logs, decision logs, photographs, sketches, digital records, audit trails, transparency, quality assurance, version control, review of methodology, effectiveness, compliance, justified improvement opportunities; documentation examples e.g. exhibit labels, continuity forms, risk assessments, photographic logs, recovery records, submission forms

Presentation skills: structure, clarity, professional terminology, evidence-based rationale, logical sequencing, visual support, audience awareness, time management, response to questions, justification of decisions; presentation formats e.g. briefing, verbal presentation, annotated methodology, flow chart, evidence recovery plan, simulated scene report.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explore methods used for the recognition and collection of biological evidence at crime scenes</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate selected methods used for the recognition and collection of biological, chemical and physical evidence at crime scenes in relation to evidential integrity and differing crime scene conditions.</td></tr>
<tr><td>P1 Explore methods used for the recognition and collection of biological evidence at crime scenes.

P2 Discuss the issues of contamination risk, preservation and crime scene constraints in the context of the recognition and collection of biological evidence at crime scenes.</td><td>M1 Analyse the appropriateness of biological evidence recognition and collection methods in relation to contamination risk, preservation requirements and crime scene constraints.</td></tr>
<tr><td colspan="2">LO2 Examine methods used for the recognition and collection of chemical evidence at crime scenes</td></tr>
<tr><td>P3 Examine methods used for the recognition and collection of chemical evidence at crime scenes.

P4 Discuss the issues of safety risks, preservation requirements and scene constraints in the context of the recognition and collection of chemical evidence at crime scenes.</td><td>M2 Assess the appropriateness of chemical evidence recognition and collection methods in relation to safety risks, preservation requirements and crime scene constraints.</td></tr>
<tr><td colspan="2">LO3 Review methods used for the recognition and collection of physical evidence at crime scenes</td></tr>
<tr><td>P5 Review methods used for the recognition and collection of physical evidence at crime scenes.

P6 Explain methods used to collect physical evidence while maintaining evidence condition, integrity and scene constraints.</td><td>M3 Analyse the appropriateness of physical evidence recognition and collection methods in relation to evidence condition, preservation requirements and crime scene constraints.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Develop a regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence for a simulated crime scene		**LO4**
P7 Develop a regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence for a simulated crime scene. **P8** Present a regulatory-compliant methodology for the collection, preservation and documentation of forensic evidence for a simulated crime scene.	**M4** Analyse the methodology used for forensic evidence collection in relation to sequencing, documentation and compliance with relevant professional standards.	**D2** Critically evaluate the effectiveness of the forensic evidence collection methodology in maintaining evidential integrity and regulatory compliance.

Recommended Resources

Textbooks

Houck, M.M. and Siegel, J.A. (2006) *Fundamentals of Forensic Science*. 4th edn. London: Academic Press.

Jackson, A.R.W., Jackson, J.M. and Mount, H. (2016) *Forensic Science*. 4th edn. Harlow: Pearson Education.

Mozayani, A. and Noziglia, C. (2006) *The Forensic Laboratory Handbook: Procedures and Practice*. Totowa, NJ: Humana Press.

NicDaeid, N. and White, P.C. (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Pfefferli, P. (2015) *Forensic Evidence Field Guide: Best Practices at Crime Scenes*. Massachusetts: Academic Press.

Robertson, J., Roux, C. and Wiggins, K. (2017) *Forensic Examination of Trace Evidence*. 2nd edn. Boca Raton, FL: CRC Press.

Saferstein, R. (2018) *Forensic Science: From the Crime Scene to the Crime Lab*. 4th edn. Boston, MA: Pearson.

Singh, J. and Sharma, N.R. (2023) *Crime Scene Management within Forensic Science*. Singapore: Springer.

Websites

https://www.crime-scene-investigator.net	Crime Scene Investigator Network Evidence collection and documentation resources (General reference)
https://enfsi.eu	European Network of Forensic Science Institutes (ENFSI) Best practice manuals and forensic standards (Standards)
https://www.fbi.gov/services/laboratory	Federal Bureau of Investigation - Laboratory Services Forensic evidence collection and handling guidance (Standards)

https://nij.ojp.gov	National Institute of Justice Crime scene and forensic science research and guidance (Research)
https://www.nist.gov	National Institute of Standards and Technology Forensic science standards and digital evidence guidance (Standards)
https://www.ojp.gov	Office of Justice Programs Digital evidence and crime scene documentation resources (General reference)
https://wilenet.widoj.gov	Wisconsin Law Enforcement Network Evidence handling and forensic practice manuals (Training)
https://www.unodc.org	United Nations Office on Drugs and Crime Crime scene and forensic investigation guidance (General reference)

Journals and articles

Adamczyk, M., *et al.* (2017) 'Three-dimensional measurement system for crime scene documentation', *Proceedings of SPIE*, 10441. Available at: https://doi.org/10.1117/12.2278489.

Galanakis, G., *et al.* (2021) 'A study of 3D digitisation modalities for crime scene investigation', *Forensic Sciences*, 1(2), pp. 56–85. Available at: https://doi.org/10.3390/forensicsci1020008.

Garrett, B.L. (2022) 'Policing forensic evidence', *American Journal of Law and Equality*, 2, pp. 107–121. Available at: https://doi.org/10.1162/ajle_a_00042.

Guttman, B., White, D.R. and Walraven, T. (2022) 'Digital Evidence Preservation: Considerations for Evidence Handlers', *NIST Interagency Report*, 8387. Available at: https://doi.org/10.6028/NIST.IR.8387.

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Panchal, V. and Mia, R. (2022) 'Detection of Footprint Impressions at the Scene of Crime<en-dash>A Review', *Journal of Forensic Science and Criminal Investigation*, 15(4). Available at: https://doi.org/10.19080/JFSCI.2022.15.555919.

Zhang, M. (2022) 'Forensic Imaging: A Powerful Tool in Modern Forensic Investigation', *Forensic Sciences Research*, 7(3), pp. 385–392. Available at: https://doi.org/10.1080/20961790.2021.2008705.

Zahra, S. and Lohani, A. (2022) 'Intersection of Justice, Crime Scene Investigation and Forensic Evidence in Pakistani Court', *Journal of Law and Social Studies*, 3(2), pp. 202–213. Available at: https://doi.org/10.52279/jlss.03.02.202213.

Links

This unit links to the following related units:

Unit 421: Volume Crime Scene Science

Unit 422: Forensic Anthropology and Pathology

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 510: Forensic Evidence Evaluation and Reporting

Unit 511: Applied Forensic Science

Unit 523: Principles of Pharmacology

Unit 527: Clinical Chemistry

Unit 528: Manage Forensic Investigations at Scenes.

Unit 510: Forensic Evidence Evaluation and Reporting

Unit code: J/652/3069

Unit level: 5

Credit value: 15

Introduction

The evaluation and interpretation of forensic evidence play a critical role in the administration of justice. Decisions made by forensic experts influence investigative direction, charging decisions, courtroom proceedings and, ultimately, legal outcomes. This unit develops students' ability to evaluate forensic evidence in a structured, transparent and defensible manner, recognising the scientific, professional and legal responsibilities associated with expert forensic practice.

The unit focuses on the foundational principles that underpin forensic evidence evaluation, including validity, reliability, uncertainty, evidential strength and the distinction between investigative information and evaluative opinion. Students will explore how forensic conclusions are formed, challenged and scrutinised within legal contexts, and how expert reasoning must withstand examination by courts, legal professionals and other decision makers. Emphasis is placed on proportionality, transparency and the avoidance of bias, ensuring that evaluative judgements are robust, traceable and professionally defensible.

Students will examine the roles and responsibilities of the forensic expert within legal and scientific frameworks, including duties to the court, ethical conduct, disclosure obligations, professional standards and accreditation frameworks governing forensic practice. The unit considers how these responsibilities shape evaluative decision making, particularly under adversarial conditions, time pressures and resource constraints common in contemporary forensic practice. Digital record-keeping, audit trails and electronic disclosure processes are introduced as integral features of modern forensic evaluation and reporting.

On completion of this unit, students will be able to demonstrate analytical reasoning for evaluation of forensic evidence and communicate their findings to appropriate technical and non-technical audiences, supporting progression into forensic science practice or investigative roles. The unit therefore contributes to the development of informed, reflective practitioners who understand the significance of evidence-based decisions and how to communicate them.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Review the foundational principles of forensic evidence evaluation

LO2 Discuss the roles and responsibilities of the forensic expert within legal and scientific contexts

LO3 Apply structured analytical reasoning to evaluate evidential materials

LO4 Communicate forensic findings and conclusions appropriate to technical and non-technical audiences.

Essential Content

LO1 **Review the foundational principles of forensic evidence evaluation**

Core evaluative principles:

Evaluation: validity, reliability, relevance and limitations of forensic evidence; evidential strength and probative value e.g. weight of evidence in relation to competing propositions; evaluation scales and qualitative/quantitative approaches

Uncertainty: sources and types of uncertainty affecting interpretation e.g. distinction between investigative information and evaluative opinion; case context and defined propositions; evaluative positioning; traceability of evaluative statements within documented case materials and digital records e.g. linking conclusions to specific observations, identifying uncertainty arising from sample quality.

Interpretation and evaluative reasoning:

Interpretation frameworks: hypothesis-led evaluation e.g. likelihood-based reasoning; consideration of competing propositions; inferential reasoning and logical coherence; role of case information and task-relevant information in evaluative judgement; management of contextual bias, including separation of task-relevant and task-irrelevant information

Evaluation: e.g. proportionality in evaluation relative to evidential value, case requirements and resource constraints; evaluation aligned to defined propositions e.g. comparing evidential support for alternative explanations, applying proportional reasoning where evidential value is limited.

Defensibility, uncertainty and auditability:

Defensibility and robustness of forensic conclusions: articulation of limitations, uncertainty and confidence; types of uncertainty e.g. measurement, epistemic, contextual; evaluation under conditions of incomplete or degraded data; consistency between evidence, interpretation and conclusions; scope and limits of evaluative expertise; distinction between evaluation, interpretation and reporting; traceability and reproducibility of evaluative decisions

Documentation: e.g. decision logs, notes and reports; auditability within digital systems, including version control and disclosure compliance; transparency for legal scrutiny; avoidance of overstatement or unsupported inference e.g. justifying evidential weight under cross-examination, demonstrating linkage between evidence and conclusions.

LO2 **Discuss the roles and responsibilities of the forensic expert within legal and scientific contexts**

Professional roles and boundaries:

Professional roles: scope and limits of the forensic expert role e.g. role boundaries in relation to commissioning parties, investigative teams and the court; independence, objectivity and impartiality e.g. distinction between expert opinion and advocacy; evaluative versus investigative roles

Accountability: e.g. professional accountability for evaluative decisions; maintenance of professional competence and scope of expertise; role clarity in adversarial contexts e.g. avoiding opinion beyond area of expertise, maintaining independence when instructed by legal representatives.

Legal, ethical and professional responsibilities:

Legal responsibilities: duties to the court as a primary obligation; professional standards and codes of conduct; regulatory and accreditation frameworks governing forensic practice e.g. ISO/IEC 17025 laboratory competence; ISO/IEC 17020 inspection activities, ISO 21043 forensic science processes, national regulatory codes of practice, accreditation bodies and quality assurance frameworks; compliance with legal frameworks governing expert evidence across jurisdictions; data protection and information governance frameworks

Ethical principles: integrity, transparency, impartiality; disclosure obligations and evidential continuity; confidentiality and secure handling of sensitive case materials; documentation integrity within digital systems e.g. audit trails, version control, meeting disclosure requirements, ensuring documentation is complete and traceable.

Impact on evaluative decision making and practice:

Impact of judgement: influence of professional responsibilities on evaluative judgement e.g. separation of task-relevant and task-irrelevant information; management of uncertainty, limitations and evidential constraints; avoidance and mitigation of cognitive and contextual bias

Decision making: decision making under legal, time and resource constraints; proportionality in evaluation and reporting; accountability for defensible conclusions; responsiveness to legal scrutiny and challenge; professional judgement in resolving conflicting information or limitations e.g. adjusting evaluative scope under disclosure constraints, recognising where contextual information may bias interpretation.

LO3 **Apply structured analytical reasoning to evaluate evidential materials**

Structured analytical reasoning and evaluation approaches:

Application of structured reasoning principles: hypothesis-led evaluation, formulation and testing of competing propositions; evaluative reasoning frameworks; likelihood-based reasoning approaches; logical coherence and internal consistency

Evaluation: sequencing from observation to conclusion; alignment of evaluation with case propositions; evaluative decision making based on evidential interpretation; documentation of reasoning pathways within case materials e.g. evaluating evidential support under alternative propositions; recording reasoning steps in decision logs.

Evaluation of evidential strength and uncertainty:

Assessment: evaluation of evidential strength and probative value e.g. calibration of conclusions in relation to evidential strength, proportionality of conclusions relative to evidential support; interpretation of findings in context; sensitivity of conclusions to case information

Impact of uncertainty: e.g. impact of uncertainty on evaluative judgement; sources and types of uncertainty; limitations of data quality, quantity and relevance e.g. incomplete or ambiguous evidential material

Communicating uncertainty: traceability between data, interpretation and conclusions e.g. communicating uncertainty where evidential support is limited; assessing evidential strength under competing explanations.

Bias management, robustness and defensibility of reasoning:

Bias management: recognition of cognitive and contextual biases affecting evaluation; structured approaches to minimise bias; separation of task-relevant and task-irrelevant information; critical testing of reasoning against alternative interpretations

Robustness and reliability of conclusions: identification of limitations and potential sources of error; consistency and transparency in reasoning processes; defensibility of evaluative outcomes under scrutiny; justification of conclusions in relation to evidential constraints and reasoning processes e.g. testing reasoning against competing explanations, identifying potential bias arising from contextual information.

LO4 **Communicate forensic findings and conclusions appropriate to technical and non-technical audiences**

Principles of forensic communication and audience adaptation:

Communication: purpose and context of forensic communication e.g. communication aligned to technical and non-technical audiences; clarity, precision and proportionality; distinction between evaluation, interpretation and reporting

Audience adaptation: audience knowledge, expectations and requirements e.g. adaptation of language and structure to support understanding, adapting terminology for non-specialist audiences; communication aligned to legal and professional contexts; communication supporting evaluative decision making e.g. presenting findings appropriately for expert reports and court summaries.

Professional accuracy, structure and reporting standards:

Accuracy: accurate and balanced representation of findings, reasoning and conclusions; use of appropriate terminology; acknowledgement of limitations, uncertainty and evidential constraints

Structure: structured presentation of forensic information e.g. consistency between evidence, interpretation and conclusions; proportional reporting relative to evidential strength

Reporting standards: documentation within digital systems e.g. traceability, audit trails, version control; alignment with professional standards and disclosure requirements e.g. ensuring conclusions do not exceed evidential support; maintaining consistency across report sections.

Effectiveness, evaluation and defensibility of communication:

Effectiveness: preparation for written and oral communication of findings; evaluation of communication effectiveness in relation to audience understanding e.g. clarity, transparency and accessibility of forensic outputs; impact of communication on interpretation and legal decision making

Defensibility of communicated conclusions under scrutiny: e.g. avoidance of overstatement, ambiguity or unsupported inference; responsiveness to feedback and clarification requirements; communication in adversarial contexts; reflection on strengths and limitations of communication approaches e.g. evaluating how reports support judicial understanding, responding to questioning under cross-examination.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Review the foundational principles of forensic evidence evaluation</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate forensic evidence evaluation by considering how evaluative principles, professional responsibilities and structured analytical reasoning produce defensible conclusions.</td></tr>
<tr><td>P1 Review core principles underpinning forensic evidence evaluation.

P2 Explain how interpretation and proportional reasoning support defensible conclusions.</td><td>M1 Analyse how forensic evidence evaluation principles influence evidential interpretation.</td></tr>
<tr><td colspan="2">LO2 Discuss the roles and responsibilities of the forensic expert within legal and scientific contexts</td></tr>
<tr><td>P3 Discuss the professional roles and responsibilities of the forensic expert.

P4 Examine the impact of legal, ethical, regulatory and accreditation frameworks on forensic decision making.</td><td>M2 Assess how professional roles and responsibilities influence forensic decision making.</td></tr>
<tr><td colspan="2">LO3 Apply structured analytical reasoning to evaluate evidential materials</td></tr>
<tr><td>P5 Apply structured analytical reasoning to evaluate evidential materials.

P6 Discuss evidential strength, uncertainty and potential bias.</td><td>M3 Assess evidential strength, uncertainty, and potential bias using structured analytical reasoning.</td></tr>
<tr><td colspan="2">LO4 Communicate forensic findings and conclusions appropriate to technical and non-technical audiences</td><td rowspan="2">LO4

D2 Critically evaluate the identified audience feedback in relation to the forensic findings and conclusions.</td></tr>
<tr><td>P7 Communicate forensic findings and conclusions for identified audiences to obtain feedback.

P8 Review the feedback obtained to identify strengths and weaknesses in the forensic findings and conclusions.</td><td>M4 Analyse the identified audience feedback in relation to the forensic findings and conclusions.</td></tr>
</table>

Recommended Resources

Textbooks

Adam, C. (2016) *Forensic Evidence in Court: Evaluation and Scientific Opinion*. Oxford: Wiley-Blackwell.

Aitken, C., Taroni, F. and Bozza, S. (2021) *Statistics and the Evaluation of Evidence for Forensic Scientists*. 3rd edn. Chichester: Wiley.

Biedermann, A., Taroni, F. and Aitken, C. (2006) *Bayesian Networks and Probabilistic Inference in Forensic Science*. Chichester: Wiley.

Edmond, G. (2017) *Expert Evidence and Scientific Proof in Criminal Trials*. London: Routledge.

Kahneman, D., Sibony, O. and Sunstein, C. (2021) *Noise: A Flaw in Human Judgment*. London: HarperCollins.

NicDaeid, N. and White, P.C. (eds.) (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Roberts, P. and Stockdale, M. (2018) *Forensic Science Evidence and Expert Witness Testimony*. Cheltenham: Edward Elgar.

Shelton, D.E. (2025) *The Role of Science in the Criminal Justice System*. Boca Raton, FL: CRC Press.

Websites

https://www.cps.gov.uk	Crown Prosecution Service (UK) Prosecution guidance on expert evidence and disclosure (Professional guidance)
https://www.ukas.com	United Kingdom Accreditation Service Accreditation of forensic laboratories and inspection bodies against ISO standards (e.g. ISO/IEC 17025, ISO/IEC 17020) (Regulatory guidance)
https://www.gov.uk/government/organisations/forensic-science-regulator	Forensic Science Regulator (UK) Codes of practice and regulatory guidance for forensic science (Regulatory guidance)

https://www.lawcom.gov.uk	Law Commission of England and Wales Law reform publications relevant to expert evidence (General reference)
https://nij.ojp.gov	National Institute of Justice (NIJ) Forensic training and guidance on reporting and courtroom testimony (Training)
https://www.nist.gov	National Institute of Standards and Technology (NIST) Forensic science standards and communication of findings (Standards)
https://www.proskauer.com	Proskauer Rose LLP Insights on expert evidence and disclosure practice (Article)
https://www.justice.gov	U.S. Department of Justice Forensic science guidance (e.g. bias and context management) (Professional guidance)

Journals and articles

Baxter, I., *et al.* (2025) 'Can science comics aid lay audiences' comprehension of forensic science?', *Journal of Science Communication*, 24(1), A01. Available at: https://doi.org/10.22323/2.24010201.

Cooper, G. and Meterko, V. (2021) 'Cognitive bias research in forensic science: A systematic review', *Forensic Science International*, 297, pp. 35–46. Available at: https://doi.org/10.1016/j.forsciint.2019.01.016.

Georgiou, N., Morgan, R.M. and French, J.C. (2020) 'Conceptualising, evaluating and communicating uncertainty in forensic science: Identifying commonly used tools through an interdisciplinary configurative review', *Science & Justice*, 60(4), pp. 313–336. Available at: https://doi.org/10.1016/j.scijus.2020.04.002.

Georgiou, N., Morgan, R.M. and French, J.C. (2023) 'The shifting narrative of uncertainty: a case for the coherent and consistent consideration of uncertainty in forensic science', *Australian Journal of Forensic Sciences*, 55(6), pp. 781–797. Available at: https://doi.org/10.1080/00450618.2022.2104370.

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Koch, S.L. (2025) 'Communicating Forensic Findings: Current Practices and Future Directions', *NIST Interagency Report*, NIST IR 8510sup1. Available at: https://doi.org/10.6028/NIST.IR.8510sup1.

Neuteboom, W., *et al.* (2024) 'Quantitative Evaluation of the Results of Digital Forensic Investigations: A Review of Progress', *Forensic Science International*, 358, 111779. Available at: https://doi.org/10.1016/j.forsciint.2023.111779.

Neuteboom, W., *et al.* (2024) 'Quality management and competencies in forensic science', *WIREs Forensic Science*. Available at: https://doi.org/10.1002/wfs2.1513.

Overill, R.E. and Collie, J. (2021) 'Quantitative evaluation of the results of digital forensic investigations: A review of progress', *Forensic Sciences Research*, 6(1), pp. 13–18. Available at: https://doi.org/10.1080/20961790.2020.1837429.

Spellman, B.A., Eldridge, H. and Bieber, P. (2022) 'Challenges to reasoning in forensic science decisions', *Forensic Science International: Synergy*, 4, 100200. Available at: https://doi.org/10.1016/j.fsisyn.2021.100200.

Taylor, M., *et al.* (2024) 'Forensic DNA Interpretation and Human Factors: Improving Practice Through a Systems Approach', *NIST Interagency Report*, NIST IR 8503. Available at: https://doi.org/10.6028/NIST.IR.8503.

Tewari, S., *et al.* (2024) 'Measurement uncertainty in testing of biologicals for ISO/IEC 17025: Practical approaches', *Accreditation and Quality Assurance*, 29, pp. 1–11. Available at: https://doi.org/10.1007/s00769-024-01589-8.

Ward, T. (2020) 'Explaining and trusting expert evidence: What is a "sufficiently reliable scientific basis"?', *The International Journal of Evidence & Proof*, 24(3), pp 233–254. Available at: https://doi.org/10.1177/1365712720927622.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 409: Fundamentals of Forensic Science

Unit 410: Criminal Investigation

Unit 501: Personal and Professional Development for Scientists

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 511: Applied Forensic Science.

Unit 511: Applied Forensic Science

Unit code: **M/652/3070**

Unit level: **5**

Credit value: **15**

Introduction

Forensic science brings together scientific principles, investigative practice and professional judgement to support decision making in forensic contexts. This unit introduces students to applied forensic approaches used to examine defined investigative scenarios and to consider how evidence can be selected, interpreted and communicated in a defensible way. It emphasises the importance of scientific reasoning, evidential integrity and professional accountability when working with complex or uncertain case information.

Students will explore forensic approaches across domains such as fire investigation, forensic toxicology, materials and trace evidence analysis. They will consider the suitability of different approaches in relation to case context, evidential relevance, investigative objectives, practical constraints, professional standards and limitations. This includes consideration of how regulatory expectations, validation, quality assurance and jurisdictional context can influence the selection and use of forensic approaches.

A key focus of the unit is the integration of multiple lines of forensic evidence. Students will examine how evidential weight, conflict, uncertainty and contextual factors can influence interpretation and decision making. They will apply structured forensic reasoning to develop conclusions that are coherent, proportionate and supported by evidence, while recognising assumptions, limitations and alternative explanations.

On completion of this unit, students will be able to assess forensic approaches, integrate evidence, justify investigative conclusions and report findings in a professionally structured case report. They will be able to communicate findings, reasoning, limitations and uncertainty clearly for relevant audiences. The unit supports progression to further study in forensic science, forensic toxicology, fire investigation or applied science, and to roles where evidence evaluation, structured reasoning and professional reporting are required.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss the suitability of different forensic approaches for defined investigative scenarios

LO2 Review how multiple lines of forensic evidence are integrated to support investigative and legal decision making

LO3 Apply structured forensic reasoning to a defined case study to develop and justify investigative conclusions

LO4 Produce a professionally structured forensic case report for a defined case study.

Essential Content

LO1 **Discuss the suitability of different forensic approaches for defined investigative scenarios**

Forensic approaches across applied domains:

Applied forensic domains: comparative suitability, evidential relevance, investigative value, limitations e.g. fire investigation, forensic toxicology, materials and trace evidence analysis

Fire investigation: fire behaviour, ignition, spread, burn pattern interpretation and cause classification e.g. accidental, deliberate or undetermined fire scenarios

Forensic toxicology: toxicokinetics, toxicodynamics, analytical detection, timing of exposure and physiological impact e.g. alcohol, drugs, poisons or combustion products

Materials and trace evidence: transfer, persistence, comparison, source attribution and analytical characterisation e.g. fibres, glass, gunshot residue, soil, polymers, metals or coatings.

Approach selection criteria and constraints:

Selection criteria for forensic approaches: evidential relevance, investigative questions, comparative sensitivity and specificity, substrate suitability, environmental conditions, methodological limitations, compatibility with available information e.g. degraded samples, limited residues, contaminated substrates, complex scenes

Practical and professional constraints: feasibility, proportionality, time-criticality, resource limitations, risk of compromised evidence, decision-making value e.g. restricted scene access, unstable samples, limited material, contamination risk

Regulatory and quality considerations: fit-for-purpose principles, validation status, professional standards, quality assurance, auditability, jurisdictional context e.g. Forensic Science Regulator Codes of Practice, ISO/IEC 17025, Criminal Procedure Rules

Limitations and uncertainty: degradation, contamination, sampling constraints, interpretive boundaries, ambiguous outcomes e.g. partial burn patterns, low-level toxicological findings, mixed trace evidence, environmental exposure.

Alignment of approaches to investigative context:

Alignment to investigative objectives: propositions, decision points, evidential value, case-specific constraints, justification of approach selection e.g. cause, mechanism, timing or association

Case context: nature of incident, scene conditions, available evidence, investigative questions, evidential expectations, interpretive boundaries, decision points e.g. cause, mechanism, timing or association.

Complementary and constraining approaches: strengths, limitations, sequencing across domains e.g. combining fire, toxicology and trace evidence findings.

LO2 **Review how multiple lines of forensic evidence are integrated to support investigative and legal decision making**

Evidential integration principles:

Evidential integration principles: complementary evidence, competing evidence, independence and dependency, corroboration, contradiction, sequencing, prioritisation e.g. scene observations, laboratory results, witness accounts, incident timelines

Integration across forensic domains: scene, laboratory and contextual findings e.g. fire scene indicators, toxicological results, materials or trace evidence findings

Coherent evidential picture: links between evidence types, relative evidential strength, conditional relevance, avoidance of isolated interpretation e.g. scene observations, laboratory findings, contextual information, incident chronology.

Evidential weight, conflict and uncertainty:

Evidential weight, strength and relevance: probative value, reliability, evidential hierarchy, relative contribution of evidence types e.g. association evidence, exclusionary findings, contextual evidence, corroborative findings

Conflicting findings, alternative interpretations and competing explanations: conflict, contradiction, testing, qualification of conclusions e.g. conflict across forensic evidence lines

Sources of uncertainty: analytical limitations, contextual ambiguity, incomplete information, residual uncertainty e.g. transfer and persistence variability

Transparent integration: assumptions, limitations, conditional interpretations, interpretive boundaries, contextual factors, uncertainty in combined evidence e.g. incomplete records, contested accounts, limited sampling, variable scene conditions.

Decision-making support through integrated evidence:

Decision-making support: investigative direction, prioritisation of enquiries, evidential significance, professional judgement e.g. suspect prioritisation, further testing, case review, legal disclosure

Investigative intelligence and evaluative evidence: distinction, purpose, evidential use, defensible decisions e.g. intelligence logs, screening results, confirmatory findings, expert opinion

Evidential narrative: coherence, consistency, logical sufficiency, defensible professional judgement e.g. incident timeline, evidence matrix, case chronology, summary of findings.

LO3 **Apply structured forensic reasoning to a defined case study to develop and justify investigative conclusions**

Structured forensic reasoning frameworks:

Structured reasoning approaches: hypothesis-based reasoning, proposition-based reasoning, inferential chains, logical argument structures, hypothesis testing, competing explanations e.g. prosecution and defence propositions, source-level propositions, activity-level propositions

Evidence-to-conclusion traceability: observations, interpretations, conclusions, inferential validity, logical consistency, case context e.g. exhibit notes, analytical results, interpretation records, conclusion summaries

Defensible conclusions: transparency, coherence, bias mitigation, contextual assumptions, avoidance of unsupported inference, case-context reasoning e.g. scene assumptions, witness accounts, investigative bias, contextual bias.

Application of reasoning across forensic domains:

Reasoning across forensic domains: domain-specific findings, investigative conclusions e.g. fire investigation, toxicology, materials or trace evidence

Domain-specific influences on inferential reasoning: mechanisms, timing, transfer, persistence, context e.g. fire dynamics, metabolism, material transfer

Consistency across evidence types: over-reliance on single evidence lines, quality of evidence, evidential strength, evidence-base limitations e.g. trace evidence, toxicology findings, fire scene indicators, contextual information.

Alternative explanations and limitations:

Alternative explanations: plausible alternatives, competing propositions, comparison, evaluation, exclusion, qualification e.g. accidental, deliberate or environmental explanations

Confounding factors and artefacts: distortion, obscurity or mimicry of evidential meaning e.g. secondary transfer, post-incident change, scene alteration

Limitations and uncertainty: information gaps, interpretive boundaries, reliability, quality and strength of evidence, proportionality of conclusions e.g. degraded evidence, incomplete scene records, mixed samples, inconclusive results.

LO4 **Produce a professionally structured forensic case report for a defined case study**

Forensic case report structure and conventions:

Purpose and audience of forensic case reports: audience-appropriate and accessible communication, evidential transparency, decision-making needs e.g. investigative, technical, legal and decision-making stakeholders

Professional conventions: objective tone, clarity, precision, terminology consistency, professional defensibility, avoidance of overstatement e.g. findings, interpretation and opinion

Report components: case context, methods overview, findings, integrated interpretation, evidential strength, conclusions, limitations e.g. exhibit summary, results table, interpretation section, limitations statement.

Integration and coherence in reporting:

Integrated findings: coherent narrative, evidence-interpretation-conclusion links, integration across forensic domains e.g. toxicology findings, fire scene findings, trace evidence findings, contextual findings.

Structuring and signposting: logical flow, clear reasoning, audit trail, reader understanding, scrutiny of conclusions e.g. headings, numbered exhibits, evidence tables, conclusion sections

Alignment of conclusions: evidential strength, proportionality, support from findings, interpretive boundaries, defensible judgement e.g. qualified conclusions, exclusionary conclusions, association conclusions, inconclusive findings.

Communication effectiveness and professional standards:

Communication of uncertainty: assumptions, limitations, strength of conclusions, residual uncertainty, conditional language e.g. supports, is consistent with, cannot exclude, limited support

Transparency and traceability: evidence-to-conclusion pathway, auditability of reasoning, basis for interpretation e.g. evidence logs, assumption records, reasoning summaries, audit trails

Stakeholder relevance and impact: decision-making value, audience needs, measured and unbiased communication of certainty and uncertainty e.g. investigators, legal professionals, technical reviewers, court users

Professional standards: auditability, professional accountability, evidential integrity, defensibility of written reporting.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss the suitability of different forensic approaches for defined investigative scenarios</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the effectiveness of an integrated forensic strategy in supporting investigative and legal decision making within defined scenarios.</td></tr>
<tr><td>P1 Discuss the suitability of selected forensic approaches in relation to case context, evidence type and investigative objectives.

P2 Explore relevant selection criteria for forensic approach selection within defined investigative scenarios.</td><td>M1 Justify the selection of forensic approaches in relation to investigative objectives, case context and constraints.</td></tr>
<tr><td colspan="2">LO2 Review how multiple lines of forensic evidence are integrated to support investigative and legal decision making</td></tr>
<tr><td>P3 Review how multiple lines of forensic evidence are integrated within defined scenarios.

P4 Discuss the impact of evidential weight, conflict and uncertainty on forensic decision making.</td><td>M2 Analyse the effectiveness of evidential integration within defined forensic scenarios.</td></tr>
<tr><td colspan="2">LO3 Apply structured forensic reasoning to a defined case study to develop and justify investigative conclusions</td></tr>
<tr><td colspan="3">LO3 and LO4

D2 Critically evaluate the effectiveness of the forensic case report in supporting defensible investigative conclusions for a defined case study.</td></tr>
<tr><td>P5 Apply structured forensic reasoning to evidence from a defined case study to develop investigative conclusions.

P6 Review investigative conclusions by considering alternative explanations, limitations and uncertainty.</td><td>M3 Analyse the effectiveness of structured forensic reasoning within a defined case study.</td></tr>
<tr><td colspan="2">LO4 Produce a professionally structured forensic case report for a defined case study</td></tr>
<tr><td>P7 Produce a professionally structured forensic case report for a defined case study.</td><td>M4 Analyse the effectiveness of the forensic case report in communicating integrated findings, evidential reasoning, limitations and uncertainty to a relevant audience.</td></tr>
</table>

Recommended Resources

Textbooks

Bell, S. (2022) *Forensic Chemistry*. 3rd edn. Boca Raton: CRC Press.

Desiderio, V.J., Taylor, C.E. and Nic Daéid, N. (2020) *Handbook of Trace Evidence Analysis*. Hoboken, NJ: Wiley.

Girard, J.E. (2020) *Criminalistics: Forensic Science, Crime, and Terrorism*. 4th edn. Burlington, MA: Jones & Bartlett Learning.

Houck, M.M. and Siegel, J.A. (2015) *Fundamentals of Forensic Science*. 3rd edn. London: Academic Press.

Levine, B.S. and Kerrigan, S. (2020) *Principles of Forensic Toxicology*. 5th edn. Cham: Springer.

Mozayani, A. and Noziglia, C. (2010) *The Forensic Laboratory Handbook: Procedures and Practice*. 2nd edn. Totowa, NJ: Humana Press.

Nic Daéid, N. and White, P.C. (eds.) (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Pazarena, L., Kessler, M. and Watroba, A. (2022) *Report Writing for Crime Scene Investigators*. Abingdon: Routledge.

Saferstein, R. and Roy, T. (2025) *Forensic Science: From the Crime Scene to the Crime Lab*. 5th edn. Harlow: Pearson.

Websites

https://www.aafs.org/	American Academy of Forensic Sciences Research and education on forensic standards (General reference)
https://www.atf.gov/	Bureau of Alcohol, Tobacco, Firearms and Explosives Resources around firearms, explosives and arson (General reference)
https://www.cfsre.org/	The Center for Forensic Science Research & Education Forensic science training (Training)

https://www.cfitrainer.net/	CFITrainer.Net Forensic science training based on case studies (Training)
https://enfsi.eu/	European Network of Forensic Science Institutes Forensic science information exchange network (General reference)
https://www.gov.uk/government/organisations/forensic-science-regulator	Forensic Science Regulator UK forensic science regulation and guidelines (General reference)
https://www.nist.gov/trace-evidence	National Institute of Standards and Technology – Trace Evidence Research around trace evidence (General reference)
https://nij.ojp.gov/topics/forensics/trace-evidence	National Institute of Justice - Trace Evidence Articles around trace evidence (Research)
https://tiaft.org/	The International Association of Forensic Toxicologists Professional association for forensic toxicology (Professional association)

Journals and articles

Aron, I. (2021) 'Forensic Investigation of Fires and Explosions', *Bulletin of the Transilvania University of Braşov*, 14(63). Available at: https://doi.org/10.31926/but.ssl.2021.14.63.1.14.

Biedermann, A. and Champod, C. (2024) 'Decisionalizing forensic inference: Reliance, reasoning and responsibility', *Law, Probability and Risk*, 23, mgae007. Available at: https://doi.org/10.1093/lpr/mgae007.

Icove, D.J. and May, T.R. (2021) 'Computer Fire Modeling and the Law: Application to Forensic Fire Engineering Investigations', *Journal of the National Academy of Forensic Engineers*, 38(1). Available at: https://doi.org/10.51501/jotnafe.v38i1.167.

Khalid, W., Burneo, M. and Hvam, L. (2021) 'A Framework for Multiple Fire Investigation Using Big Data and Statistical Analysis', *Journal of Failure Analysis and Prevention*, 21, pp. 890–903. Available at: https://doi.org/10.1007/s11668-021-01125-7.

Levine, B.S. and Kerrigan, S. (2021) 'Principles of Forensic Toxicology (book review)', *Journal of Analytical Toxicology*, 45(4), pp. e6–e7. Available at: https://doi.org/10.1093/jat/bkab020.

Malaca, S., Carlier, J. and Busardò, F.P. (2020) 'Advances in Forensic Toxicology', *Current Pharmaceutical Design*, 26(31), pp. 3779–3792. Available at: https://doi.org/10.2174/1381612826312008101236 37.

Meilia, P.D.I. (2022) *Evidence-Based Practice in Forensic Medicine: From INFERENCE to PERFORMance*. Doctoral thesis. Maastricht: Maastricht University. Available at: https://doi.org/10.26481/dis.20220124pm.

Solanke, A.A. and Biasiotti, M.A. (2022) 'Digital Forensics AI: Evaluating, Standardizing and Optimizing Digital Evidence Mining Techniques', *KI - Künstliche Intelligenz*, 36, pp. 143–161. Available at: https://doi.org/10.1007/s13218-022-00763-9.

Links

This unit links to the following related units:

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 510: Forensic Evidence Evaluation and Reporting

Unit 528: Manage Forensic Investigations at Scenes.

Unit 512: Solid State and Transition Metal Chemistry

Unit code: R/652/3071

Unit level: 5

Credit value: 15

Introduction

Solid-state and transition metal chemistry underpin many materials and technologies used in modern scientific and industrial practice. These areas support applications in electronic and magnetic materials, catalysts, energy-storage systems, sensors and advanced functional solids. At Level 5, students are expected to move beyond descriptive chemistry and develop a more integrated understanding of how atomic structure, bonding and electronic behaviour influence the properties and performance of real materials.

The unit introduces the principles governing solid-state structures, including crystal lattices, unit cells, atomic packing and defects. Students will explore how these structural features affect material behaviour and how idealised models can support, but also limit, the interpretation of real solids. This provides a foundation for considering structure–property relationships in applied contexts, including materials selection, material performance and sustainability.

Students will also examine the electronic structure of transition metals, with a focus on d-orbital occupancy, oxidation states and crystal field effects. The unit considers how electronic structure models are used to interpret colour, magnetism, stability and bonding in transition metal complexes. Students will apply analytical and evaluative approaches when considering the strengths and limitations of these models.

On completion of this unit, students will be able to investigate analytical techniques used to characterise transition metal complexes and present findings from laboratory-based methods or real-world case studies. They will develop skills in interpreting analytical evidence, recognising data limitations and drawing justified conclusions. This supports progression to further study or employment in materials science, analytical chemistry, industrial chemistry, quality control, laboratory analysis and research environments.

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Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the principles governing solid-state structures

LO2 Explore the electronic structure of transition metals

LO3 Discuss the structure–property relationships in solid-state materials

LO4 Present, using either real-world case studies or laboratory-based methods, an investigation into the analytical techniques used to characterise transition metal complexes.

Essential Content

LO1 **Explain the principles governing solid-state structures**

Crystal lattice types and unit cells:

Common crystal lattice types in solid-state materials: simple cubic (SC), body-centred cubic (BCC), face-centred cubic (FCC)

Lattice structure concepts: e.g. lattice points, basis, Bravais lattice, unit-cell definition, representation, unit-cell content (atoms per cell), fractional coordinates, lattice parameters (a, b, c; α, β, γ), symmetry features

Coordination number: coordination number as structural descriptor; packing fraction/atomic packing factor; comparison of lattice efficiency and packing density across lattice types e.g. high packing efficiency of FCC in many metals (e.g. Al, Cu), lower packing of BCC but common in Fe at room temperature, SC rare in elemental solids.

Atomic packing and defects in solids:

Atomic packing concepts: e.g. close-packed structures, packing efficiency, hexagonal close packing (HCP), FCC as close-packed variant, stacking sequences (ABAB versus ABCABC)

Ideal versus real crystalline solids: point defects e.g. vacancies, interstitials, substitutional defects; Schottky, Frenkel defect concepts for ionic solids; extended defects such as dislocations, grain boundaries; defect concentration concepts, thermal generation

Influence of defects: influence on the mechanical and physical behaviour of solids e.g. dislocation mobility linked to ductility versus brittleness, vacancy-assisted diffusion in alloys, grain boundaries influencing corrosion, strength in polycrystalline materials.

Structural models and their limitations:

Idealised solid-state models for real materials: assumptions underpinning lattice models e.g. limitations for non-stoichiometric, amorphous or defect-rich solids; polymorphism, phase stability concepts

Choice of model: model appropriateness across material classes e.g. metallic lattices, delocalised electrons in Na and Cu, ionic lattice models for NaCl-type solids, covalent network models for diamond and SiO_2; amorphous solids requiring short-range order descriptions e.g. glassy silica.

LO2 **Explore the electronic structure of transition metals**

d-orbital occupancy and electronic configuration:

Electronic configuration of transition metals: d-subshell occupancy, relative energies of s, d orbitals in atoms, ions

Oxidation states: influence on electronic structure e.g. first-row versus second/third-row trends, common oxidation state patterns

Relationship between electronic configuration and chemical behaviour: variable oxidation state behaviour, redox flexibility, ligand substitution tendencies e.g. Fe^{2+}/Fe^{3+} redox interconversion, Mn exhibiting multiple oxidation states, Cu^{+} versus Cu^{2+} stability differences.

Crystal field splitting and coordination environment:

Crystal field theory: crystal field theory as model for d-orbital splitting in coordination environments e.g. octahedral, tetrahedral splitting patterns, magnitude of crystal field splitting (Δ_o, Δ_t), energy level concepts

Influence of ligand type and metal ion on splitting patterns: spectrochemical series positioning, ligand field strength, pairing energy versus Δ_o competition, high-spin, low-spin configurations as ligand field strength outcomes e.g. $[Fe(H_2O)_6]^{2+}$ typically high-spin, $[Fe(CN)_6]^{4-}$ typically low-spin, tetrahedral complexes commonly high-spin due to smaller Δ_t.

Use and limitations of electronic structure models:

Uses of electronic structure models: e.g. electronic structure models applied to trends in colour, magnetism, stability of transition metal complexes; qualitative interpretation of spectrochemical series, spin-only magnetism versus orbital contributions, paramagnetism/diamagnetism, unpaired electron count

Limitations of crystal field theory: advanced models for covalency and metal-ligand interactions e.g. ligand-to-metal/metal-to-ligand charge transfer contributions to colour, π-bonding effects with CO or CN^{-}, cases where pure ionic CFT predictions fail.

LO3 **Discuss the structure–property relationships in solid-state materials**

Bonding models in solid-state materials:

Bonding models in solids: ionic, metallic, covalent models; delocalised electron models in metals; network covalent bonding in extended structures

Relationship between bonding type and macroscopic properties: melting point, hardness, conductivity e.g. high melting points and brittleness in ionic solids, electrical/thermal conductivity in metallic solids, hardness and high melting points in network covalent solids/giant structures.

Electronic structure and material properties:

Electronic structure influence on physical properties of solids: qualitative description of electrical conductivity in metals, semiconductors, insulators

Band gap concept: valence/conduction band, Fermi level, doping concepts (n-type/p-type), carrier concentration as property driver

Relationship between electronic configuration and magnetic behaviour in solid-state materials: introductory band structure concepts for property interpretation e.g. Si as a semiconductor with dopants such as P or B, wide band gap insulators such as Al_2O_3, ferromagnetism in Fe, Co, Ni linked to unpaired d electrons, exchange interactions.

Interpretation of structure-property relationships:

Structure–property relationships: e.g. structural features, bonding models, electronic structure linked to observed material properties

Interpretation: comparison of materials with similar structures but differing properties; structure–property trade-offs e.g. strength versus ductility, conductivity versus stability

Material selection: considerations of strengths and weaknesses of simplified structure–property models e.g. material performance, efficiency, longevity in sustainable material selection; uses e.g. defect engineering to improve semiconductor performance, alloys to improve corrosion resistance, material lifetime considerations in magnetic components and energy devices.

LO4 **Present, using either real-world case studies or laboratory-based methods, an investigation into the analytical techniques used to characterise transition metal complexes**

Analytical techniques for characterisation:

Analytical techniques for transition metal complex characterisation: e.g. ultraviolet–visible spectroscopy, infrared spectroscopy, magnetic susceptibility measurements

Structural and electronic information from each technique: selection logic for complementary techniques, fitness-for-purpose, complementary techniques use for characterisation e.g. UV–Vis for d-d/charge transfer features, IR for ligand functional-group binding shifts such as CO/CN, magnetic susceptibility to infer unpaired electrons, likely high-spin/low-spin assignments.

Analytical evidence and data interpretation:

Data interpretation: spectral features, trends relevant to transition metal complexes e.g. absorption bands, ligand-related vibrations

Beer–Lambert considerations (qualitative): peak position/intensity interpretation, baseline/solvent considerations

Qualitative interpretation of magnetic data: digitally generated analytical outputs e.g. electronic spectra, software-processed magnetic data for interpretation

Comparison, presentation of results: consistency of analytical evidence with proposed structural models e.g. octahedral versus tetrahedral assignment supported by splitting patterns, magnetic moment range, IR shifts supporting coordination mode changes such as monodentate versus bidentate carboxylate trends.

Quality, limitations and validity of analytical evidence:

Sources of uncertainty, limitation in analytical data: e.g. instrumental, methodological constraints, ambiguity in spectral interpretation, signal-to-noise, resolution, overlapping bands, sample purity, solvent effects

Alternative explanations: competing interpretations; justification of conclusions based on quality, completeness, reliability of available analytical evidence e.g. multiple plausible geometries from UV–Vis alone, need to triangulate with IR and magnetic data, limitations of qualitative assignments where reference data are incomplete.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the principles governing solid-state structures</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate the effectiveness of structural and electronic models for material property interpretation.</td></tr>
<tr><td>P1 Compare common crystal lattice types and unit-cell parameters in solid-state structures.

P2 Explain atomic packing and defect types in real crystalline solids.</td><td>M1 Analyse the influence of crystal lattice type, atomic packing and defects on solid-state structure.</td></tr>
<tr><td colspan="2">LO2 Explore the electronic structure of transition metals</td></tr>
<tr><td>P3 Explain electronic configuration trends and oxidation states in transition metals.

P4 Explore crystal field splitting and properties of transition metal complexes.</td><td>M2 Assess how electronic configuration and crystal field splitting influence transition metal complex behaviour.</td></tr>
<tr><td colspan="2">LO3 Discuss the structure–property relationships in solid-state materials</td></tr>
<tr><td>P5 Explain relationships between bonding models and properties of solid-state materials.

P6 Discuss electronic structure concepts in relation to differences between classes of solid-state materials.</td><td>M3 Analyse the relative influence of bonding and electronic structure on material properties.</td></tr>
<tr><td colspan="2">LO4 Present, using either real-world case studies or laboratory-based methods, an investigation into the analytical techniques used to characterise transition metal complexes</td><td rowspan="2">LO4

D2 Critically evaluate the effectiveness of the analytical techniques used to characterise transition metal complexes.</td></tr>
<tr><td>P7 Investigate, using either real-world case studies or laboratory-based methods, analytical techniques for transition metal complex characterisation.

P8 Present findings from an investigation into transition metal complex characterisation.</td><td>M4 Assess the effectiveness of the analytical techniques used to characterise transition metal complexes.</td></tr>
</table>

Recommended Resources

Textbooks

Burrows, A., *et al.* (2021) *Chemistry: Introducing Inorganic, Organic and Physical Chemistry*. 4th edn. Oxford: Oxford University Press.

House, J.E. (2025) *Inorganic Chemistry*. 4th edn. London: Academic Press.

Housecroft, C.E. and Sharpe, A.G. (2018) *Inorganic Chemistry*. 5th edn. Harlow: Pearson Education.

Khomskii, D.I. (2014) *Transition Metal Compounds*. Cambridge: Cambridge University Press.

Lalena, J.N., Cleary, D.A. and Hardouin Duparc, O.B.M. (2020) *Principles of Inorganic Materials Design*. 3rd edn. Hoboken: Wiley.

Miessler, G.L., Fischer, P.J. and Tarr, D.A. (2013) *Inorganic Chemistry*. 5th edn. Boston, MA: Pearson.

Moore, E.A. and Smart, L.E. (2021) *Solid State Chemistry: An Introduction*. 5th edn. Boca Raton: CRC Press.

Norman, N.C. (2021) *Periodicity and the s- and p-Block Elements*. 2nd edn. Oxford: Oxford University Press.

Weller, M., Rourke, J., Armstrong, F., Lancaster, S. and Overton, T. (2025) *Inorganic Chemistry*. 8th edn. Oxford: Oxford University Press.

Woodward, P.M., *et al.* (2021) *Solid-State Materials Chemistry*. Cambridge: Cambridge University Press.

Websites

https://pubs.acs.org/	American Chemical Society Publications (Research)
https://chem.libretexts.org/Bookshelves/General_Chemistry/Chemistry_2e_(OpenStax)/10%3A_Liquids_and_Solids/10.06%3A_Lattice_Structures_in_Crystalline_Solids	Chemistry LibreTexts Crystal lattices and unit cells (Student reference)

https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Map%3A_Inorganic_Chemistry_(Housecroft)/20%3A_d-Block_Metal_Chemistry-_Coordination_Complexes/20.06%3A_Crystal_Field_Theory	Chemistry LibreTexts Crystal field theory (Student reference)
https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Map%3A_Inorganic_Chemistry_(Housecroft)/20%3A_d-Block_Metal_Chemistry-_Coordination_Complexes/20.07%3A_High_Spin_and_Low_Spin_Complexes	Chemistry LibreTexts High-spin and low-spin complexes (Student reference)
https://chem.libretexts.org/Bookshelves/Inorganic_Chemistry/Introduction_to_Inorganic_Chemistry_(Wikibook)/08%3A_Ionic_and_Covalent_Solids_-_Structures/8.07%3A_Band_Theory_of_Solids	Chemistry LibreTexts Band theory of solids (Student reference)
https://ocw.mit.edu/courses/3-091sc-introduction-to-solid-state-chemistry-fall-2010/pages/electronic-materials/	MIT OpenCourseWare Electronic materials and band theory (Teaching resource)
https://pubs.rsc.org/	Royal Society of Chemistry Journals (Research)

Journals and articles

Dichiarante, V., Strada, A. and Bergamaschi, G. (2021) 'Photochemistry of transition-metal complexes (2019-2020)', *Photochemistry*, 49, pp. 177–211. Available at: https://doi.org/10.1039/9781839165269-00177.

Ferrari, S., *et al.* (2021) 'Solid-State Post Li Metal Ion Batteries: A Sustainable Forthcoming Reality?', *Advanced Energy Materials*, 11, 2100785. Available at: https://doi.org/10.1002/aenm.202100785.

Huang, W.-H., *et al.* (2021) 'Recent progress and perspectives on metal- and covalent-organic framework based solid-state electrolytes for lithium-ion batteries', *Materials Chemistry Frontiers*, 5, pp. 4596–4620. Available at: https://doi.org/10.1039/D0QM00936A.

Huo, H. and Janek, J. (2023) 'Solid-state batteries: From "all-solid" to "almost-solid"', *National Science Review*, 10(6), nwad098. Available at: https://doi.org/10.1093/nsr/nwad098.

Ma, M., *et al.* (2023) 'A review of all-solid-state electrolytes for lithium batteries: high-voltage cathode materials, solid-state electrolytes and interfaces', *Materials Chemistry Frontiers*, 7, pp. 1268–1297. Available at: https://doi.org/10.1039/D2QM01071B.

Schlem, R., *et al.* (2021) 'Energy Storage Materials for Solid-State Batteries: Design by Mechanochemistry', *Advanced Energy Materials*, 11, 2101022. Available at: https://doi.org/10.1002/aenm.202101022.

Turner, J.J., *et al.* (2022) 'Photochemistry of transition metal carbonyls', *Chemical Society Reviews*, 51, pp. 5300–5329. Available at: https://doi.org/10.1039/D1CS00826A.

Wang, H., *et al.* (2024) 'Advances in solid-state batteries: Materials, interfaces, characterisation and devices', *MRS Bulletin*, 48, pp. 1221–1229. Available at: https://doi.org/10.1557/s43577-023-00649-7.

Yang, Y.-N., *et al.* (2021) 'A Surface Coordination Interphase Stabilizes a Solid-State Battery', *Angewandte Chemie International Edition*, 60, pp. 20704–20710. Available at: https://doi.org/10.1002/anie.202108050.

Zhou, G. and Liang, Z. (2023) 'Toward Sustainable All Solid-State Li–Metal Batteries: Perspectives on Battery Technology and Recycling Processes', *Advanced Materials*, 35, 2301540. Available at: https://doi.org/10.1002/adma.202301540.

Links

This unit links to the following related units:

Unit 411: Inorganic Chemistry

Unit 413: Physical Chemistry

Unit 423: Analytical Chemistry

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 514: Spectroscopy, Surface Chemistry and Equilibria

Unit 526: Further Analytical Chemistry.

Unit 513: Aromatic and Carbonyl Compounds

Unit code: T/652/3072

Unit level: 5

Credit value: 15

Introduction

Aromatic and carbonyl compounds are central to organic chemistry and to many applications in chemical manufacturing, pharmaceuticals, materials science, analytical science and sustainable synthesis. This unit builds on Level 4 organic chemistry by developing students' understanding of how structure, bonding and electron distribution influence the behaviour of important organic functional groups. Students will examine aromatic systems in terms of ring structure, planarity, conjugation, aromaticity criteria and substitution patterns, including the classification of aromatic, anti-aromatic and non-aromatic systems.

Students will use resonance and molecular orbital models to interpret aromatic stability, electron density and reactivity, while recognising the limitations of simplified bonding models. They will explore electrophilic aromatic substitution reactions, including electrophile generation, σ-complex formation, re-aromatisation and catalyst regeneration. The unit considers how substituent effects, directing influence, steric factors and competing directors affect reaction rate, position and product outcomes.

Carbonyl chemistry is developed through the structure and polarity of the carbonyl group, electrophilicity, nucleophilic addition, oxidation–reduction behaviour and α-carbonyl chemistry. Students will consider enolisation, keto–enol equilibrium, enolate formation, α-substitution and diagnostic reactions, including the scope and limitations of the iodoform test. They will also consider reaction selectivity, side reactions, purification burden, waste minimisation and the suitability of carbonyl transformations in synthetic contexts. Practical and case-study evidence will support investigation into synthetic and analytical approaches applied to aromatic and carbonyl compounds. Students will interpret spectroscopic and chromatographic evidence, use digital tools to process and present data, and evaluate the validity, reliability and limitations of conclusions drawn from analytical evidence.

On completion of this unit, students will be able to apply organic chemistry principles to explain and evaluate the reactivity of aromatic and carbonyl compounds in laboratory and industrial contexts. The unit supports progression to further study in chemistry, medicinal chemistry, pharmaceutical science, analytical chemistry, forensic

science, materials science, chemical engineering and related applied science degrees. It also supports career routes in research and development, quality control, analytical testing, environmental analysis, process chemistry, formulation science, technical services and laboratory-based roles within chemical, pharmaceutical and allied industries.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the structural and electronic features of aromatic compounds

LO2 Discuss the mechanisms of electrophilic aromatic substitution reactions

LO3 Explain the structure and reactivity of carbonyl compounds

LO4 Present, using either real-world case studies or laboratory-based methods, an investigation into the synthetic and analytical approaches applied to aromatic and carbonyl compounds.

Essential Content

LO1 **Explain the structural and electronic features of aromatic compounds**

Aromatic structural features and classification:

Aromatic ring frameworks: mono- and polysubstituted aromatic systems; planarity, cyclic conjugation, continuous p-orbital overlap

Aromaticity criteria: aromatic, anti-aromatic, non-aromatic classification; electron-count criteria; structural constraints e.g. cyclopentadienyl anion versus cyclobutadiene, cyclooctatetraene as non-planar nonaromatic system

Positional nomenclature: e.g. ortho/meta/para distribution patterns; 1,2-/1,3-/1,4-isomer sets.

Electronic structure and bonding models:

Resonance representations: π-molecular orbital (MO) descriptions; qualitative electron density distribution in aromatic systems

Structure–property and structure–reactivity relationships: delocalisation; resonance stabilisation; comparison of structural/electronic models; scope of applicability; model limitations

Substituent electronic effects: inductive and mesomeric effects; electron density distribution; predicted reactivity trends e.g. pyridine vs pyrrole lone-pair participation, anisole vs nitrobenzene as electron-rich vs electron-poor aromatic systems

Limitations of simplified models: substituted, fused and heteroatom-containing aromatic systems; borderline classifications; competing effects.

Experimental and spectroscopic evidence for aromatic structure:

Chemical and spectroscopic evidence: diagnostic indicators; interpretive cues for aromatic structure and substitution patterns; evidence weighting; limitations of single-technique inference

Evidence support: evidence support or challenge for proposed structural/electronic models e.g. ^{1}H NMR aromatic region patterns, integration and symmetry-linked simplification in para-disubstituted systems, IR aromatic C=C features, substitution-pattern-sensitive out-of-plane C-H bending indicators.

LO2 **Discuss the mechanisms of electrophilic aromatic substitution reactions**

Core electrophilic aromatic substitution (EAS) pathways:

General EAS mechanistic framework: electrophile generation; σ-complex (arenium ion) formation; re-aromatisation; catalyst regeneration; rate-determining step; intermediate stability

Mechanistic conventions: pathway and intermediate representation; common EAS reaction families e.g. nitration, sulfonation, halogenation; electrophile generation conditions e.g. nitronium ion (NO_2^+) formation in nitration mixtures, halogenation using $FeBr_3$/$AlCl_3$ as halogen carriers

Friedel–Crafts alkylation and acylation: constraints and failure modes e.g. polyalkylation tendencies, deactivation with strongly electron-withdrawing substituents.

Substituent effects on rate and position:

Substituent electronic effects: activating/deactivating behaviour; directing influence; ortho/para versus meta outcomes; resonance and inductive effects

Steric effects: e.g. competing director influences in polysubstituted systems

Rate/position outcomes through mechanistic reasoning: predictive limitations; regioselectivity trends e.g. nitration of acetanilide vs nitrobenzene, competing directors in 1-bromo-4-methylbenzene, steric hindrance effects on ortho outcomes.

Mechanistic explanation of reactivity patterns:

Mechanistic explanation of observed substitution patterns: regioselectivity; product distribution; selectivity constraints; prediction limits; evidential support where outcomes are ambiguous

Mechanistic plausibility versus evidential support: efficiency-linked implications of competing pathways e.g. multiple substitution risk during nitration and effects on product distribution, polyalkylation in Friedel–Crafts alkylation as driver of by-product formation and purification burden.

LO3 **Explain the structure and reactivity of carbonyl compounds**

Carbonyl structure and fundamental reactivity:

Carbonyl functional-group structure: e.g. bond polarisation, electrophilicity, qualitative LUMO/electron-acceptor ideas

Factors affecting electrophilicity and nucleophilic addition outcomes: e.g. electronic effects, steric effects, conjugation

Aldehyde and ketone comparative reactivity: structure–reactivity relationships; nucleophilic addition; oxidation–reduction behaviour e.g. aldehyde oxidation to carboxylic acids, reduction of aldehydes/ketones to alcohols

Chemoselectivity trends: e.g. constraints in systems containing multiple functional groups.

α-Carbonyl chemistry: acidity, enolisation and enolates:

α-hydrogen acidity: enolisation; keto–enol equilibrium position; stability comparison

Resonance delocalisation in enols and enolates: stabilisation drivers; enolate formation and relative stability; kinetic versus thermodynamic control; solvent/base effects; stabilised enol forms in specific structural contexts e.g. β-dicarbonyl systems and enol stabilisation, intramolecular hydrogen bonding in enol-favoured structures.

α-Substitution outcomes and diagnostic reactions:

α-halogenation under acidic and basic conditions: e.g. key mechanistic contrasts, selectivity constraints, competing outcomes in α-substitution contexts; haloform reaction as base-promoted multi-halogenation outcome

Iodoform test scope and limitations: diagnostic link to carbonyl/enolate chemistry e.g. methyl ketone requirement, ethanol oxidation products as positive cases; conceptual interpretation of reactivity outcomes versus procedural laboratory detail.

Evaluation of carbonyl reactions in synthetic contexts:

Evaluation: e.g. carbonyl transformation evaluation for synthetic usefulness, reaction scope, selectivity, chemo- and regioselectivity, side-reaction susceptibility, efficiency trade-offs

Suitability constraints: e.g. mixture formation, purification burden, avoidable waste streams

Transformation choice: step economy; avoidance of unnecessary derivatisation e.g. selectivity constraints leading to mixtures; self-condensation/aldol-type risks in reactive carbonyl systems affecting yield and waste.

LO4 **Present, using either real-world case studies or laboratory-based methods, an investigation into the synthetic and analytical approaches applied to aromatic and carbonyl compounds**

Investigation contexts and evidence base:

Investigation purpose and scope: alignment to aromatic/carbonyl chemistry; laboratory-based investigations or real-world case studies as evidence sources

Evidence types: e.g. dataset characteristics, uncertainty sources, bias/interference considerations, audience suitability

Presentation: presentation structures for investigation communication and conclusions e.g. lab-generated IR/NMR/chromatography outputs, published spectral libraries, journal supplementary datasets.

Synthetic approaches applied to aromatic and carbonyl compounds:

Synthetic approaches: synthetic approaches for formation or modification of aromatic and carbonyl compounds; route rationale; step economy concepts; outcome interpretation

Approach selection criteria: e.g. desired transformation, chemoselectivity; by-product risk, waste minimisation, purification burden; trade-off decisions in route design e.g. single-step versus multi-step route selection considering yield versus purity, avoiding protecting-group/derivatisation steps where selectivity allows.

Analytical approaches, interpretation, digital tools, and limitations:

Analytical approaches: analytical techniques for characterisation of aromatic and carbonyl compounds e.g. spectroscopic and chromatographic approaches

Interpretation: evidence triangulation for identity/structure/purity claims e.g. interpretive cues, interference sources, confidence in assignment

Digital tools: digital tools for processing, visualisation and presentation.

Validity, reliability and limitations of conclusions: evidence sufficiency; fitness for purpose of methods e.g. reaction monitoring by thin-layer chromatography (TLC)/high-performance liquid chromatography (HPLC), purity profiling by gas chromatography (GC), combined infrared (IR) and nuclear magnetic resonance (NMR) for structural assignment, chromatography + spectroscopy for purity and identity.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the structural and electronic features of aromatic compounds</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate reactivity trends in aromatic and carbonyl compounds.</td></tr>
<tr><td>P1 Explain aromaticity, aromatic classification and substitution patterns.

P2 Discuss electronic models used to interpret aromatic structure and evidence.</td><td>M1 Analyse how structural and electronic features influence stability and reactivity in aromatic compounds.</td></tr>
<tr><td colspan="2">LO2 Discuss the mechanisms of electrophilic aromatic substitution reactions</td></tr>
<tr><td>P3 Discuss mechanisms of electrophilic aromatic substitution reactions.

P4 Explain substituent effects on electrophilic aromatic substitution rate and position.</td><td>M2 Assess how substituent effects influence rate, position and product outcomes in electrophilic aromatic substitution reactions.</td></tr>
<tr><td colspan="2">LO3 Explain the structure and reactivity of carbonyl compounds</td></tr>
<tr><td>P5 Explain carbonyl structure and fundamental reactivity.

P6 Explore α-carbonyl chemistry and diagnostic reactions.</td><td>M3 Analyse how electronic effects influence reactivity trends and outcomes in carbonyl compounds.</td></tr>
<tr><td colspan="2">LO4 Present, using either real-world case studies or laboratory-based methods, an investigation into the synthetic and analytical approaches applied to aromatic and carbonyl compounds</td><td rowspan="2">LO4

D2 Critically evaluate the effectiveness of the synthetic and analytical approaches applied to aromatic and carbonyl compounds.</td></tr>
<tr><td>P7 Present findings from an investigation into the synthetic and analytical approaches applied to aromatic and carbonyl compounds.

P8 Review the synthetic and analytical approaches applied to aromatic and carbonyl compounds.</td><td>M4 Analyse the effectiveness of the synthetic and analytical approaches applied to aromatic and carbonyl compounds.</td></tr>
</table>

Recommended Resources

Textbooks

Brown, W.H., *et al.* (2022) *Organic Chemistry*. 9th edn. Boston: Cengage Learning.

Clayden, J., Greeves, N. and Warren, S. (2012) *Organic Chemistry*. 2nd edn. Oxford: Oxford University Press.

Fernandez, I. (ed.) (2021) *Aromaticity: Modern Computational Methods and Applications*. Amsterdam: Elsevier.

Fleming, I. and Williams, D.H. (2020) *Spectroscopic Methods in Organic Chemistry*. 7th edn. Cham: Springer.

Klein, D.R. (2020) *Organic Chemistry*. 4th edn. Hoboken, NJ: Wiley.

McMurry, J. (2023) *Organic Chemistry*. 10th edn. Houston, TX: OpenStax.

Smith, M.B. (2020) *March's Advanced Organic Chemistry: Reactions, Mechanisms, and Structure*. 8th edn. Hoboken, NJ: Wiley.

Solomons, T.W.G., Fryhle, C.B. and Snyder, S.A. (2016) *Organic Chemistry*. 12th edn. Hoboken, NJ: Wiley.

Wade, L.G. and Simek, J.W. (2022) *Organic Chemistry, Global Edition*. 10th edn. Harlow: Pearson.

Websites

https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Map%3A_Organic_Chemistry_%28Wade%29_Complete_and_Semesters_I_and_II/Map%3A_Organic_Chemistry_II_%28Wade%29/17%3A_Aromatic_Compounds	Chemistry LibreTexts Aromatic compounds chapter covering aromaticity, substitution patterns and spectroscopy (Student reference)
https://www.acs.org/education/resources/undergraduate.html	American Chemical Society Undergraduate chemistry education resources, including instructional materials and green chemistry modules (General reference)
https://www.organic-chemistry.org/namedreactions/friedel-crafts-acylation.shtm	Organic Chemistry Portal Friedel–Crafts acylation named reaction page, with mechanism, related reactions and literature examples (General reference)

http://orgchemboulder.com/Spectroscopy/Problems/index.shtml	University of Colorado Boulder – Organic Chemistry Practice IR/NMR spectroscopy problems for organic compound structure determination (Tutorials)
https://openstax.org/details/books/organic-chemistry	OpenStax Organic Chemistry: A Tenth Edition by John McMurry, free online textbook for students and instructors (eBook)
https://www.rsc.org/policy-and-campaigning/policy-library/green-shoots-part-3	Royal Society of Chemistry Sustainable chemistry curriculum report supporting integration of sustainability and climate change into chemistry education (Report)

Journals and articles

Budnikova, Y.H., *et al.* (2023) 'Electrochemistry in organics: a powerful tool for green synthesis', *Journal of Solid State Electrochemistry*, 27(4), pp. 987–1005. Available at: https://doi.org/10.1007/s10008-023-05507-9.

Cai, Y., Hua, Y. and Xia, H. (2021) 'Electrophilic aromatic substitution reactions of Craig-Möbius aromatic compounds', *Proceedings of the National Academy of Sciences*, 118(32), e2102310118. Available at: https://doi.org/10.1073/pnas.2102310118.

Galabov, B., *et al.* (2022) 'Mini-Review on Structure–Reactivity Relationship for Aromatic Molecules: Recent Advances', *ACS Omega*, 7(9), pp. 8199–8208. Available at: https://doi.org/10.1021/acsomega.1c07176.

Lin, J., *et al.* (2023) 'Cleavage of non-polar C(sp^2)-C(sp^2) bonds in cycloparaphenylenes via electric field-catalyzed electrophilic aromatic substitution', *Nature Communications*, 13, Article 35686. Available at: https://doi.org/10.1038/s41467-022-35686-4.

Martí, T., *et al.* (2024) 'Electrophilic aromatic substitution in eutectic-type mixtures: from an old concept to new sustainable horizons', *RSC Sustainability*, 2, pp. 1215–1230. Available at: https://doi.org/10.1039/D4SU00051J.

Mayer, R.J., Allihn, P.W.A. and Ofial, A.R. (2021) 'Electrophilic reactivities of cyclic enones and α,β-unsaturated lactones', *Chemical Science*, 12, pp. 4850–4865. Available at: https://doi.org/10.1039/D0SC06628A.

Rubab, L., Anum, A., Al-Hussain, S.A., Irfan, A., Ahmad, S., Ullah, S., Al-Mutairi, A.A. and Zaki, M.E.A. (2022) 'Green chemistry in organic synthesis: recent update on green catalytic approaches in synthesis of 1,2,4-thiadiazoles', *Catalysts*, 12(11), Article 1329. Available at: https://doi.org/10.3390/catal12111329.

Zhang, Y., Huang, H., Liang, Z., *et al.* (2017) 'Microscopic progression in the free radical addition reaction: modeling, geometry, energy, and kinetics', *Journal of Molecular Modeling*, 23, Article 73. Available at: https://doi.org/10.1007/s00894-017-3217-z

Links

This unit links to the following related units:

Unit 412: Organic Chemistry

Unit 423: Analytical Chemistry

Unit 511: Applied Forensic Science

Unit 512: Solid State and Transition Metal Chemistry

Unit 514: Spectroscopy, Surface Chemistry and Equilibria

Unit 526: Further Analytical Chemistry.

Unit 514: Spectroscopy, Surface Chemistry and Equilibria

Unit code: A/652/3074

Unit level: 5

Credit value: 15

Introduction

Spectroscopy, surface chemistry and chemical equilibria form a core part of physical chemistry and underpin many analytical, industrial and research-based applications within the applied sciences. At Level 5, students develop their knowledge beyond descriptive understanding to consider how theoretical models explain chemical behaviour and how effectively those models represent real systems. This unit provides an integrated theoretical framework that connects molecular spectroscopy, surface-controlled processes and equilibrium behaviour within chemically relevant contexts.

The unit introduces the principles of molecular spectroscopy and explores how interactions between electromagnetic radiation and matter produce observable spectral features. Students examine simplified spectroscopic models, their assumptions and their limitations, developing the ability to relate spectral features to molecular structure, functional groups and chemical environment. Emphasis is placed on understanding what spectroscopic data can and cannot reveal, supporting informed interpretation of analytical outputs rather than treating spectra as direct representations of chemical reality.

Surface chemistry concepts are explored through adsorption, interfacial behaviour and catalytic activity, highlighting the importance of surfaces in controlling chemical processes. Students consider how surface chemistry models explain behaviour at interfaces and how model assumptions affect their usefulness in real systems, including colloidal and formulated systems. Alongside this, chemical equilibria are examined through quantitative and thermodynamic models, enabling students to predict system behaviour and consider the reliability of model-based predictions under changing conditions.

On completion of this unit, students will have developed a coherent, model-based understanding of spectroscopy, surface chemistry and equilibria that supports progression to further study in areas such as analytical chemistry, materials science, chemical engineering, forensic science, biomedical science, pharmaceutical science and environmental science. The knowledge and analytical skills developed in this unit

may also support career pathways in analytical chemistry, materials research, forensic analysis, laboratory analysis, quality control, process development, technical sales, applications science and research and development. Students will also be able to apply analytical reasoning to chemically relevant data, including digitally generated and processed spectroscopic datasets, and consider how theoretical models support optimisation of chemical processes, efficiency and resource use in applied contexts.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the theoretical principles of molecular spectroscopy

LO2 Review spectroscopic data to determine structural, functional and quantitative properties of chemical species within a defined analytical context

LO3 Describe surface chemistry concepts governing adsorption, interfacial behaviour and catalytic activity

LO4 Discuss chemical equilibria using quantitative models to predict system behaviour.

Essential Content

LO1 **Explain the theoretical principles of molecular spectroscopy**

Fundamental principles of molecular spectroscopy:

Fundamental principles: electromagnetic radiation as energy carrier, radiation–matter interaction, absorption processes, emission processes, energy-frequency–wavelength relationship

Energy levels: quantised atomic and molecular energy levels; electronic, vibrational, rotational transitions; selection rules; transition probability; molecular degrees of freedom; energy level spacing; population distribution concepts e.g. Boltzmann distribution; temperature dependence; radiative, non-radiative relaxation pathways.

Spectroscopic models and spectral features:

Theoretical spectroscopy models: simplified molecular energy level representations; interaction Hamiltonians; spectral feature origin, interpretation e.g. peak position, intensity, shape

Band structure: fine structure; line broadening mechanisms e.g. Doppler broadening, pressure, collisional broadening, lifetime broadening; instrument response: resolution

Features: molecular structure-chemical environment-spectral feature relationships; Beer–Lambert law as quantitative absorption model; assumptions e.g. monochromatic radiation, homogeneous sample, negligible scattering, linear response.

Model assumptions and limitations:

Spectroscopic model assumptions: e.g. isolated molecules, harmonic oscillator, rigid rotor approximations, linear response, negligible intermolecular interactions; validity domains; boundary conditions

Real-system limitations: e.g. overlapping signals, matrix effects, baseline drift, deviations from ideal behaviour; spectral congestion; assignment ambiguity; sample state; interpretation of spectral data with model constraints; uncertainty.

Environment impacts: e.g. solvent polarity effects, hydrogen bonding, aggregation, pH-dependent speciation

LO2 **Review spectroscopic data to determine structural, functional and quantitative properties of chemical species within a defined analytical context**

Interpretation of spectroscopic data:

Spectroscopic output analysis: structural, functional, quantitative information; data pre-processing concepts e.g. smoothing, baseline correction, normalisation; calibration and quantification approaches e.g. external calibration, internal standardisation, standard addition

Characteristic spectral features: chemical environments; peak fitting; deconvolution; multivariate pattern recognition concepts e.g. principal component analysis (PCA) for spectral classification; comparative reasoning; defined analytical context

Digital tools: digitally generated, processed spectroscopic datasets: analytical software outputs e.g. automated peak picking, library matching, chemometric models.

Handling uncertainty and ambiguity in spectroscopic analysis:

Uncertainty: sources of uncertainty in spectroscopic data e.g. instrumental resolution, signal-to-noise ratio, wavelength, wavenumber accuracy, signal overlap, background interference; sampling, preparation variability

Ambiguity: e.g. ambiguous, overlapping spectral features; replicate measurements; alternative spectral regions; confirmatory features; orthogonal evidence; detection limit; quantitation limit; justification of interpretations based on strength, consistency, coherence of evidence.

Reliability and limitations of analytical conclusions:

Reliability: e.g. confidence in conclusions from spectroscopic data; traceability of analytical reasoning from raw output to interpreted claim; limitations of single-technique interpretation; triangulation using complementary evidence e.g. infrared (IR) with nuclear magnetic resonance (NMR) for functional-group structural confirmation; UV–Vis with calibration standards for concentration; data quality

Limitations: e.g. model assumptions, contextual constraints, reliability of analytical outcomes, plausible alternative interpretations; rationale for preferred assignment.

LO3 **Describe surface chemistry concepts governing adsorption, interfacial behaviour and catalytic activity**

Surface chemistry concepts and interfacial behaviour:

Surface chemistry: e.g. surfaces, interfaces; bulk, surface property distinction; surface functional groups; surface charge concepts; adsorption phenomena at solid–gas, solid–liquid interfaces; physical, chemical adsorption as conceptual models; surface energy

Interfacial behaviour: e.g. wetting; contact angle concepts, interfacial tension concepts, electrical double layer concepts; zeta potential as stability indicator in dispersed systems e.g. colloidal suspensions.

Surface chemistry models and explanation of behaviour:

Surface chemistry models: e.g. adsorption behaviour, catalytic activity; idealised adsorption isotherms e.g. Langmuir, Freundlich; adsorption kinetics concepts; surface site, active-site concepts; surface structure; porosity; interaction strength

Observed behaviour: e.g. adsorption processes–catalytic performance links; heterogeneous catalysis models; surface reaction pathway concepts e.g. adsorption-reaction-desorption sequence.

Model effectiveness in real systems:

Effectiveness of surface chemistry models in real systems: e.g. surface heterogeneity, multilayer adsorption, non-ideal interactions, competitive adsorption, dynamic conditions, mass transfer, diffusion limitations, surface poisoning, deactivation concepts; colloidal, formulated systems with surface-controlled stability e.g. dispersions, emulsions, flocculation, coalescence; surface-mediated processes; catalysis

Efficiency: resource optimisation in applied contexts e.g. catalyst surface area effects on conversion, adsorption-based water treatment.

LO4 **Discuss chemical equilibria using quantitative models to predict system behaviour**

Chemical equilibrium and thermodynamic models:

Dynamic equilibrium in chemical systems: equilibrium constants as quantitative descriptors of equilibrium position e.g. K_c, K_p; reaction quotient e.g. Q as direction predictor; activity coefficient; non-ideality; Gibbs free energy change as equilibrium, feasibility criterion; chemical potential concept

Thermodynamic parameter-equilibrium behaviour relationships: temperature dependence of equilibrium e.g. van 't Hoff relationship; acid–base equilibria concepts e.g. K_a, pK_a, buffer action; complex formation equilibria concepts; phase equilibrium as equilibrium model application; temperature-pressure-phase stability relationships in multi-phase systems.

Effect of changing conditions on equilibrium behaviour:

Effect of changing conditions: e.g. influence of concentration, temperature, pressure on equilibrium position; Le Chatelier's principle as qualitative prediction framework; model-based system response; quantitative, thermodynamic reasoning

Equilibrium behaviour: qualitative and quantitative prediction of equilibrium shifts; competing equilibria; coupled equilibria concepts e.g. precipitation in the presence of complexing agents; buffer capacity; pH control in equilibrium systems e.g. formulation stability.

Effectiveness of equilibrium models in prediction:

Effectiveness of equilibrium models in real-system prediction: ideal equilibrium treatment assumptions e.g. ideal gas behaviour, dilute solution approximations, constant temperature

Sensitivity of predictions to parameter uncertainty: limitations in complex, non-ideal systems e.g. high ionic strength solutions, heterogeneous multi-phase reactions, slow approach to equilibrium, kinetic control; equilibrium-based predictions; optimisation of conditions; yield

Efficiency: reduced material waste e.g. optimisation of pH for metal-ion extraction, temperature selection for reversible reactions.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the theoretical principles of molecular spectroscopy</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate spectroscopy models and the reliability of conclusions from spectroscopic data.</td></tr>
<tr><td>P1 Explain molecular spectroscopy principles.

P2 Explore links between spectroscopy models and spectral features.</td><td>M1 Analyse relationships between theoretical spectroscopy models and observed spectral features.</td></tr>
<tr><td colspan="2">LO2 Review spectroscopic data to determine structural, functional and quantitative properties of chemical species within a defined analytical context</td></tr>
<tr><td>P3 Review structural and functional properties of chemical species from spectroscopic data in context.

P4 Determine quantitative properties of chemical species from spectroscopic data in context.</td><td>M2 Assess the reliability of conclusions drawn from spectroscopic data.</td></tr>
<tr><td colspan="2">LO3 Describe surface chemistry concepts governing adsorption, interfacial behaviour and catalytic activity</td><td rowspan="5">LO3 and LO4

D2 Critically evaluate model-based predictions of chemical system behaviour.</td></tr>
<tr><td>P5 Discuss adsorption, interfacial behaviour and catalytic activity concepts.

P6 Describe how surface chemistry models account for observed behaviour.</td><td>M3 Analyse how surface chemistry models account for adsorption, interfacial behaviour and catalytic activity under stated conditions.</td></tr>
<tr><td colspan="2">LO4 Discuss chemical equilibria using quantitative models to predict system behaviour</td></tr>
<tr><td>P7 Discuss chemical equilibria using quantitative and thermodynamic models.

P8 Describe how changing conditions affect equilibrium position.</td><td>M4 Assess predicted equilibrium behaviour under changing conditions.</td></tr>
</table>

Recommended Resources

Textbooks

Atkins, P., de Paula, J. and Keeler, J. (2022) *Atkins' Physical Chemistry*. 12th edn. Oxford: Oxford University Press.

Attard, G. and Barnes, C. (1998) *Surfaces*. Oxford: Oxford University Press.

Bernath, P.F. (2020) *Spectra of Atoms and Molecules*. 4th edn. Oxford: Oxford University Press.

Brown, J.M. (1998) *Molecular Spectroscopy*. Oxford: Oxford University Press.

de Levie, R. (2001) *Aqueous Acid-Base Equilibria and Titrations*. Oxford: Oxford University Press.

Duckett, S. and Gilbert, B. (2000) *Foundations of Spectroscopy*. Oxford: Oxford University Press.

Price, G. (2019) *Thermodynamics of Chemical Processes*. 2nd edn. Oxford: Oxford University Press.

Saleh, T.A. (2022) *Surface Science of Adsorbents and Nanoadsorbents: Properties and Applications in Environmental Remediation*. Amsterdam: Elsevier.

Somorjai, G.A. and Li, Y. (2010) *Introduction to Surface Chemistry and Catalysis*. 2nd edn. Hoboken: Wiley.

Websites

https://www.spectroscopyonline.com/topic/tutorials	Spectroscopy Online Tutorials section (Tutorials)
https://andor.oxinst.com/	Oxford Instruments Andor Learning Centre: Fundamentals of spectroscopy (General reference)
https://chem.libretexts.org/Bookshelves	Chemistry LibreTexts Molecular spectroscopy (General reference)

https://chem.libretexts.org/Bookshelves	Chemistry LibreTexts Adsorption isotherms and surface coverage (General reference)
https://chem.libretexts.org/	Chemistry LibreTexts Thermodynamics and equilibrium chemistry (General reference)
https://edu.rsc.org/	Royal Society of Chemistry Education Spectroscopy in a Suitcase resource pack (Training)
https://www.coblentz.org/education/recommended-resources/	Coblentz Society Recommended spectroscopy education resources (General reference)
https://link.springer.com/	SpringerLink Surface chemistry and catalysis book resource (E-books)

Journals and articles

Awasthi, H., *et al.* (2025) 'Spectroscopic Characterization', in Goel, S. (ed.) *Micro Electromechanical Systems (MEMS): Practical Lab Manual*. Hoboken: Wiley. Available at: https://doi.org/10.1002/9781394229864.ch9.

Majd, M.M., *et al.* (2022) 'Adsorption isotherm models: A comprehensive and systematic review (2010-2020)', *Science of the Total Environment*, 812, article 151334. Available at: https://doi.org/10.1016/j.scitotenv.2021.151334.

Murphy, O.P., *et al.* (2023) 'A Review on the Adsorption Isotherms and Design Calculations for the Optimization of Adsorbent Mass and Contact Time', *ACS Omega*, 8(20), pp. 17407–17430. Available at: https://doi.org/10.1021/acsomega.2c08155.

Roos, W.A. and Zietsman, J.H. (2022) 'Accelerating complex chemical equilibrium calculations: A review', *Calphad*, 77, article 102380. Available at: https://doi.org/10.1016/j.calphad.2021.102380.

McLean, A., *et al.* (2024) 'Evolution of vibrational biospectroscopy: multimodal techniques and miniaturisation supported by machine learning', *Vibrational Spectroscopy*, 133, article 103708. Available at: https://doi.org/10.1016/j.vibspec.2024.103708.

Zhao, W., *et al.* (2022) 'A critical review on surface-modified nano-catalyst application for the photocatalytic degradation of volatile organic compounds', *Environmental Science: Nano*, 9(1), pp. 61–80. Available at: https://doi.org/10.1039/D1EN00955A.

Links

This unit links to the following related units:

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 411: Inorganic Chemistry

Unit 412: Organic Chemistry

Unit 413: Physical Chemistry

Unit 512: Solid State and Transition Metal Chemistry

Unit 517: Environmental Monitoring and Analysis

Unit 526: Further Analytical Chemistry.

Unit 515: Green Chemistry

Unit code: D/652/3075

Unit level: 5

Credit value: 15

Introduction

Green chemistry has become a central approach within modern chemical science as industries and regulators seek to reduce environmental impact while maintaining technical performance and economic viability. Increasingly, chemists are expected to build sustainability into processes from the outset rather than relying on waste treatment or clean-up after production. This unit introduces green chemistry as a design-focused approach that prepares students for careers in chemical manufacturing, applied chemistry, sustainability and related fields.

The unit focuses on the principles that underpin green chemistry and how these principles inform sustainable chemical practice across synthesis and manufacturing contexts. Students examine how traditional processes contribute to resource use, energy demand and waste, and how these impacts connect to wider sustainability goals. The unit develops professional judgement, enabling students to evaluate environmental impacts and identify practical, lower-impact alternatives without sacrificing performance.

Key areas of study include the exploration of sustainable alternatives to traditional chemical processes, such as the use of renewable feedstocks, catalytic methods and solvent substitution. Students apply green chemistry metrics to assess sustainability using case studies, simulated datasets or laboratory-based examples. Digital tools, data visualisations and comparative indicators are used throughout to support analysis and decision making in line with modern chemical practice.

On completion of this unit, students will be able to apply green chemistry principles and metrics to evaluate the sustainability of chemical processes and to make informed judgements about alternative design choices. These skills support progression to further study in applied chemistry, chemical engineering and sustainability-focused disciplines, and are directly relevant to careers in research, manufacturing, process development and environmental innovation where sustainable practice is essential.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles of green chemistry

LO2 Discuss the environmental impacts of conventional chemical processes

LO3 Explore sustainable alternative processes to conventional chemical processes in synthesis and manufacturing

LO4 Apply, using either real-world case studies or laboratory-based methods, green chemistry metrics to assess process sustainability.

Essential Content

LO1 Explain the fundamental principles of green chemistry

Green chemistry principles:

Twelve principles of green chemistry: waste prevention, atom economy, less hazardous chemical syntheses, design of safer chemicals, safer solvents and auxiliaries, energy efficiency, renewable feedstocks, reduced derivatives, minimised protecting groups, catalysis, design for degradation, real-time analysis for pollution prevention, inherently safer chemistry

Hazard and risk: e.g. system boundaries, trade-offs; constraints e.g. end-of-pipe treatment versus redesigned synthesis route without toxic intermediates, catalytic route versus stoichiometric reagent with salt waste.

Role in sustainable chemical practice:

Green chemistry principles in chemical synthesis, processing and manufacturing: reduced environmental impact, principle-led design, sustainability outcomes, waste reduction, lower energy demand, decreased hazard. Scalability, compliance drivers

Option appraisal: process change recommendations e.g. chlorinated solvent replacement with lower-hazard alternative; yield, purification, waste stream implications; fossil-derived feedstocks to bio-based feedstocks: supply resilience, land-use trade-offs.

Design-led decision making:

Green chemistry principles as decision-making framework: e.g. chemical process evaluation, design-stage improvement, digitally presented process descriptions, data summaries, sustainability indicators, evidence-based recommendations

Uncertainty: assumptions, limitations; multi-criteria comparison for preferred route justification e.g. yield, solvent hazard, energy input, waste mass; safety data sheet (SDS) hazard information with process data for substitution priorities.

LO2 Discuss the environmental impacts of conventional chemical processes

Environmental impacts of conventional processes:

Environmental impacts: environmental impacts of traditional chemical processes e.g. resource depletion, energy intensity, waste generation, emissions, toxicity, persistence

Design choices: impact of process design choices e.g. environmental burden across production and manufacturing, impact hotspots, exposure pathways

Baseline performance: e.g. likely emission points on simplified process flow, venting, solvent losses, aqueous waste; excess-reagent processes vs higher-selectivity routes.

Sustainability considerations:

Sustainability: environmental impacts in relation to sustainability objectives e.g. material use efficiency, waste management challenges, long-term environmental consequences

Considerations: life-cycle thinking, cradle-to-gate, circularity; carbon footprint considerations e.g. solvent recovery impacts on overall waste profile; energy source e.g. grid versus renewable; carbon impact with unchanged chemistry.

Evidence-informed judgement:

Scientific and technical evidence: e.g. published studies, process data, environmental datasets; digitally derived summaries, visualisations, comparative indicators; sustainability judgements; data quality e.g. comparability, bias

Contextual relevance: e.g. waste by mass contribution chart for dominant waste streams; conflicting sources e.g. industry case study vs academic paper; scenario applicability.

LO3 **Explore sustainable alternative processes to conventional chemical processes in synthesis and manufacturing**

Sustainable process alternatives:

Alternative approaches aligned with green chemistry principles: e.g. bio-based feedstocks, renewable raw materials, catalytic processes, solvent substitution, process intensification, route selection, selectivity, process integration

Sustainability outcomes: e.g. catalytic hydrogenation rather than stoichiometric metal reduction; water, ethanol or supercritical CO_2 solvent systems; flow processing as conceptual intensification approach.

Resource efficiency and environmental performance:

Conventional and alternative process comparison: e.g. resource efficiency waste reduction, energy demand, environmental impact; digitally presented comparative data

Performance indicators: benchmarking; normalised results e.g. two-route key performance indicator (KPI) table; waste mass per kg product, energy per batch, solvent volume, purification steps.

Applicability and limitations:

Suitability factors for sustainable alternatives: e.g. technical feasibility, scalability, economic considerations; potential trade-offs e.g. industrial contexts, manufacturing contexts

Evaluation: digitally supported evaluations e.g. scenario comparisons, operability; supply-chain constraints e.g. greener solvent with increased separation difficulty and energy use, bio-based feedstock with variable purity and process control impacts.

LO4 **Apply, using either real-world case studies or laboratory-based methods, green chemistry metrics to assess process sustainability**

Green chemistry metrics:

Metrics: common green chemistry metrics e.g. atom economy, E-factor; carbon intensity; hazard-based metrics; process sustainability assessment

Metric selection: e.g. functional units, system boundaries; interpretation e.g. atom economy as theoretical indicator versus E-factor as practical waste indicator, high atom-economy route with poor E-factor due to solvents and work-up.

Use of data in sustainability assessment:

Use of data: green chemistry metrics with case study information, simulated datasets or laboratory-derived data: sustainability assessment; process comparison; digital calculation tools

Data summaries: visual representations e.g. contribution plots; uncertainty e.g. E-factor from simplified mass balance with solvents and aqueous waste; sensitivity to assumptions: e. g. spreadsheet ‘what-if’ scenarios for solvent recovery at 0%, 50% and 90%.

Decision making and sustainability evaluation:

Metric outcomes in sustainability-focused decision making: chemical process design; strengths, limitations, appropriate contexts for metric use; digitally supported comparison; evaluation outputs; multi-criteria decision approaches

Evaluation: justified recommendations e.g. preferred route with improved carbon intensity but increased hazard, explicit trade-off justification, short decision rationale integrating quantitative metrics with qualitative hazard considerations.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental principles of green chemistry</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate green chemistry principles and sustainable alternatives for reducing environmental impacts from conventional chemical processes.</td></tr>
<tr><td>P1 Explain the fundamental principles of green chemistry.

P2 Explore green chemistry principles in sustainable chemical practice and design-led decision making.</td><td>M1 Analyse the contribution of green chemistry principles to improved sustainability in chemical practice.</td></tr>
<tr><td colspan="2">LO2 Discuss the environmental impacts of conventional chemical processes</td></tr>
<tr><td>P3 Explain the environmental impacts of conventional chemical processes.

P4 Discuss environmental impacts in relation to sustainability objectives.</td><td>M2 Assess the sustainability significance of environmental impacts from conventional chemical processes.</td></tr>
<tr><td colspan="2">LO3 Explore sustainable alternative processes to conventional chemical processes in synthesis and manufacturing</td></tr>
<tr><td>P5 Explore sustainable alternatives to conventional chemical processes used in synthesis and manufacturing.

P6 Compare sustainable alternatives in terms of resource efficiency and environmental performance.</td><td>M3 Assess the suitability of sustainable alternatives for resource efficiency and environmental performance.</td></tr>
<tr><td colspan="2">LO4 Apply, using either real-world case studies or laboratory-based methods, green chemistry metrics to assess process sustainability</td><td rowspan="2">LO4

D2 Critically evaluate green chemistry metrics for sustainable decision making in chemical process design.</td></tr>
<tr><td>P7 Apply green chemistry metrics to case study or laboratory-derived data.

P8 Assess the sustainability of chemical processes using metric outcomes.</td><td>M4 Analyse metric outcomes to compare the sustainability of chemical processes.</td></tr>
</table>

Recommended Resources

Textbooks

Ameta, S. and Ameta, R. (2018) *Green Chemistry: Fundamentals and Applications*. Boca Raton, FL: CRC Press.

Clark, J.H. and Macquarrie, D.J. (2018) *Handbook of Green Chemistry and Technology*. Oxford: Wiley-Blackwell.

Dunn, P.J., Wells, A.S. and Williams, M.T. (2012) *Green Chemistry in the Pharmaceutical Industry*. Weinheim: Wiley-VCH.

Hill, J.W., McCreary, T.W. and Kolb, D.K. (2022) *Chemistry for Changing Times*. 13th edn. Harlow: Pearson.

Lancaster, M. (2025) *Green Chemistry: An Introductory Text*. 4th edn. Cambridge: Royal Society of Chemistry.

Matlack, A.S. (2022) *Introduction to Green Chemistry*. 3rd edn. Boca Raton, FL: CRC Press.

Prasad, L., *et al.* (eds.) (2025) *Green Chemistry: A Path to Sustainable Development*. Amsterdam: Elsevier.

Zhang, W. and Cue, B.W. (eds.) (2018) *Green Techniques for Organic Synthesis and Medicinal Chemistry*. 2nd edn. Hoboken, NJ: Wiley.

Websites

https://www.acs.org/green-chemistry-sustainability.html	American Chemical Society – Green Chemistry Institute (ACS GCI) Nexus blog and newsletter (General reference)
https://acsgcipr.org	ACS Green Chemistry Institute Pharmaceutical Roundtable (GCIPR) Industry resources on sustainability (General resources)
https://www.ctpa.org.uk/green-chemistry	Cosmetic, Toiletry and Perfumery Association (CTPA) Green Chemistry Hub (General resources)
https://www.ncl.ac.uk/business-and-partnerships/latest-news/item/great-british-chemicals-green-chemistry/	Great British Chemicals UK research consortium (Research)

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https://www.rsc.org/policy-and-campaigning/sustainability	Royal Society of Chemistry Sustainability and Green Chemistry (General resource)
UK Chemicals Stakeholder Forum (UKCSF) - GOV.UK	UK Government (GOV.UK) Chemicals Stakeholder Forum (Policy and regulation)
https://www.unep.org/topics/chemicals-and-pollution-action/circularity-sectors/green-and-sustainable-chemistry	United Nations Environment Programme Green and Sustainable Chemistry (General resources)

Journals and articles

Alfonsi, K., *et al.* (2008) 'Green chemistry tools to influence a medicinal chemistry and research chemistry-based organisation', *Green Chemistry*, 10(1), pp. 31–36. Available at: https://doi.org/10.1039/B711717E

Anastas, P.T. and Zimmerman, J.B. (2003) 'Design Through the 12 Principles of Green Engineering', *Environmental Science & Technology*, 37(5), pp. 94A–101A. Available at: https://doi.org/10.1021/es032373g

Clark, J.H. (1999) 'Green chemistry: challenges and opportunities', *Green Chemistry*, 1(1), pp. 1–8. Available at: https://doi.org/10.1039/A807961G

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Curzons, A.D., *et al.* (2001) 'So you think your process is green, how do you know? – Using principles of sustainability to determine what is green – a corporate perspective', *Green Chemistry*, 3(1), pp. 1–6. Available at: https://doi.org/10.1039/B007871I

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Kümmerer, K. (2017) 'Sustainable Chemistry: A Future Guiding Principle', *Angewandte Chemie International Edition*, 56(52), pp. 16420–16421. Available at: https://doi.org/10.1002/anie.201709949

Sheldon, R.A. (2017) 'The *E* factor 25 years on: the rise of green chemistry and sustainability', *Green Chemistry*, 19(1), pp. 18–43. Available at: https://doi.org/10.1039/C6GC02157C

United Nations Environment Programme (2021) *Green and Sustainable Chemistry: Framework Manual* Nairobi: United Nations Environment Programme. Available at: https://www.unep.org/resources/toolkits-manuals-and-guides/green-and-sustainable-chemistry-framework-manual

Zimmerman, J.B., *et al.* (2020) 'Designing for a green chemistry future', *Science*, 367(6476), pp. 397–400. Available at: https://doi.org/10.1126/science.aay3060

Links

This unit links to the following related units:

Unit 417: Principles of Ecology

Unit 418: Managing Environmental Resources

Unit 423: Analytical Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 526: Further Analytical Chemistry

Unit 531: Soil Science and Geochemical Processes.

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Unit 516: Sources, Impact and Control of Pollution

Unit code: F/652/3076

Unit level: 5

Credit value: 15

Introduction

Environmental pollution is a significant global challenge affecting air, water and soil systems across local, regional and international contexts. Pollution from industrial, agricultural, transport, energy and domestic sources can affect ecosystem quality, biodiversity, natural resources and human health. Understanding the sources, classifications and pathways of pollutants is essential for interpreting how pollution moves through environmental media and how environmental and health impacts may arise.

This unit introduces students to the scientific principles used to explain pollution sources, pollutant behaviour and the impacts of selected pollutants on the environment and human health. Students will consider how scientific evidence from environmental monitoring, ecological studies, toxicological data, epidemiological research and modelling can be used to support impact assessment and risk-informed professional judgement.

Students will review pollution prevention, control and mitigation strategies used in industrial and environmental management contexts. They will examine how management decisions are shaped by legislation, regulatory requirements, operational constraints, stakeholder expectations and environmental protection objectives. The unit also supports the development of applied decision-making skills through the selection, presentation and review of pollution management strategies for identified scenarios.

On completion of this unit, students will be able to explain pollution sources, classifications and pathways, discuss impacts of selected pollutants, review pollution management and regulation strategies, and develop pollution management strategies for applied environmental scenarios. The knowledge and skills developed support progression to further study in environmental science, environmental management, sustainability, public health, conservation, environmental monitoring and related science courses. They also support career pathways in environmental consultancy, environmental regulation, pollution control, sustainability, waste and resource management, environmental compliance and industrial environmental management.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain sources, classifications and pathways of environmental pollution

LO2 Discuss the impacts of selected pollutants on the environment and human health

LO3 Review industrial pollution management and regulation strategies

LO4 Develop a pollution management strategy for an identified scenario.

Essential Content

LO1 **Explain sources, classifications and pathways of environmental pollution**

Sources of environmental pollution:

Sources of environmental pollution: e.g. industrial, agricultural, transport, energy and domestic sources; natural and anthropogenic sources; point sources e.g. stack emissions and sewage outfalls; diffuse sources e.g. agricultural nitrate run-off, tyre and brake wear particles and urban run-off

Emission and discharge type: e.g. scale, intermittency, abnormal and accidental releases.

Classifications of environmental pollutants:

Classification: physical, chemical and biological pollutant classifications e.g. pollutant nature, environmental medium, persistence, mobility, solubility, speciation, bioavailability, toxicity

Hazard and risk distinction: bioaccumulation potential e.g. chromium speciation affecting toxicity, methylmercury bioaccumulation in food chains, hydrophobic pollutants binding to sediments; regulatory categories e.g. priority pollutants, hazardous substances, emerging contaminants, PFAS, pharmaceuticals, endocrine-disrupting chemicals, nanomaterials.

Pollution pathways through environmental media:

Pollution pathways: air, water and soil environments; pollutant transfer within and between media e.g. atmospheric deposition, surface run-off, leaching, infiltration, sediment interaction, food-chain transfer, bioaccumulation

Source-pathway-receptor framework: pollutant fate e.g. microplastics transported via wastewater effluent to rivers and marine environments; receptor sensitivity e.g. pesticides leaching to groundwater depending on soil properties; intervention points; spatial and temporal variation; local, regional and global scales e.g. atmospheric deposition contributing to soil and water contamination.

LO2 **Discuss the impacts of selected pollutants on the environment and human health**

Environmental impacts of selected pollutants:

Selected pollutants: e.g. particulate matter, nitrogen oxides, nutrients, pesticides, heavy metals, hydrocarbons, microplastics

Environmental impacts: biodiversity, habitat quality, nutrient cycling, soil fertility, water quality, atmospheric processes, ecotoxicity, eutrophication, acidification, oxygen depletion, smothering, food-web disruption

Cumulative effects: long-term effects, ecosystem resilience; ecosystem services e.g. nutrient enrichment causing algal blooms and hypoxia, sediment-associated contaminants reducing benthic invertebrate diversity.

Human health impacts of selected pollutants:

Exposure pathways: e.g. inhalation, ingestion, dermal contact; acute exposure, chronic exposure

Dose-response relationships: e.g. duration, frequency, concentration

Selected pollutants: e.g. particulate matter, nitrogen dioxide, ozone, lead, mercury, pesticides, persistent organic pollutants

Health impacts: respiratory effects, cardiovascular effects, neurological effects, carcinogenic effects, vulnerable populations; differential exposure risks e.g. particulate air pollution and respiratory health, ingestion of contaminants via drinking water or food-chain transfer.

Scientific evidence for impact assessment:

Scientific evidence: impact analysis, epidemiological studies, toxicological data, field studies, laboratory studies, ecological survey data, environmental monitoring results

Impact assessment: e.g. modelling outputs, risk assessment data, exposure assessment, dose-response evidence, digitally derived data summaries, evidence quality

Uncertainty and limitations: correlation and causation, weight-of-evidence approaches, risk-informed professional judgement e.g. monitoring trends for particulate matter, nitrate or heavy metals combined with toxicological reference values, exposure data and ecological survey findings to prioritise controls.

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LO3 **Review industrial pollution management and regulation strategies**

Industrial pollution prevention strategies:

Source reduction: e.g. process optimisation; materials substitution e.g. hazardous solvent substitution; cleaner production; waste minimisation e.g. process redesign to reduce waste streams; low-emission raw materials; prevention hierarchy, life-cycle thinking, circular economy; resource efficiency e.g. closed-loop water reuse; spill prevention through bunding, inspection and maintenance

Green chemistry principles: preventive maintenance; feasibility; trade-offs; unintended consequences; operational decision making e.g. substitution hierarchy; product and process redesign.

Industrial pollution control and mitigation strategies:

Control technologies: end-of-pipe treatment; engineering controls; containment measures; abatement systems; air pollution controls e.g. air scrubbers, electrostatic precipitators and bag filters; water pollution treatment e.g. activated carbon, membrane filtration and nutrient removal in water treatment; soil pollution remediation e.g. soil capping, excavation and bioremediation; treatment systems; remediation techniques

Mitigation strategies: e.g. monitoring-informed optimisation, emergency response planning, control performance, residual risk, failure modes, pollution swapping, secondary containment and spill response.

Regulatory and operational influences on strategy selection:

Regulation: international frameworks and standards e.g. Environmental Permitting Regulations; Industrial Emissions Directive; Water Framework Directive; REACH; CLP/GHS labelling; ISO 14001; Stockholm Convention; Basel Convention; Minamata Convention; World Bank Group/IFC Environmental, Health and Safety Guidelines

Environmental legislation: national air quality standards e.g. permits; standards; guidance; regulatory requirements; compliance monitoring; enforcement

Environmental management systems: best available techniques e.g. Good International Industry Practice, OECD Best Available Techniques guidance, WHO Global Air Quality Guidelines, UNEP pollution-free planet guidance, UN system Common Approach Towards a Pollution-Free Planet

Constraints: e.g. technical constraints, economic constraints, site-specific constraints, retrofit controls meeting permit limits within space and energy constraints.

LO4 **Develop a pollution management strategy for an identified scenario**

Pollution management approaches in context:

Integrated pollution management: defined environmental scenarios e.g. urban river affected by storm overflows and road run-off, contaminated brownfield redevelopment, industrial site with odour or NO_x complaints; prevention measures e.g. contingency planning for chemical spill response; control measures; mitigation measures; hierarchy of controls; source-pathway-receptor analysis; compliance

Risk prioritisation: option appraisal e.g. effectiveness, feasibility, cost, sustainability; precautionary principle; polluter pays principle; best practicable environmental option e.g. nature-based solutions e.g. reed beds or constructed wetlands for runoff treatment.

Effectiveness in addressing environmental impacts:

Impact reduction: e.g. environmental impact reduction, human health impact reduction, unintended consequences, residual risk, protection of the most sensitive receptor

Measurable outcomes: e.g. performance indicators, success criteria, baseline and post-intervention comparison, monitoring and review, adaptive management, compliance outcomes; ecosystem recovery indicators e.g. predicted versus observed improvement; digitally supported evaluation outputs.

Contextual factors and environmental protection objectives:

Site-specific conditions: e.g. land-use context; pathway dynamics e.g. community context; pollutant behaviour; management effectiveness; trade-offs e.g. effective end-of-pipe controls generating hazardous waste; environmental protection objectives e.g. water, air and soil quality objectives

Pollution reduction targets: e.g. ecosystem protection, biodiversity protection, sustainable outcomes, climate resilience, cumulative impacts, energy use, waste generation; long-term maintenance e.g. short-term remediation requiring longer-term habitat mitigation.

Stakeholder communication and feedback:

Stakeholder priorities: e.g. inclusive stakeholder engagement, environmental justice, differential exposure, community impact; implementation planning e.g. stakeholder feedback informing prioritisation of mitigation measures

Communication: presentation of strategy; accessible communication e.g. accessible summaries for local communities, visual presentation of management options for technical and non-technical stakeholders; feedback collection.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain sources, classifications and pathways of environmental pollution</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate environmental and human health risks from pollution sources and selected pollutants, using evidence of pollutant classifications, pathways, exposure and impact severity.</td></tr>
<tr><td>P1 Explain major sources and classifications of environmental pollutants across air, water and soil contexts.

P2 Explore pollutant pathways within and between environmental media.</td><td>M1 Analyse relationships between pollution sources, pollutant types, environmental media and pathway dynamics.</td></tr>
<tr><td colspan="2">LO2 Discuss the impacts of selected pollutants on the environment and human health</td></tr>
<tr><td>P3 Explain impacts of selected pollutants on the environment using scientific evidence.

P4 Discuss impacts of selected pollutants on human health using scientific evidence.</td><td>M2 Analyse the relative severity of impacts of selected pollutants on the environment and human health using scientific evidence.</td></tr>
<tr><td colspan="2">LO3 Review industrial pollution management and regulation strategies</td><td rowspan="5">LO3 and LO4

D2 Critically evaluate the effectiveness of pollution management strategies in achieving environmental protection objectives, considering regulatory requirements, operational constraints and stakeholder feedback within an identified scenario.</td></tr>
<tr><td>P5 Review pollution prevention, control and mitigation strategies in industrial contexts.

P6 Explain how regulatory requirements and operational constraints influence pollution management strategy selection.</td><td>M3 Assess pollution prevention, control and mitigation strategies in relation to regulatory requirements and operational constraints.</td></tr>
<tr><td colspan="2">LO4 Develop a pollution management strategy for an identified scenario</td></tr>
<tr><td>P7 Develop a pollution management strategy for an identified scenario.

P8 Present the pollution management strategy to identified stakeholders to obtain feedback.</td><td>M4 Review how effectively the pollution management strategy meets the requirements of the identified scenario, drawing on stakeholder feedback.</td></tr>
</table>

Recommended Resources

Textbooks

Goodsite, M.E., Johnson, M.S. and Hertel, O. (eds.) (2021) *Air Pollution Sources, Statistics and Health Effects*. 2nd ed. New York: Springer.

Harrison, R.M. (ed.) (2013) *Pollution: Causes, Effects and Control*. 5th ed. Cambridge: Royal Society of Chemistry.

Kuo, J. (2018) *Air Pollution Control: Fundamentals and Applications*. Boca Raton, FL: CRC Press.

Ogwu, M.C. and Izah, S.C. (eds.) (2025) *Evaluating Environmental Processes and Technologies*. Cham: Springer.

Rao, C.S. (2018) *Environmental Pollution Control Engineering*. 3rd edn. New Delhi: New Age International.

Rocha-Santos, T., Cachada, A. and Duarte, A.C. (eds.) (2025) *Soil Pollution: From Monitoring to Remediation*. 2nd ed. London: Academic Press.

Saxena, P. and Naik, V. (eds.) (2019) *Air Pollution: Sources, Impacts and Controls*. Wallingford: CABI.

Spellman, F.R. (2017) *The Science of Environmental Pollution*. 3rd edn. Boca Raton, FL: CRC Press.

United Nations Environment Programme (2021) *From Pollution to Solution: A Global Assessment of Marine Litter and Plastic Pollution*. Nairobi: UNEP.

Vallero, D.A. (2004) *Environmental Contaminants: Assessment and Control*. Amsterdam: Elsevier Academic Press.

Wark, K., Warner, C.F. and Davis, W.T. (1998) *Air Pollution: Its Origin and Control*. 3rd edn. Menlo Park, CA: Addison-Wesley.

Websites

https://www.cleanairfund.org/resources/	Clean Air Fund Resources to support the clean air movement (Non-governmental organisations)
https://www.clientearth.org/what-we-do/air-pollution/	ClientEarth Resources around clean air (Non-governmental organisations)

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https://www.gov.uk/guidance/pollution-prevention-for-businesses	Environment Agency Pollution prevention guidance for business (Government and regulatory bodies)
https://www.eea.europa.eu/en/topics/in-depth/air-pollution	European Environment Agency (EEA) Key facts and resources (Government and regulatory bodies)
https://friendsoftheearth.uk/climate/cleaner-air-our-campaign	Friends of the Earth (UK) Clean air campaigning and case studies (Non-governmental organisations)
https://www.eri.ac.uk/pollution	University of the Highlands and Islands (Scotland) Environmental Research Institute (ERI) (Research)
https://www.imperial.ac.uk/school-public-health/environmental-research-group/	Imperial College London (UK) Environmental Research Group (ERG) (Research)
https://www.daera-ni.gov.uk/topics/pollution	Department of Agriculture, Environment and Rural Affairs, Northern Ireland Pollution resources and guidance (Government and regulatory bodies)
https://www.oecd.org/en/topics/pollution.html	Organisation for Economic Co-operation and Development (OECD) Pollution reports and data (Government and regulatory bodies)
https://www.port.ac.uk/environmental-pollution-and-microbiology-research-group	University of Portsmouth (UK) Environmental Pollution and Microbiology Research Group (Research)
https://beta.sepa.scot/topics/air/	Scottish Environment Protection Agency Air quality guidance (Government and regulatory bodies)

https://www.unep.org/beatpollution/	United Nations Environment Programme (UNEP) Towards a pollution free-planet (Government and regulatory bodies)

Journals and articles

Awewomom, J., *et al.* (2024) 'Addressing global environmental pollution using environmental control techniques: a focus on environmental policy and preventive environmental management', *Discover Environment*, 2, Article 8. Available at: https://doi.org/10.1007/s44274-024-00033-5.

Fuller, R., *et al.* (2022) 'Pollution and health: a progress update', *The Lancet Planetary Health*, 6(6), pp. e535–e547. Available at: https://doi.org/10.1016/S2542-5196(22)00090-0.

González-Fernández, D., *et al.* (2023) 'Diverging estimates of river plastic input to the ocean', *Nature Reviews Earth & Environment*, 4(7), pp. 424–426. Available at: https://doi.org/10.1038/s43017-023-00448-3.

Hossain, M. and Engelhardt, I. (2025) 'Global plastic footprint: unveiling property trends, environmental fate, and emerging threats of microplastic and nanoplastics pollution across ecosystems', *Energy, Ecology and Environment*, 10(6), pp. 637–674. Available at: https://doi.org/10.1007/s40974-025-00383-7.

Maggi, F., Tang, F.H.M. and Tubiello, F.N. (2023) 'Agricultural pesticide land budget and river discharge to oceans', *Nature*, 620(7976), pp. 1013–1017. Available at: https://doi.org/10.1038/s41586-023-06296-x.

Nieder, R. and Benbi, D.K. (2024) 'Potentially toxic elements in the environment: a review of sources, sinks, pathways and mitigation measures', *Reviews on Environmental Health*, 39(3), pp. 561–575. Available at: https://doi.org/10.1515/reveh-2022-0161.

Piscopo, M., Marinaro, C. and Lettieri, G. (2024) 'The Multifaceted Impact of Environmental Pollutants on Health and Ecosystems', *Biomolecules*, 14(8), Article 1021. Available at: https://doi.org/10.3390/biom14081021.

Shetty, S.S., *et al.* (2023) 'Environmental pollutants and their effects on human health', *Heliyon*, 9(9), Article e19496. Available at: https://doi.org/10.1016/j.heliyon.2023.e19496.

Vilcins, D., *et al.* (2024) 'Updates in Air Pollution: Current Research and Future Challenges', *Annals of Global Health*, 90(1), Article 9. Available at: https://doi.org/10.5334/aogh.4363.

Wu, H., Eckhardt, C.M. and Baccarelli, A.A. (2023) 'Molecular mechanisms of environmental exposures and human disease', *Nature Reviews Genetics*, 24(5), pp. 332–344. Available at: https://doi.org/10.1038/s41576-022-00569-3.

Links

This unit links to the following related units:

Unit 417: Principles of Ecology

Unit 418: Managing Environmental Resources

Unit 515: Green Chemistry

Unit 517: Environmental Monitoring and Analysis

Unit 529: Conservation and Biodiversity

Unit 531: Soil Science and Geochemical Processes.

Unit 517: Environmental Monitoring and Analysis

Unit code: H/652/3077

Unit level: 5

Credit value: 15

Introduction

Environmental monitoring and analysis are essential to understanding environmental conditions, identifying change and producing reliable evidence for regulatory, scientific and industrial decision making. Across environmental science, environmental chemistry and sustainability-related sectors, monitoring data are used to assess environmental quality, support compliance, inform risk-based decisions and communicate environmental information to technical and non-technical audiences. Practitioners working in these areas need to understand how monitoring evidence is generated, controlled, interpreted and reviewed in different environmental contexts.

This unit introduces students to the principles that underpin regulatory-compliant environmental monitoring. Students will consider the purpose of monitoring, the influence of regulatory and professional frameworks, and the importance of fitness for purpose, traceability, data quality and quality assurance/quality control. The unit places emphasis on defensible monitoring evidence and the need to apply appropriate methods and judgement when monitoring air, water, soil and other environmental media.

Students will explore environmental field sampling methods through real-world case studies or laboratory-based approaches, and consider how sampling method selection is influenced by monitoring objectives, analyte properties, site conditions, regulatory expectations and practical constraints. They will then develop an environmental monitoring strategy for a specified setting, selecting appropriate sampling approaches and quality controls. This supports the development of applied technical skills, professional judgement and clear communication of monitoring decisions.

On completion of this unit, students will be able to explain regulatory-compliant environmental monitoring principles, explore environmental field sampling methods, develop a monitoring strategy for a specified setting and review its effectiveness with selected stakeholders. The knowledge and skills developed support progression to further study in environmental science, environmental chemistry, environmental management, analytical science, sustainability, conservation, ecology and related

applied science courses. They also support career pathways in environmental monitoring, environmental consultancy, environmental regulation, laboratory analysis, water and wastewater monitoring, contaminated land investigation, air quality monitoring, sustainability and environmental compliance.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain regulatory-compliant environmental monitoring principles

LO2 Explore, using either real-world case studies or laboratory-based methods, environmental field sampling methods

LO3 Develop an environmental monitoring strategy for a specified setting using appropriate sampling approaches and quality controls

LO4 Review the effectiveness of the developed monitoring strategy with selected stakeholders.

Essential Content

LO1 **Explain regulatory-compliant environmental monitoring principles**

Purpose and regulatory context of environmental monitoring:

Environmental monitoring purpose: e.g. regulatory drivers, environmental risk context, receptor-based thinking, compliance versus investigative monitoring e.g. compliance monitoring for permitted discharges, baseline characterisation, trend detection, incident response monitoring e.g. incident response monitoring following a fuel spill, environmental management decision support, public health protection, ecosystem service protection e.g. baseline river monitoring prior to a construction project, sustainability and precautionary principle

Monitoring programmes: e.g. data defensibility, evidential standards, auditability, transparency, stakeholder confidence, enforcement context

Evidence use; fit-for-purpose argumentation, communication of environmental significance e.g. permit compliance checks, Environmental Impact Assessment (EIA) support datasets, local authority air quality evidence packs.

Regulatory compliance and fitness-for-purpose principles:

Regulatory hierarchy and requirements: e.g. legislation versus guidance, standards frameworks e.g. drinking water quality standards, permitting and consent conditions e.g. regulated discharge permits, monitoring frequency expectations, reporting requirements, duty of care, competence requirements, ethical practice, professional accountability

Compliance: international standards and cross-jurisdiction regulatory variation e.g. ambient air quality objectives, ISO 14001, ISO/IEC 17025, ISO 5667, MCERTS, WHO guidance, national and regional permitting regimes and environmental quality standards; comparability of monitoring data across national and international contexts

Fitness-for-purpose principle: proportionality of monitoring design e.g. monitoring objective alignment; decision thresholds e.g. guideline thresholds for nutrients in surface waters; regulatory comparators, action levels e.g. action levels for exposure-style monitoring; trigger values e.g. trigger values for contaminated land screening; defensible rationale for methods and frequency;

Traceability and accountability: traceability of monitoring records e.g. field notebooks with unique monitoring identifiers, data identity integrity, audit trail, document control, controlled versions e.g. version-controlled monitoring records; change control, deviation/non-conformance awareness, record retention, data governance e.g. controlled monitoring standard operating procedures (SOPs).

Data quality, traceability and quality assurance/quality control (QA/QC):

Monitoring representativeness: spatial coverage e.g. storm-event 'first flush' effects, temporal coverage e.g. diurnal variation in dissolved oxygen, seasonal nutrient change; monitoring frequency; baseline and trend comparability; bias, uncertainty, error propagation; reproducibility and fitness for purpose

Monitoring compliance principles: documentation requirements; monitoring plan alignment with regulatory objectives e.g. accessible, transparent reporting for technical and non-technical audiences; defensible monitoring design e.g. data integrity, traceability, audit trail and reporting expectations

Data quality indicators: data quality objectives (DQOs) e.g. precision, accuracy, comparability, completeness, validity, data defensibility, sensitivity and detection limits; method performance characteristics e.g. target detection limits aligned to standards, duplicate precision expectations, completeness targets

Quality assurance and quality control (QA/QC) controls e.g. calibration status, verification checks, blanks, duplicate/replicated measurements, spiked checks, reference materials, data capture conditions, calibration checks, verification checks, reporting time frames; field documentation e.g. field logs and verification records.

LO2 **Explore, using either real-world case studies or laboratory-based methods, environmental field sampling methods**

Environmental field sampling methods across different media:

Air monitoring methods: e.g. passive versus active sampling, real-time sensors versus grab samples, indoor/outdoor contexts; particulate versus gaseous sampling e.g. diffusion tubes for nitrogen dioxide (NO_2), high-volume samplers for particulate matter (PM); multi-gas meters

Water sampling methods: surface versus groundwater sampling e.g. groundwater sampling from monitoring boreholes, depth profiling, flow-dependent and event-based sampling, upstream/downstream logic; preservation constraints e.g. river grab samples, wastewater composite samples

Soil and sediment sampling methods: surface versus subsurface profiles e.g. topsoil sampling for metals, core sampling, sediment grabs; discrete versus composite sampling; increment sampling; disturbed versus undisturbed sampling; volatilisation risk; cross-contamination.

Sampling method selection factors:

Sampling strategies: e.g. grab versus composite sampling, random, systematic and judgemental approaches, stratified sampling, transects and grids, temporal design, replicates, sample size considerations; adaptation for urban, rural, coastal, remote and resource-limited settings e.g. grid sampling for contaminated land, transect sampling across estuaries, composite sampling for discharge monitoring

Method selection factors: monitoring objectives, analyte properties e.g. volatility, reactivity; matrix interference, detection limits, logistics e.g. site access, weather constraints, health and safety, regulatory acceptance; climate and seasonal variation across different global environmental contexts e.g. use of amber glass for light-sensitive analytes, avoiding plastics for certain organics, low-flow groundwater sampling.

Sampling limitations, adaptation and practical application:

Sampling limitations: contamination sources e.g. contaminated tubing effects, equipment carryover, handling artefacts, preservation failure; volatilisation e.g. loss of volatile organic compounds (VOCs); adsorption, turbidity effects, representativeness limits; sensor drift e.g. drift in low-cost sensors

Adaptation and contingency: mitigation strategies e.g. increased sampling during rainfall events, use of duplicate samples, relocation of sampling points for safety; deviation control e.g. re-sampling triggers, field decision making, documentation of departures

Exploration approaches: e.g. interpretation of real-world monitoring case studies, comparison of published field sampling protocols, laboratory-based simulation of field sampling decisions, mock sample handling, preservation and contamination-control activities.

LO3 **Develop an environmental monitoring strategy for a specified setting using appropriate sampling approaches and quality controls**

Defining monitoring objectives and scope:

Monitoring objectives: conceptual site model (CSM); source-pathway-receptor relationships e.g. industrial outfall monitoring, roadside air quality monitoring near a school, contaminated land redevelopment sites; boundaries, priority pollutants, compliance drivers, stakeholder requirements, risk-based prioritisation; international good practice and differing regulatory thresholds

Monitoring context: baseline requirements; spatial and temporal domains; seasonal influences e.g. seasonal nutrient monitoring; operational cycles, episodic events e.g. storm-event sampling; decision endpoints; monitoring in differing climatic, infrastructure and resource settings e.g. baseline sampling before remediation.

Designing and justifying a monitoring strategy:

Monitoring design: monitoring networks e.g. upstream/downstream monitoring points, fixed and rotating air monitoring sites, plume boundary sampling, resource planning; method justification e.g. sampling location rationale, frequency, duration, replicates, comparators

Method integration: field versus laboratory methods e.g. multimedia monitoring, triangulation of evidence; screening versus confirmatory analysis e.g. screening kits followed by accredited laboratory analysis; outsourced analysis controls; integration of sensor data with reference sampling.

Quality control planning and professional judgement:

Quality planning: quality assurance/quality control (QA/QC) schedules; blank and duplicate frequency e.g. one field blank per sampling day, duplicates at approximately 10% frequency; calibration plans e.g. calibration checks throughout the sampling period; acceptance criteria, corrective action triggers, data management, traceability

Constraints and judgement: as low as reasonably practicable (ALARP) e.g. reduced sampling frequency with enhanced QA/QC, compromise documentation; safety principles, safe systems of work e.g. lone working arrangements, risk-based prioritisation, access constraints, resource limitations; weather contingency e.g. redesign due to flood risk.

LO4 **Review the effectiveness of the developed monitoring strategy with selected stakeholders**

Reviewing monitoring strategy effectiveness:

Effectiveness review: alignment with monitoring objectives e.g. appropriateness of sampling approaches; suitability for the specified setting e.g. reviewing whether sampling locations capture likely pollutant pathways; adequacy of quality controls, data defensibility, practicality, resource use e.g. whether duplicate frequency supports confidence, whether monitoring frequency is proportionate; health and safety e.g. responsiveness to environmental risk and regulatory expectations.

Stakeholder engagement and feedback:

Stakeholder perspectives: e.g. regulator, client, community representative, site operator, laboratory provider, environmental consultant, health and safety lead

Stakeholder information needs: communication requirements, practical constraints, acceptability, transparency, confidence in evidence; inclusive engagement and accessible communication formats for different cultural, community and technical audiences e.g. stakeholder review meeting, written feedback on monitoring plan, discussion of access constraints or reporting expectations

Use of feedback: e.g. identifying strengths, limitations, risks, omissions and improvements; responding to challenge; documenting amendments; recognising competing priorities; professional justification of decisions; consideration of environmental justice and differential exposure where monitoring affects communities.

Recommendations and professional reflection:

Review conclusions: e.g. evidence-based judgement, limitations and assumptions, uncertainty in strategy design, residual risk, proportionality, feasibility, compliance confidence, stakeholder acceptance, prioritised recommendations e.g. increasing sampling frequency during high-risk periods, adding a field blank, relocating an unsafe sampling point, improving reporting formats

Professional reflection: e.g. lessons learned, ethical and sustainable practice, communication of uncertainty, accountability, continuous improvement, future monitoring needs.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain regulatory-compliant environmental monitoring principles</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate how regulatory, quality and practical considerations influence environmental monitoring principles and field sampling method selection in different contexts.</td></tr>
<tr><td>P1 Explain the purpose and regulatory context of environmental monitoring.

P2 Describe the regulatory and quality requirements that support defensible environmental monitoring data.</td><td>M1 Assess how regulatory and quality requirements influence environmental monitoring activities.</td></tr>
<tr><td colspan="2">LO2 Explore, using either real-world case studies or laboratory-based methods, environmental field sampling methods</td></tr>
<tr><td>P3 Explore, using either real-world case studies or laboratory-based methods, environmental field sampling methods used across different environmental media.

P4 Explain, using either real-world case studies or laboratory-based methods, factors that influence the selection of environmental field sampling methods.</td><td>M2 Analyse, using either real-world case studies or laboratory-based methods, the suitability of environmental field sampling methods using real-world or laboratory-based evidence.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Develop an environmental monitoring strategy for a specified setting using appropriate sampling approaches and quality controls		**LO3 and LO4** **D2** Critically evaluate the effectiveness of the optimised environmental monitoring strategy for the identified scenario, considering design decisions, quality controls and stakeholder feedback.
P5 Develop an environmental monitoring strategy for a specified setting using appropriate sampling approaches. **P6** Explain the quality controls included in the developed monitoring strategy.	**M3** Justify the design choices, sampling approaches and quality control measures used in the environmental monitoring strategy.	
LO4 Review the effectiveness of the developed monitoring strategy with selected stakeholders		
P7 Review the effectiveness of the developed monitoring strategy against monitoring objectives, quality controls and practical constraints.	**M4** Optimise, using the results of stakeholder feedback, the developed monitoring strategy to effectively meet the requirements of the identified scenario.	

Recommended Resources

Textbooks

Artiola, J.F., Pepper, I.L. and Brusseau, M.L. (2004) *Environmental Monitoring and Characterization*. 1st edn. Amsterdam: Elsevier Academic Press.

Brusseau, M.L., Pepper, I.L. and Gerba, C.P. (2019) *Environmental and Pollution Science*. 3rd edn. Amsterdam: Academic Press.

Keith, L.H. (ed.) (1996) *Principles of Environmental Sampling*. 2nd edn. Washington, DC: American Chemical Society.

Ott, W.R. (1995) *Environmental Statistics and Data Analysis*. 1st edn. Boca Raton, FL: CRC Press.

Radojevic, M. and Bashkin, V.N. (2006) *Practical Environmental Analysis*. 2nd edn. Cambridge: Royal Society of Chemistry.

Taberlet, P., *et al.* (2018) *Environmental DNA: For Biodiversity Research and Monitoring*. Oxford: Oxford University Press.

Websites

https://www.teledyne.com/what-we-do/instrumentation/environmental-instrumentation	Teledyne Technologies Environmental Instrumentation (Equipment supplier)
https://www.teledyneisco.com/water-and-wastewater	Teledyne ISCO Water and Wastewater Monitoring (Equipment supplier)
https://www.fieldenvironmental.com/equipment-sales/	Field Environmental Instruments (FEI) Air and water quality monitoring equipment (Equipment supplier)
https://www.epa.gov/environmental-topics/water-topics	United States Environmental Protection Agency Water Topics (Government and regulatory)
https://www.gov.uk/government/collections/monitoring-discharges-to-water-environmental-permits	UK Environment Agency Monitoring Discharges to Water (Government & regulatory)

A simple methodology for water quality monitoring - GOV.UK	UK Government: Foreign, Commonwealth & Development Office Simple methodology for water quality monitoring (Government & regulatory)
https://www.nature.com/subjects/environmental-monitoring	Nature Portfolio Environmental Monitoring (Research)

Journals and articles

Bărbulescu, A., Barbeş, L. and Dumitriu, C.Ș. (2024) 'Advances in Water, Air and Soil Pollution Monitoring, Modeling and Restoration', *Toxics*, 12(4), Article 244. Available at: https://www.mdpi.com/2305-6304/12/4/244.

Calka, B. and Szostak, M. (2025) 'GIS-Based Environmental Monitoring and Analysis', *Applied Sciences*, 15(6), Article 3155. Available at: https://www.mdpi.com/2076-3417/15/6/3155.

Kovačević, M., *et al.* (2023) 'Application of machine learning in modeling the relationship between catchment attributes and instream water quality in data-scarce regions', *Toxics*, 11(12), Article 996. Available at: https://www.mdpi.com/2305-6304/11/12/996.

Sudasman, F.H. and Gereuw, G.E. (2025) 'Integration of AI and GIS in clean water quality monitoring in urban and rural communities', *RIGGS: Journal of Artificial Intelligence and Digital Business*, 4(2), pp. 5338–5344. Available at: https://doi.org/10.31004/riggs.v4i2.1425.

White, P.J.C., *et al.* (2026) 'Robots for ecological monitoring: a review', *Biodiversity and Conservation*.Available at: https://link.springer.com/article/10.1007/s10531-026-03339-3.

Links

This unit links to the following related units:

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 519: Science Laboratory Management

Unit 529: Conservation and Biodiversity

Unit 531: Soil Science and Geochemical Processes.

Unit 518: Calculus for the Applied Sciences

Unit code: J/652/3078

Unit level: 5

Credit value: 15

Introduction

Calculus plays a central role in applied science, particularly where change, variation and measurable behaviour must be understood and interpreted. Calculus provides the tools needed to describe how scientific systems behave over time or across space, enabling the analysis of rates, trends and accumulated effects within systems or processes. These mathematical techniques allow practitioners to interpret data and model scientific processes clearly across a range of applied science contexts.

The aim of this unit is to develop students' understanding of calculus as an applied mathematical tool for solving problems within applied science. Students will build confidence in using calculus to analyse scientific situations, interpret results and support decision making. The unit focuses on practical application and understanding, rather than abstract mathematical theory, ensuring relevance to real scientific contexts.

This unit covers key areas of calculus used in applied science. Differential calculus is explored as a means of analysing rates of change and optimisation problems, while integral calculus is used to model accumulation and physical quantities. The unit also introduces differential equations as tools for representing and interpreting dynamic scientific systems. Throughout the unit, applied science scenarios are used to reinforce understanding and application, culminating in students applying their mathematical knowledge to an applied science scenario.

On successful completion of this unit, students will be able to apply calculus techniques to interpret scientific data, model applied science systems and communicate quantitative findings clearly. These skills support progression into further study and are directly relevant to roles such as Laboratory Technician, Applied Science Technician, Process Analyst, Quality Control Technician and Technical Support Scientist.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explore how differential calculus techniques are used to solve applied science problems

LO2 Discuss the applications of integral calculus in modelling physical or scientific systems

LO3 Explain how differential equations can be used to represent dynamic processes in applied sciences

LO4 Apply calculus-based analysis to an identified applied sciences scenario to obtain useful insights.

Essential Content

LO1 **Explore how differential calculus techniques are used to solve applied science problems**

Limits, continuity and rate-of-change meaning:

Limits: e.g. approach behaviour, boundary values; one-sided limits e.g. left-hand behaviour, right-hand behaviour; two-sided limits e.g. convergence, limit existence

Continuity: e.g. smooth behaviour, unbroken functions; discontinuity types e.g. jump discontinuities, asymptotic behaviour; differentiability conditions e.g. continuity requirement, smoothness requirement

Rate of change meaning: rate-of-change interpretation e.g. temporal variation, spatial variation; instantaneous reaction rate e.g. chemical kinetics, reaction progress; instantaneous change in concentration e.g. dilution processes, reaction monitoring.

Differentiation techniques and forms:

Differentiation rules: e.g. power rule, constant rule; chain rule e.g. composite functions, nested variables

Advanced techniques: implicit differentiation e.g. constrained variables, linked equations; higher derivatives e.g. second derivatives, third derivatives

Function behaviour: stationary points e.g. turning points, equilibrium points; concavity e.g. upward curvature, downward curvature; points of inflection e.g. curvature change, behaviour transition.

Optimisation and related rates:

Optimisation set-up: objective functions e.g. yield functions, cost functions; constraints e.g. material limits, process limits

Optimisation analysis: maxima identification e.g. peak output, optimal conditions; minima identification e.g. minimum cost, least energy; optimisation limitations e.g. model simplifications, ideal assumptions

Related rates: related rates set-up e.g. linked variables, simultaneous change; variable dependency e.g. functional relationships, dependent quantities; time differentiation e.g. temporal change, dynamic behaviour

Result interpretation: e.g. physical meaning, contextual relevance; units e.g. rate units, derived units; model meaning e.g. system representation, process description.

LO2 **Discuss the applications of integral calculus in modelling physical or scientific systems**

Integral calculus concepts and methods:

Indefinite integrals: e.g. antiderivatives, inverse differentiation; constants of integration e.g. initial conditions, reference states

Definite integrals: e.g. accumulation over intervals, total change; fundamental theorem of calculus e.g. derivative–integral link, evaluation method

Integration methods: substitution e.g. composite functions, variable change; integration by parts e.g. product functions, algebraic-exponential forms

Common integration methods; substitution (*u*-substitution) and integration by parts; method selection cues based on integrand structure e.g. composite functions, products of algebraic and exponential/trigonometric forms.

Applications of integral calculus in physical/scientific modelling:

Area under curves: area under curves e.g. accumulated quantity, total effect; signed area e.g. net change, opposing contributions; average value e.g. mean behaviour, representative value

Accumulation models: e.g. mass transfer, dose calculation; time-varying rates e.g. changing concentration, variable flow

Volumes of solids: volumes of revolution e.g. cylindrical symmetry, rotational models; cross-section methods e.g. slicing approach, shape variation

Model interpretation: parameter meaning e.g. physical significance, variable roles; unit checking e.g. dimensional consistency, rate units; modelling assumptions e.g. idealised systems, constant properties.

LO3 **Explain how differential equations can be used to model dynamic processes in applied sciences**

Representing dynamic processes using differential equations:

Dynamic process representation: first-order differential equation model e.g. rate relationships, time-dependent systems, dynamic systems; relationships between variables e.g. variable coupling, system linkage, rate dependence

State and rate variables: dependent variables e.g. concentration, population size, temperature; rate variables e.g. growth rate, decay rate, change rate

Model structure: first-order differential equations e.g. proportional models, balance models, competing-process models.

System behaviour, equilibrium and interpretation:

Initial conditions: starting values e.g. initial concentration, initial population, initial temperature; system trajectories e.g. solution paths, response curves, behaviour profiles

Behaviour over time: transient behaviour e.g. short-term response, adjustment phase, response dynamics; long-term behaviour e.g. steady trends, saturation states, limiting states

Equilibrium concepts: steady states e.g. dynamic equilibrium, balance points, constant states; stability types e.g. stable states, unstable states, neutral states.

Model assumptions and limitations:

Typical applied science models: chemical kinetics e.g. first-order reactions, reaction decay, concentration change; biological systems e.g. population growth, population decline, survival models; environmental systems e.g. mixing systems, clearance systems, flow systems

Model assumptions: ideal conditions e.g. constant parameters, homogeneous systems, uniform properties; system boundaries e.g. closed systems, isolated systems, controlled systems

Model limitations and appropriateness: validity ranges e.g. timescales, operating ranges, parameter bounds; model suitability e.g. context suitability, process suitability, data suitability.

LO4 **Apply calculus-based analysis to an identified applied sciences scenario to obtain useful insights**

Scenario definition and problem framing:

Scenario: context e.g. reaction kinetics study, diffusion process, population change, thermal system; problem definition e.g. rate determination, optimisation aim, accumulation estimate

Variables and parameters: independent variables, dependent variables, constants e.g. time, concentration, temperature

Assumptions and constraints: modelling assumptions e.g. ideal behaviour, closed system; practical constraints e.g. measurement limits, data resolution.

Selection of appropriate calculus approaches:

Technique selection: differential calculus e.g. rate of change, optimisation; integral calculus e.g. accumulation, total quantity; differential equations e.g. dynamic modelling, system behaviour

Method justification: technique suitability e.g. problem fit, data availability; methodological rationale e.g. analytical vs numerical

Numerical methods: approximation techniques e.g. finite differences, numerical integration; accuracy considerations e.g. step size, truncation error

Tool usage: computational tools e.g. spreadsheets, graphing software; calculator functionality e.g. numerical solvers, regression.

Insight generation:

Quantitative results: calculated values e.g. maximum rate, accumulated quantity; solution outputs e.g. equilibrium values, time constants

Trend identification: behavioural trends e.g. increasing rates, diminishing returns; comparative outcomes e.g. scenario comparisons

Sensitivity awareness: parameter sensitivity e.g. effect of initial conditions, variable changes; robustness considerations e.g. stability of results

Contextual meaning: scientific interpretation e.g. physical significance, process behaviour; relevance to scenario e.g. practical implications.

Presentation of findings and meaning:

Graphical presentation: appropriate charts e.g. bar charts, line graphs, scatter plots; clear labelling e.g. titles, units, legends

Interpreting results: linking findings to the scenario e.g. answering the question, relating to context; identifying key outcomes e.g. main trends, notable differences

Communicating conclusions: clear summaries e.g. plain-language explanations, short conclusions; awareness of limits e.g. assumptions made, confidence in results.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explore how differential calculus techniques are used to solve applied science problems</td><td rowspan="7">LO1, LO2 and LO3

D1 Critically evaluate, using a selection of real-world examples, the effectiveness and limitations of differential calculus, integral calculus and differential equation methods in identified applied science contexts.</td></tr>
<tr><td>P1 Explore, using a selection of real-world examples, the meaning of limits, continuity and derivatives as used in the applied sciences.

P2 Explore, using a selection of real-world examples, how differentiation techniques are used to solve the problems of optimisation and related rates within applied science contexts.</td><td>M1 Analyse, using a selection of real-world examples, the calculus techniques used to solve applied science problems.</td></tr>
<tr><td colspan="2">LO2 Discuss the applications of integral calculus in modelling physical or scientific systems</td></tr>
<tr><td>P3 Explain, using a selection of real-world examples, the concepts and methods of integral calculus used in the applied sciences.

P4 Discuss, using a selection of real-world examples, the applications of integral calculus in modelling physical or scientific systems.</td><td>M2 Analyse, using a selection of real-world examples, the suitability of different integral calculus methods in the creation of models of physical or scientific systems.</td></tr>
<tr><td colspan="2">LO3 Explain how differential equations can be used to represent dynamic processes in applied sciences</td></tr>
<tr><td>P5 Explain, using a selection of real-world examples, how differential equations are used to represent dynamic processes and system behaviour in applied science contexts.

P6 Explore, using a selection of real-world examples, the assumptions and limitations of differential equation models when representing dynamic processes in applied sciences.</td><td>M3 Analyse, using a selection of real-world examples, the use of differential equations to represent dynamic processes in applied sciences.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Apply calculus-based analysis to an identified applied sciences scenario to obtain useful insights		**LO4**
P7 Apply calculus-based analysis to an identified applied sciences scenario to obtain useful insights. **P8** Present the insights obtained from the calculus-based analysis to an identified target audience to obtain feedback.	**M4** Evaluate, using audience feedback, the quality and reliability of the insights obtained from the identified scenario, considering the choice of calculus methods.	**D2** Justify the quality and reliability of the insights obtained from the identified scenario, considering the choice of calculus methods.

Recommended Resources

Textbooks

Alvey, C. and Alvey, D. (2024) *Mathematical Biology: Discrete and Differential Equations.* Chapman & Hall/CRC.

Ducrot, A., *et al.* (2022) *Differential Equations and Population Dynamics I: Introductory Approaches.* Springer.

Foo, D. (ed.) (2022) *Chemical Engineering Process Simulation.* 2nd edn. Elsevier.

Goldstein, L.J., Schneider, D.I. and Lay, D.C. (2022) *Calculus and Its Applications.* 15th edn. Harlow: Pearson Education.

Greenwell, R.N. and Ritchey, N.P. (2022) *Calculus for the Life Sciences.* 2nd edn. Pearson.

Straub, J.E. (2022) *Mathematical Methods for Molecular Science: Theory and Applications, Visualizations and Narrative*. MIT Press.

Websites

https://tutorial.math.lamar.edu/Classes/CalcI/RelatedRates.aspx	Paul's Online Math Notes Related rates problems using real-world and scientific scenarios (Tutorial)
https://tutorial.math.lamar.edu/Classes/DE/Intro.aspx	Paul's Online Math Notes Introduction to differential equations with applied science examples (Tutorial)
https://www.khanacademy.org/math/differential-equations/first-order-differential-equations	Khan Academy First-order differential equations and modelling dynamic systems (Tutorial)
https://tutorial.math.lamar.edu/Classes/CalcI/Optimization.aspx	Paul's Online Math Notes Structured approach to calculus-based problem solving and interpretation (Tutorial)
https://www.numberanalytics.com/blog/modeling-differential-equations-guide	Number Analytics Overview of modelling dynamic systems using differential equations (Blog)

https://www.geeksforgeeks.org/maths/real-life-applications-of-mathematical-optimization/	GeeksforGeeks Overview of optimisation methods and applications across scientific and technical fields (Article)

Journals and articles

Ahamed, B., *et al.* (2024) 'Differential Equations in the Modeling of Biological Systems: Advancing AI and Nanotechnology-Based Engineering Applications', *Nanotechnology Perceptions*, 20(S15), pp. 2085–2098. Available at: https://nano-ntp.com/index.php/nano/article/download/4146/3157/7931

Beira, M. J. and Sebastião, P. J. (2021) 'A differential equations model-fitting analysis of COVID-19 epidemiological data to explain multi-wave dynamics', *Scientific Reports*, 11, 16312. Available at: https://doi.org/10.1038/s41598-021-95494-6

Martin-Vaquero, J., *et al.* (2021) 'Editorial: Analytical and Numerical Methods for Differential Equations and Applications', *Frontiers in Applied Mathematics and Statistics*, 7, 712813. Available at: https://doi.org/10.3389/fams.2021.712813

Nardini, J. T., *et al.* (2021) 'Learning differential equation models from stochastic agent-based model simulations', *Journal of the Royal Society Interface*, 18(176), 20200987. Available at: https://doi.org/10.1098/rsif.2020.0987

West, B. J. (2021) 'Fractional Calculus and the Future of Science', *Entropy*, 23(12), 1566. Available at: https://doi.org/10.3390/e23121566

Zhang, E. (2022) 'Mathematical Foundations of Multivariable Calculus in Engineering Analysis', *American Journal of Engineering Mathematics*, 3(6). pp. 12–16. Available at: https://doi.org/10.71465/ajem736

Links

This unit links to the following related units:

Unit 404: Mathematics and Statistics for the Applied Sciences.

Unit 519: Science Laboratory Management

Unit code: K/652/3079

Unit level: 5

Credit value: 15

Introduction

Science laboratories operate across a wide range of applied science contexts, including analytical services, research, education and quality control. Effective laboratory management is essential to ensure that laboratory activities are safe, efficient, reliable and aligned with organisational, regulatory and quality requirements. Laboratory managers and supervisors are responsible for coordinating people, equipment, materials, data and procedures to support accountability, consistency and confidence in laboratory outputs.

This unit introduces the principles and practices that support effective laboratory management, including quality planning, quality assurance, quality control, governance, risk-based management and documented procedures. Students will consider how laboratory quality management systems support data integrity, traceability, regulatory compliance and continuous improvement. The unit also explores relevant local, national and international standards, accreditation requirements and health and safety legislation, including examples such as ISO/IEC 17025 where appropriate to the laboratory context.

Students will explore the design of regulatory-compliant laboratory workflows for identified scenarios, including the coordination of activities, resources, communication, risk controls and digital systems. They will also develop standard operating procedures (SOPs) that support clarity, consistency, document control and safe, inclusive laboratory practice. Consideration is given to sustainable laboratory operations, including efficient resource use and responsible waste handling.

On completion of this unit, students will be able to apply laboratory management principles to realistic laboratory scenarios, design compliant workflows and develop controlled SOPs for defined laboratory activities. The knowledge and skills developed support progression into roles such as Laboratory Supervisor, Laboratory Manager, Quality Officer, Quality Assurance Technician, Technical Specialist or Compliance Coordinator. The unit also provides a foundation for further study in applied sciences, laboratory management, quality management and professional scientific practice.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss the principles of laboratory quality management

LO2 Review a range of quality assurance and quality control processes used in scientific laboratories

LO3 Design regulatory-compliant laboratory management workflows to optimise laboratory efficiency for an identified scenario

LO4 Develop regulatory-compliant standard operating procedures (SOPs) for an identified laboratory workflow.

Essential Content

LO1 **Discuss the principles of laboratory quality management**

Laboratory quality management principles and frameworks:

Purpose, scope of laboratory quality management: e.g. quality planning, quality assurance, quality control as interrelated components; alignment of laboratory activities with organisational objectives

Continuous improvement approaches: e.g. structured review, corrective action, preventive action processes e.g. Plan-Do-Check-Act cycles; digital systems for documented monitoring; review of quality performance.

Governance, roles and responsibilities:

Management accountability for laboratory activities: defined roles of laboratory managers, supervisors, technical staff; competence, authorisation, segregation of duties; responsibility for compliance, documentation, oversight in line with organisational policies; regulatory expectations e.g. duties under the Health and Safety at Work etc. Act 1974

Inclusive management practices: staff training e.g. team leadership skills, clear communication, conflict resolution; equitable allocation of duties, reasonable adjustments, accessible procedures; competency matrices.

Quality systems and risk-based management:

Laboratory quality management systems: e.g. documentation hierarchies, control of records, control of documents, internal monitoring, internal review

Risk-based thinking in laboratory management: e.g. identification, control of risks relating to data integrity, equipment reliability, resource use, staff competence.

LO2 **Review a range of quality assurance and quality control processes used in scientific laboratories**

Quality assurance processes:

Process-focused approaches for consistent laboratory performance: e.g. internal audit processes, external audit processes, training, competence assurance; management review processes e.g. audits aligned to accreditation standards such as ISO/IEC 17025, data integrity, information governance and cybersecurity controls aligned to ISO/IEC 27001; digital tools for audit trails, schedules, controlled records

Equipment: e.g. equipment calibration, equipment maintenance, waste management.

Quality control processes:

Operational controls for monitoring analytical performance: e.g. control samples, blanks, traceable reference materials; defined acceptance criteria; management of QC data

Actions: corrective action, preventive action in response to non-conforming results; reduction of rework e.g. reduction of unnecessary repeat testing; efficient, sustainable laboratory practice.

Data integrity and traceability:

Traceability of samples, data, results: record-keeping systems e.g. security of paper-based systems; electronic systems e.g. laboratory notebooks, controlled spreadsheets; version control, audit trails, integrity; laboratory information management systems e.g. management responsibilities for data accessibility, reliability, compliance.

LO3 **Design regulatory-compliant laboratory management workflows to optimise laboratory efficiency for an identified scenario**

Regulatory and organisational requirements:

Application of jurisdiction-specific health and safety legislation: regulatory guidance, accreditation requirements, recognised standards to laboratory operations e.g. Health and Safety at Work etc. Act 1974, Management of Health and Safety at Work Regulations 1999, Control of Substances Hazardous to Health (COSHH) Regulations 2002, relevant waste management regulations

Regulatory requirements within organisational policies: e.g. laboratory procedures, workflow design; environmental responsibilities associated with waste handling, resource use.

Laboratory management workflows:

Workflow design: e.g. end-to-end workflow design from sample receipt to reporting, sequencing of activities, allocation of roles, allocation of responsibilities; handover points

Documentation requirements: e.g. record requirements for regulatory compliance, quality oversight, disaster recovery, business continuity planning; digital tools for workflow coordination, communication, accessibility e.g. laboratory information management systems, electronic lab notebooks (ELN), electronic sample tracking, shared scheduling systems.

Efficiency and risk management within workflows:

Workflow approaches: e.g. Smart Labs, Laboratory 4.0 for efficient use of staff, equipment, materials, automated robotic workflows, artificial intelligence (AI), machine learning (ML)

Coordination: e.g. scheduling of laboratory activities; identification, of operational, compliance, sustainability-related risks within workflows e.g. predictive analysis; controls to reduce delays, errors, hazardous exposure, avoidable waste while maintaining safe, inclusive working practices e.g. Internet of Things (IoT) connected sensors.

LO4 **Develop regulatory-compliant standard operating procedures (SOPs) for an identified laboratory workflow**

Purpose and structure of SOPs:

Role of SOPs: standardisation, compliance, training e.g. defined scope, limitations; structured formats for clarity, consistency, usability, accessibility; inclusive language; accessible presentation to support staff with differing levels of experience, responsibility, training needs.

Regulatory alignment and document control:

Regulatory alignment: e.g. incorporation of local, national, international, organisational requirements into SOPs; alignment with relevant legislation, guidance, accreditation expectations, recognised standards e.g. COSHH requirements, safe systems of work; approval, authorisation, review processes

Document control: electronic document control systems e.g. version control, change management, archiving, decommissioning.

Use of SOPs in laboratory practice:

Application of SOPs for consistent laboratory practice: e.g. staff competence, quality outcomes; role of SOPs in audits, training, continuous improvement; contribution of well-designed SOPs to efficient resource use e.g. reduction of errors, safe, inclusive laboratory working environments.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss the principles of laboratory quality management</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the effectiveness of laboratory quality management systems in supporting regulatory compliance, data integrity, traceability and consistent quality outcomes in scientific laboratories.</td></tr>
<tr><td>P1 Explain laboratory quality management principles, including quality planning, quality assurance and quality control.

P2 Discuss governance, roles and risk-based management within laboratory quality systems.</td><td>M1 Analyse the contribution of laboratory quality management principles, governance and risk-based management to regulatory compliance and consistent quality outcomes.</td></tr>
<tr><td colspan="2">LO2 Review a range of quality assurance and quality control processes used in scientific laboratories</td></tr>
<tr><td>P3 Explain quality assurance processes used in scientific laboratories.

P4 Review quality control processes used to monitor analytical performance in scientific laboratories.</td><td>M2 Assess the role of quality assurance and quality control processes in maintaining data integrity and traceability.</td></tr>
<tr><td colspan="2">LO3 Design regulatory-compliant laboratory management workflows to optimise laboratory efficiency for an identified scenario</td></tr>
<tr><td>P5 Design regulatory-compliant laboratory management workflows for an identified scenario.

P6 Explain the workflow activities, resources and risk controls for the identified scenario.</td><td>M3 Analyse the contribution of workflow design to laboratory efficiency, regulatory compliance and risk control.</td><td>LO3 and LO4

D2 Critically evaluate the effectiveness of regulatory-compliant laboratory management workflows and SOPs in supporting safe and efficient practice for an identified scenario.</td></tr>
<tr><td colspan="2">LO4 Develop regulatory-compliant standard operating procedures (SOPs) for an identified laboratory workflow</td></tr>
<tr><td>P7 Develop a regulatory-compliant standard operating procedure for an identified laboratory workflow.

P8 Explain the document control and regulatory requirements applied within the standard operating procedure.</td><td>M4 Assess the contribution of the standard operating procedure to clarity, consistency, regulatory compliance and effective document control.</td></tr>
</table>

Recommended Resources

Textbooks

Cohen, C.M. and Cohen, S.L. (2018) *Lab Dynamics: Management and Leadership Skills for Scientists*. 3rd edn. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press.

Harmening, D.M. (2020) *Laboratory Management: Principles and Processes*. 4th edn. Fort Lauderdale, FL: D.H. Publishing & Consulting Inc.

García, L.S. (ed.) (2024) *Clinical Laboratory Management*. 3rd edn. Hoboken, NJ: Wiley.

Kinkus, C.A. (2011) *Laboratory Management: Quality in Laboratory Diagnosis*. New York, NY: Demos Medical Publishing.

Mahon, C.R. and Rentas, C.A. (2025) *Management and Leadership in the Clinical Laboratory*. 1st edn. Amsterdam: Elsevier.

Websites

https://www.who.int/publications/i/item/9789241548274	World Health Organization Laboratory quality management system: handbook (E-books)
https://extranet.who.int/hslp/content/LQMS-training-toolkit	World Health Organization Laboratory Quality Management System Training Toolkit (Training)
https://extranet.who.int/lqsi/content/write-master-sop	World Health Organization Laboratory Quality Stepwise Implementation: Write a Master SOP (Tutorials)
https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html	International Organization for Standardization ISO/IEC 17025 testing and calibration laboratories (General reference)
https://www.cdc.gov/laboratory-systems/php/educational-materials/index.html	Centers for Disease Control and Prevention Division of Laboratory Systems Educational Materials (Training)

https://oercommons.org/courseware/lesson/89106	OER Commons Fundamentals of Laboratory Management (Tutorials)

Journals and articles

Antony, J., *et al.* (2023) 'Revisiting Ishikawa's Original Seven Basic Tools of Quality Control: A Global Study and Some New Insights', *IEEE Transactions on Engineering Management*, 70(11), pp. 4005–4020. Available at: https://doi.org/10.1109/TEM.2021.3095245

Chen, S. H., *et al.* (2024) 'Implementation of electronic lab notebooks (ELNs) in science laboratory classes: student response and lessons learned', *Discover Education*, 3(1), article 70. Available at: https://doi.org/10.1007/s44217-024-00161-3

Misztal, A., *et al.* (2025) 'Possibilities of Using Contemporary Quality Management Methods and Tools for the Sustainable Development of the Organization', *Sustainability*, 17(2), article 617. Available at: https://doi.org/10.3390/su17020617

Pillai, S., *et al.* (2022) 'Practical considerations for laboratories: Implementing a holistic quality management system', *Frontiers in Bioengineering and Biotechnology*, 10, article 1040103. Available at: https://doi.org/10.3389/fbioe.2022.1040103

Pillai, S. P., *et al.* (2025) 'Laboratory quality management system fundamentals', *Frontiers in Bioengineering and Biotechnology*, 13, article 1578654. Available at: https://doi.org/10.3389/fbioe.2025.1578654

Resnik, D. B. ,*et al.* (2024) 'Ethical decision-making and role conflict in managing a scientific laboratory', *Accountability in Research*, 31(8), pp. 1198–1221. Available at: https://doi.org/10.1080/08989621.2023.2236553

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 403: Fundamentals of Chemical Laboratory Protocols and Techniques

Unit 405: Applied Experimental Methodology (Pearson-set)

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set).

Unit 520: Stem Cell Biology

Unit code: **R/652/3080**

Unit level: **5**

Credit value: **15**

Introduction

Stem cell biology is an important area of modern bioscience with applications in biomedical research, regenerative medicine, biotechnology and therapeutic development. This unit provides students with an introduction to the principles that define stem cells and influence their behaviour, supporting understanding of their scientific relevance in laboratory and applied settings.

Students will explore stem cell properties and classification, including self-renewal, differentiation and potency, alongside the processes involved in cell fate determination and lineage commitment. The unit also examines how intrinsic and extrinsic factors regulate stem cell behaviour, enabling students to develop knowledge of the biological mechanisms that underpin stem cell function.

The practical and applied dimensions of the subject are also considered. Students will review stem cell culture systems, maintenance requirements and characterisation techniques through laboratory-based practice or real-world case studies. Ethical principles, governance arrangements and regulatory frameworks are also explored, supporting understanding of the responsibilities and controls associated with stem cell research and application.

On completion of this unit, students will be able to explain key concepts in stem cell biology, review stem cell culture and characterisation techniques, discuss the ethical and regulatory frameworks governing stem cell research, and investigate current and emerging applications in the field. This will support progression to further study in areas such as biomedical science, biotechnology, cell and molecular biology and regenerative medicine, and to employment in laboratory science, biotechnology, clinical research, translational research and related bioscience sectors.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the foundational concepts in stem cell biology

LO2 Review stem cell culture and characterisation techniques through laboratory-based practice or real-world case studies

LO3 Discuss the ethical and regulatory frameworks governing stem cell research

LO4 Present an investigation into the current and emerging applications of stem cell research to an intended audience.

Essential Content

LO1 **Explain the foundational concepts in stem cell biology**

Stem cell properties and classification:

Stem cell properties: e.g. stem cell definition, self-renewal, differentiation

Potency classifications: e.g. totipotent, pluripotent, multipotent

Developmental potential and constraints: embryonic stem cells, foetal stem cells, adult stem cells, somatic stem cells e.g. haematopoietic, mesenchymal, neural; induced pluripotent stem cells

Operational use of terminology in research contexts: e.g. stemness as a marker-based identity claim versus function-based evidence, pluripotency-associated markers e.g. OCT4, SOX2, NANOG.

Cell fate determination and lineage commitment:

Cell fate decisions: e.g. differentiation trajectories, symmetric and asymmetric cell division, lineage restriction, lineage commitment, germ layer specification; developmental patterning e.g. formation of nervous, digestive, respiratory and circulatory systems

Cellular heterogeneity within populations: e.g. plasticity, limits of plasticity; conceptual models of fate decision making e.g. deterministic and stochastic contributions; population-level trends; single-cell variability; representation of differentiation pathways e.g. lineage trees, trajectory maps.

Regulation of stem cell behaviour:

Intrinsic regulatory factors: e.g. gene expression programmes, transcription factors, epigenetic regulation

Extrinsic regulatory factors: e.g. cell–cell interactions, stem cell niche, growth factors, signalling pathways

Pathway cross-talk: e.g. feedback concepts, microenvironmental constraints, gradients; integration of intrinsic and extrinsic cues influencing cell fate decisions e.g. Wnt, Notch, TGF-β, BMP, FGF; niche influences e.g. extracellular matrix composition, stiffness, oxygen tension, hypoxia.

LO2 **Review stem cell culture and characterisation techniques through laboratory-based practice or real-world case studies**

Stem cell culture systems and maintenance:

In vitro culture principles: e.g. sterile technique, aseptic handling, culture media components and critical supplements e.g. basal medium, serum medium, defined supplements, growth factors; feeder-dependent systems; feeder-free systems

Culture environments: two-dimensional and three-dimensional culture environments e.g. monolayer culture, spheroids, organoid-based culture concepts; environmental control parameters e.g. temperature, CO_2, oxygen tension; culture stability; sources of variability e.g. passage number effects, genetic drift, epigenetic drift, batch-to-batch variation; contamination and failure modes e.g. mycoplasma risk, microbial contamination, differentiation drift, low post-thaw viability.

Stem cell characterisation and identity confirmation:

Stem cell characterisation: identity, purity and differentiation state as distinct characterisation claims; morphological assessment e.g. cell shape, appearance, growth pattern, cell-to-cell interactions; cell surface markers; molecular markers; transcriptional markers

Identity confirmation: functional assays supporting identity claims, potency claims and differentiation state; characterisation techniques e.g. immunostaining, flow cytometry, gene expression profiling, tri-lineage differentiation evidence in pluripotent contexts

Limitations: suitability and limitations of different evidence types; interpretation challenges e.g. marker non-specificity, population heterogeneity, assay sensitivity, assay specificity.

Evidence quality, digital data handling and interpretation:

Evidence quality: validity and reliability of characterisation data e.g. controls, replicates, acceptance criteria concepts; experimental variability e.g. confounding factors, uncertainty, bias, sample diversity and representativeness, error sources

Interpretation of digitally generated datasets: e.g. data provenance, traceability, reproducibility and repeatability considerations; international data-sharing expectations; cross-site comparability; FAIR (Findable, Accessible, Interoperable and Reusable) data principles; triangulation of evidence to strengthen confidence in findings

Digital tools: digital tools and platforms for data capture, analysis and visualisation e.g. gating strategies in flow cytometry, thresholding and segmentation choices in imaging, batch effects in transcriptomic datasets; metadata expectations e.g. sample IDs, passage number, culture conditions.

LO3 **Discuss the ethical and regulatory frameworks governing stem cell research**

Ethical principles in stem cell research:

Ethical principles: respect for persons e.g. beneficence and non-maleficence; informed consent e.g. privacy and confidentiality; proportionality of risk and benefit; embryo use e.g. tissue sourcing, donor consent, moral status debates, cultural and religious perspectives; ethical tensions in research design and communication e.g. embryo creation versus use of surplus embryos, donor withdrawal, secondary use of samples and data, therapeutic misconception risks in translational contexts.

Regulatory and legislative frameworks:

Regulatory frameworks: regulatory oversight of stem cell research e.g. national and international frameworks, Human Fertilisation and Embryology Authority (HFEA), Medicines and Healthcare products Regulatory Agency (MHRA), Food and Drug Administration (FDA) and European Medicines Agency (EMA); international guidance and standards e.g. International Society for Stem Cell Research (ISSCR) Guidelines, ISO 20387 for biobanking

Research ethics governance: approval pathways, licensing and permissions for specific stem cell activities; e.g. governance bodies, advisory committees; compliance requirements for research, clinical trials and translational activity e.g. good clinical practice (GCP), good manufacturing practice (GMP)

Statutory control of embryo and gamete use: donor consent requirements, traceability requirements; data protection obligations e.g. GDPR, Data Protection Act 2018; material transfer governance; biobanking governance; advanced therapy and clinical development oversight; post-approval monitoring; reporting obligations; controlled documentation e.g. protocols, consent forms, SOPs, data management plans; material transfer agreements for inter-institutional sharing.

Regulatory variation and ethical challenge:

Regulatory variation: similarities and differences in regulatory approaches across jurisdictions e.g. permissive frameworks, restrictive frameworks, impact of regulatory variation on collaboration, data sharing and research progression; challenges arising from regulatory inconsistency

Ethical challenge: ethical tensions between innovation, patient safety, public trust and societal values; global equity and access considerations e.g. affordability, availability, clinical trial access, representation of diverse populations

Risk-benefit framing: responsible innovation, long-term clinical impact considerations, long-term societal impact considerations e.g. differing embryo research limits, licensing approaches, thresholds for clinical translation, follow-up expectations.

LO4 **Present an investigation into the current and emerging applications of stem cell research to an intended audience**

Current and emerging stem cell applications:

Regenerative medicine and therapeutic applications: cell-based repair, e.g. corneal repair and skin regeneration; stem cell transplantation; disease modelling, e.g. Parkinson's disease, cystic fibrosis and organoids; drug discovery; toxicity testing; and personalised and precision medicine applications

Pathway concepts: translational pathway concepts from laboratory research to clinical use e.g. proof of concept, preclinical evidence, clinical translation; application-specific evidence expectations e.g. organoids for disease modelling, cell therapies for tissue repair, patient-derived models for screening and toxicity assessment.

Feasibility, intended use and sustainability considerations:

Feasibility: scientific feasibility, technical feasibility, translational readiness e.g. discovery, proof of concept, preclinical studies, clinical translation

Scalability: manufacturability e.g. expansion capacity, reproducibility, batch consistency, automation, GMP; quality attributes

Quality control: quality control considerations e.g. identity, purity, potency, safety; limitations, constraints, risk profiles associated with specific applications, resource intensity

Cost: cost drivers of stem cell production e.g. large-scale cell culture requirements, quality control testing, skilled personnel, GMP teams; global implementation contexts e.g. infrastructure, cold chain capacity, workforce expertise, affordability

Sustainability: sustainability considerations associated with research, development and clinical use e.g. automation versus manual culture trade-offs, cold chain and storage constraints, consumables use and waste streams, long-term monitoring implications.

Communication of scientific findings:

Communication*:* e.g. audience identification, audience needs, accessibility, cultural and linguistic considerations, technical and non-technical communication contexts

Evidence-to-claim alignment: e.g. uncertainty statements, limitation statements, appropriate framing to avoid overstatement; clarity and structure of communicated findings

Digital tools: digital formats and platforms for presenting scientific information e.g. patients, public audiences, regulators, ethics panels, scientific peers, industry partners; format choices e.g. posters, slide decks, briefing summaries.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the foundational concepts in stem cell biology</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the application of stem cell concepts to the selection and interpretation of culture and characterisation techniques.</td></tr>
<tr><td>P1 Explain the key features of stem cells, including potency classifications and stem cell types.

P2 Explore cell fate decisions and regulatory factors influencing stem cell behaviour.</td><td>M1 Analyse relationships between stem cell potency, lineage commitment, regulation and behaviour.</td></tr>
<tr><td colspan="2">LO2 Review stem cell culture and characterisation techniques through laboratory-based practice or real-world case studies</td></tr>
<tr><td>P3 Review stem cell culture systems and maintenance requirements.

P4 Explain techniques used to characterise stem cells and confirm identity or differentiation state.</td><td>M2 Assess the suitability and limitations of stem cell culture and characterisation techniques in relation to evidence quality and purpose.</td></tr>
<tr><td colspan="2">LO3 Discuss the ethical and regulatory frameworks governing stem cell research</td><td rowspan="5">LO3 and LO4

D2 Critically evaluate ethical and regulatory challenges associated with selected stem cell applications in relation to intended use and audience feedback.</td></tr>
<tr><td>P5 Discuss ethical issues that apply to stem cell research.

P6 Explain governance and regulatory requirements for stem cell research.</td><td>M3 Analyse the influence of ethical issues and regulatory requirements on decision making in stem cell research.</td></tr>
<tr><td colspan="2">LO4 Present an investigation into the current and emerging applications of stem cell research to an intended audience</td></tr>
<tr><td>P7 Investigate selected current and emerging applications of stem cell research.

P8 Present findings from an investigation into stem cell applications to an intended audience and obtain feedback on the investigation.</td><td>M4 Analyse evidence from selected current and emerging stem cell applications in relation to feasibility, intended use and audience feedback.</td></tr>
</table>

Recommended Resources

Textbooks

Brand-Saberi, B. (ed.) (2020) *Essential Current Concepts in Stem Cell Biology*. 1st edn. Cham: Springer Nature Switzerland AG.

Cabral, J.M.S., Lobato da Silva, C. and Diogo, M.M. (eds.) (2020) *Stem Cell Bioprocessing and Manufacturing*. Basel: MDPI.

Chapman, A.R. (2020) *The Ethical Challenges of the Stem Cell Revolution*. 1st edn. Newcastle upon Tyne: Cambridge Scholars Publishing.

Chowdhury, S. and Ghosh, S. (2021) *Stem Cells: Biology and Therapeutics*. 1st edn. Singapore: Springer Nature Singapore.

Clarke, M. and Frampton, J. (2020) *Stem Cells: Biology and Application*. 1st edn. New York: Garland Science.

Durand, C. and Charbord, P. (eds.) (2022) *Stem Cell Biology and Regenerative Medicine*. 2nd edn. New York: River Publishers.

Haider, K.H. (ed.) (2022) *Handbook of Stem Cell Therapy*. 1st edn. Singapore: Springer Nature Singapore.

Rodrigues, G. and Roelen, B.A.J. (eds.) (2020) *Concepts and Applications of Stem Cell Biology: A Guide for Students*. 1st edn. Cham: Springer.

Turksen, K. (ed.) (2021) *Stem Cells and Good Manufacturing Practices: Methods, Protocols, and Regulations*. 2nd edn. New York: Humana Press.

von Schwarz, E.R. (2024) *Ethics of Modern Stem Cell Research and Therapy*. Cham: Springer Nature Switzerland.

Websites

https://www.pharmacopoeia.com/news/key-insights-advanced-therapy-medicinal-products-guidance-development?preview=true	British Pharmacopoeia (MHRA) Advanced Therapy Medicinal Products (ATMP) guidance materials (assays, characterisation, best practice) (Standards)
https://www.eurostemcell.org/	EuroStemCell Explore Stem Cells/Medicine and Stem Cells (uses, ethics and society, clinical translation context) (General reference)

https://www.ema.europa.eu/en/human-regulatory-overview/	European Medicines Agency (EMA) Guidelines relevant for advanced therapy medicinal products (ATMPs) (Regulatory guidance)
https://www.go-fair.org/fair-principles/	GO FAIR FAIR Principles (Findable, Accessible, Interoperable, Reusable) for data stewardship (General reference)
https://www.hfea.gov.uk/about-us/how-we-regulate/	Human Fertilisation and Embryology Authority (HFEA) How we regulate embryo research and fertility treatment (licensing, inspections, standards) (Regulatory guidance)
https://www.hta.gov.uk/guidance-professionals	Human Tissue Authority (HTA) Regenerative medicine and regulation of ATMPs (licensing and oversight for tissues/cells) (Regulatory guidance)
https://www.isscr.org/guidelines	International Society for Stem Cell Research (ISSCR) Guidelines for Stem Cell Research and Clinical Translation (standards, oversight, communications) (Standards)
https://www.gov.uk/guidance	Medicines and Healthcare products Regulatory Agency (MHRA) Advanced therapy medicinal products: regulation and licensing in UK (Regulatory guidance)
https://www.thermofisher.com/	Thermo Fisher Scientific (Gibco) Cell Culture Basics (aseptic technique, environment control, passaging, freezing/thawing) (Tutorials)

Journals and articles

Abou-el-Enein, M., *et al.* (2021) 'Scalable Manufacturing of CAR T Cells for Cancer Immunotherapy', *Blood Cancer Discovery*, 2(5), pp. 408–422. Available at: https://doi.org/10.1158/2643-3230.BCD-21-0084.

Assen, L.S., *et al.* (2025) 'From responsibility to responsibilization in stem cell research: An ethical framework', *Stem Cell Reports*, 20(2), 102389. Available at: https://www.cell.com/stem-cell-reports/fulltext/S2213-6711(24)00349-7.

Bai, L., *et al.* (2023) 'Regulation of hematopoietic stem cells differentiation, self-renewal, and quiescence through the mTOR signaling pathway', *Frontiers in Cell and Developmental Biology*, 11, 1186850. Available at: https://doi.org/10.3389/fcell.2023.1186850.

Corsini, N.S. and Knoblich, J.A. (2022) 'Human organoids: New strategies and methods for analyzing human development and disease', *Cell*, 185(15), pp. 2756–2769. Available at: https://doi.org/10.1016/j.cell.2022.06.051.

Doulgkeroglou, M.-N., *et al.* (2020) 'Automation, Monitoring, and Standardization of Cell Product Manufacturing', *Frontiers in Bioengineering and Biotechnology*, 8, 811. Available at: https://doi.org/10.3389/fbioe.2020.00811.

Goldrick, C., *et al.* (2023) '3D multicellular systems in disease modelling: From organoids to organ-on-chip', *Frontiers in Cell and Developmental Biology*, 11, 1083175. Available at: https://doi.org/10.3389/fcell.2023.1083175.

Heydari, Z., *et al.* (2021) 'Organoids: a novel modality in disease modeling', *Bio-Design and Manufacturing*, 4, pp. 689–716. Available at: https://doi.org/10.1007/s42242-021-00150-7.

Hofmann, B., *et al.* (2023) 'Organoids in the Clinic: A Systematic Review of Outcomes', *Cells Tissues Organs*, 212(6), pp. 499–511. Available at: https://doi.org/10.1159/000527237.

Jacobsen, A., *et al.* (2020) 'FAIR Principles: Interpretations and Implementation Considerations', *Data Intelligence*, 2(1-2), pp. 10–29. Available at: https://doi.org/10.1162/dint_r_00024.

Ludwig, T.E., *et al.* (2023) 'ISSCR standards for the use of human stem cells in basic research', *Stem Cell Reports*, 18(9), pp. 1744–1752. Available at: https://www.cell.com/stem-cell-reports/fulltext/S2213-6711(23)00302-8.

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 408: Human Anatomy and Physiology

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 524: Immunology.

Unit 521: Infectious Disease Epidemiology and Control

Unit code: Y/652/3082

Unit level: 5

Credit value: 15

Introduction

Infectious diseases remain a significant challenge for global health systems, requiring coordinated population-level approaches to understand patterns of transmission, reduce risk and protect communities. This unit is situated within applied sciences and public health, supporting students to develop knowledge of epidemiological principles and their application to infectious disease prevention and control in clinical and community settings.

Students will examine how infectious disease patterns are identified, monitored and interpreted using surveillance systems and testing data. They will consider routine reporting, event-based surveillance, laboratory outputs and digital platforms, and explore how these sources support public health decision making. The unit also considers data quality, uncertainty, ethical responsibilities and the use of evidence to inform proportionate responses.

Students will apply surveillance findings to defined scenarios, interpreting trends, clusters and transmission risks to identify appropriate control priorities. They will consider population characteristics, settings, behaviours, inequalities and resource constraints that influence infectious disease spread. The unit also addresses the development, monitoring and adaptation of prevention and control strategies, including infection prevention and control measures, public communication and sustainable approaches to response.

On completion of this unit, students will be able to apply epidemiological reasoning to support infectious disease surveillance, risk interpretation and evidence-informed control strategies. The unit supports progression to further study in topics such as epidemiology, public health, infection prevention and control, biomedical science, global health, health data science and outbreak management. It also supports career pathways in public health, healthcare, laboratory science and community health roles, including Epidemiologist, Public Health Data Analyst, Infection Prevention and Control Practitioner, Disease Intervention Specialist, Laboratory Researcher or Field Researcher.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the epidemiological principles underpinning the spread of infectious diseases

LO2 Examine the role of infectious disease surveillance and testing data in informing public health responses

LO3 Interpret infectious disease surveillance findings for an identified scenario to determine transmission risk and control priorities

LO4 Develop evidence-informed strategies for the prevention and control of infectious diseases in clinical and community settings.

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Essential Content

LO1 **Explain the epidemiological principles underpinning the spread of infectious diseases**

Core epidemiological concepts:

Measures of disease frequency: case definitions and case ascertainment; numerator/denominator concepts and population at risk; incidence, prevalence and attack rates; crude rates and standardised rates e.g. direct and indirect standardisation; morbidity and mortality indicators e.g. case fatality ratio (CFR); endemic and endemic disease patterns

Measures of disease distribution: epidemic and pandemic patterns e.g. malaria, measles, influenza, COVID-19; reproduction numbers (R_0, R_t) and assumptions affecting interpretation; population susceptibility, immunity and herd effects

Long-term disease control: sustainability considerations in long-term disease control e.g. maintaining population immunity and preventing repeated outbreaks, balancing vaccination strategy and resource constraints.

Transmission dynamics:

Mechanisms of transmission: direct/indirect contact, droplet, airborne/aerosol, faecal–oral, vector-borne, zoonotic e.g. norovirus, measles, tuberculosis, cholera, malaria, rabies

Exposure concepts and infectious dose: e.g. contact rates, mixing patterns, contact networks; timescale e.g. incubation period, latent period, infectious period, serial interval, generation time; temporal and spatial spread and clustering

Modelling: modelling of transmission dynamics using epidemiological tools and datasets, including model assumptions and limitations e.g. epidemic curves distinguishing point-source and propagated outbreaks, compartmental models such as SIR/SEIR

Intervention: implications for sustainable intervention planning e.g. targeting high-risk settings to reduce repeated disruption.

Population-level influences:

Demographic and environmental determinants of health: e.g. population density, mobility, vulnerability; global mobility and cross-border spread; social determinants of health and health inequalities e.g. protected characteristics, language, culture, accessibility; occupational and setting-based exposure

Behavioural determinants and risk perception: e.g. differential access to prevention, testing and treatment; sustainability and equity of interventions across different population groups e.g. tuberculosis in overcrowded housing, cholera following sanitation breakdown, influenza in care homes; balancing effectiveness with social, economic and environmental impacts; reducing intervention fatigue, maintaining adherence across communities.

LO2 **Examine the role of infectious disease surveillance and testing data in informing public health responses**

Infectious disease surveillance methodologies:

Surveillance methodologies: passive, active and sentinel surveillance; syndromic surveillance and event-based surveillance; international reporting and global alert systems

Case reporting pathways and governance: surveillance attributes and quality indicators e.g. timeliness, completeness, sensitivity, specificity, representativeness; digital surveillance systems and dashboards; routine reporting platforms and interoperable data systems; data linkage and data quality assurance

Surveillance applications: e.g. influenza-like illness, COVID-19, antimicrobial-resistant infections; sustainability of surveillance infrastructure e.g. workforce capacity, maintaining consistent case definitions over time, sustaining data quality and reporting compliance.

Testing data as surveillance inputs:

Testing data: integration of laboratory testing outputs into surveillance systems; digital reporting pipelines and laboratory information flows; test performance concepts e.g. sensitivity, specificity, predictive values, pre-test probability

Interpretation: denominators and interpretation issues e.g. tests performed versus people tested, test positivity; aggregation and visualisation of testing data; interpretation of trends using digital tools e.g. dashboards showing incidence and test positivity by locality, automated reports highlighting abnormal increases

Limitations: limitations related to data completeness, unequal access to testing and reporting, and long-term sustainability of testing strategies e.g. under-ascertainment from reduced access to testing, reporting delays from laboratory turnaround times.

Public health decision making:

Considerations in decision making: e.g. use of digitally supported surveillance evidence to inform responses; thresholds and trigger points for escalation and de-escalation; triangulation of multiple indicators; proportionality and resource prioritisation; sustainability considerations in decision making e.g. targeted approaches to minimise disruption while maintaining control, maintaining surge capacity

Digital surveillance: legal, ethical and data-governance considerations in the use of digital surveillance data, according to local jurisdiction e.g. privacy, anonymisation/pseudonymisation, data sharing and retention, public interest justification.

LO3 **Interpret infectious disease surveillance findings for an identified scenario to determine transmission risk and control priorities**

Scenario-based interpretation:

Interpretation: use of digital epidemiological outputs to interpret surveillance findings e.g. baseline, trend and seasonality concepts, interpretation of time-series outputs, epidemic curves and spatial distributions; stratification by person, place and time; identification of clusters and emerging risks; triangulation of surveillance streams to support scenario interpretation e.g. norovirus outbreak in a care home, measles cluster in a school, respiratory infection increase in a hospital ward, geographic mapping of incidence by local area.

Transmission risk assessment:

Risk assessment: transmission risk assessment using multiple indicators and data streams e.g. indicators of transmission intensity and health system impact, uncertainty arising from incomplete, biased or delayed data, reporting delay and missingness, small number effects

Interpretation of confidence and uncertainty in outputs: e.g. use of digital tools supporting risk assessment and communication; sustainability considerations when prioritising responses e.g. avoidance of intervention fatigue, maintenance of public compliance, minimisation of repeated high-cost measures while targeting the highest transmission risk.

Control prioritisation:

Control prioritisation: e.g. evidence-led prioritisation of control measures aligned to scenario constraints, balancing impact, feasibility, acceptability, equity and sustainability; prioritisation frameworks for settings and population groups

Justification of priorities: e.g. use of scenario-specific data and contextual constraints, role of digital communication tools in supporting prioritised responses e.g. targeted risk communication to high-risk groups, rapid dissemination of updated guidance to clinical and community stakeholders.

LO4 **Develop evidence-informed strategies for the prevention and control of infectious diseases in clinical and community settings**

Infection prevention and control principles:

Control measures: hierarchy of control measures e.g. elimination/substitution where applicable, engineering controls, administrative controls, personal protective equipment (PPE); standard and transmission-based precautions; non-pharmaceutical and pharmaceutical interventions; outbreak control principles and source control

Regulation: regulatory and organisational infection prevention and control (IPC) requirements, according to local jurisdiction; sustainability of IPC strategies e.g. long-term effectiveness, resource use, procurement resilience, environmental considerations such as waste streams and reusable options

Decision-support tools: role of digital guidance and decision-support tools in IPC practice e.g. locally implemented digital protocols, electronic prompts for isolation and PPE requirements.

Clinical and community strategies:

Community strategies: prevention and control strategies across settings e.g. setting-based control packages for healthcare, social care and community environments; statutory reporting, outbreak notification and local regulatory requirements; workforce capability and training; stakeholder coordination and escalation routes; international coordination; inclusive, accessible and culturally responsive public communication and community engagement approaches

Digital support: use of digital tools to support implementation e.g. electronic reporting systems, case investigation and contact management platforms, digital training resources

Adaptation: adapting prevention and control strategies for disrupted or resource-constrained contexts e.g. cholera, measles, tuberculosis, Ebola virus disease, conflict-affected settings, displaced populations, breakdowns in sanitation and healthcare access; alignment with sustainable public health practice e.g. scalable approaches that can be maintained during prolonged transmission periods.

Evaluation and adaptation of strategies:

Evaluation: monitoring and evaluation concepts e.g. process measures and outcome measures; use of surveillance data and digital monitoring tools to evaluate impact; performance indicators and audit approaches; identification of unintended consequences and equity impacts

Adaptations: e.g. justification of adaptations over time in response to changing epidemiological conditions; improvement cycles supporting sustainability, efficiency and equity e.g. adapting from population-wide measures to targeted interventions as risk changes, revising IPC approaches in response to a new variant or changing transmission setting.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the epidemiological principles underpinning the spread of infectious diseases</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate the use of epidemiological principles, surveillance data and testing data in determining transmission risk and control priorities within a defined scenario.</td></tr>
<tr><td>P1 Explain core epidemiological concepts used to describe infectious disease frequency and distribution.

P2 Explore transmission routes and population-level factors influencing infectious disease spread.</td><td>M1 Analyse the interaction between epidemiological principles and infectious disease spread.</td></tr>
<tr><td colspan="2">LO2 Examine the role of infectious disease surveillance and testing data in informing public health responses</td></tr>
<tr><td>P3 Examine infectious disease surveillance approaches and data quality characteristics.

P4 Explain the interpretation of testing data to inform public health responses.</td><td>M2 Assess the effectiveness of surveillance and testing data in informing public health decision making.</td></tr>
<tr><td colspan="2">LO3 Interpret infectious disease surveillance findings for an identified scenario to determine transmission risk and control priorities</td></tr>
<tr><td>P5 Interpret surveillance findings to identify transmission risk within an identified scenario.

P6 Determine control priorities based on interpreted surveillance evidence.</td><td>M3 Analyse the implications of surveillance findings for transmission risk and control priorities within the identified scenario.</td></tr>
<tr><td colspan="2">LO4 Develop evidence-informed strategies for the prevention and control of infectious diseases in clinical and community settings</td><td rowspan="2">LO4

D2 Critically evaluate the effectiveness of evidence-informed prevention and control strategies in responding to changing clinical and community contexts.</td></tr>
<tr><td>P7 Develop evidence-informed prevention and control strategies for clinical and community settings.

P8 Explain monitoring and adaptation of prevention and control strategies over time.</td><td>M4 Assess the effectiveness of developed prevention and control strategies for clinical and community settings.</td></tr>
</table>

Recommended Resources

Textbooks

Bearman, G., *et al.* (eds.) (2022) *Infection Prevention: New Perspectives and Controversies*. 2nd edn. Cham: Springer.

Brown, H.E. and Oren, E. (2023) *Infectious Disease Epidemiology: An Introduction*. New York: Springer Publishing Company.

Gordis, L. (2023) *Epidemiology*. 7th edn. Philadelphia: Elsevier.

Lee, L.M., Teutsch, S.M. and Thacker, S.B. (eds.) (2010) *Principles and Practice of Public Health Surveillance*. 3rd edn. Oxford: Oxford University Press.

Nelson, K.E. and Williams, C.M. (eds.) (2020) *Infectious Disease Epidemiology: Theory and Practice*. 3rd edn. Burlington, MA: Jones & Bartlett Learning.

Purssell, E. and Gould, D. (2023) *Infection Prevention and Control in Healthcare Settings*. Hoboken, NJ: Wiley-Blackwell.

Webb, P., Bain, C. and Page, A. (2020) *Essential Epidemiology: An Introduction for Students and Health Professionals*. 4th edn. Cambridge: Cambridge University Press.

Websites

https://www.cdc.gov/	Centers for Disease Control and Prevention Information on diseases and conditions (General reference)
https://www.ecdc.europa.eu	European Centre for Disease Prevention and Control Surveillance and epidemic intelligence resources (Research)
https://www.who.int/emergencies/surveillance	World Health Organization Surveillance in public health emergencies (General reference)
https://www.gov.uk/government/organisations/uk-health-security-agency	UK Health Security Agency Infectious disease surveillance and control guidance (General reference)

https://www.apic.org	Association for Professionals in Infection Control and Epidemiology Infection prevention and control guidance (Training)
https://www.idsociety.org	Infectious Diseases Society of America Infection prevention, control and stewardship resources (General reference)
https://www.healthknowledge.org.uk	Health Knowledge Public health epidemiology and surveillance textbook (General reference)

Journals and articles

Coia, J.E., *et al.* (2021) 'Joint Healthcare Infection Society (HIS) and Infection Prevention Society (IPS) Guidelines for the prevention and control of methicillin-resistant *Staphylococcus aureus* (MRSA) in healthcare facilities', *Journal of Hospital Infection*, 118, pp. S1–S39. Available at: https://doi.org/10.1016/j.jhin.2006.01.001

Lee, P.S., *et al.* (2024) 'Greening Infection Prevention and Control: Multifaceted Approaches to a Sustainable Future', *Open Forum Infectious Diseases*, 12(2), ofae371. Available at: https://doi.org/10.1093/ofid/ofae371.

McClymont, H., *et al.* (2024) 'Internet-based surveillance systems and infectious disease prediction', *Journal of Epidemiology and Global Health*, 14, pp. 645-657. Available at: https://doi.org/10.1007/s44197-024-00272-y.

McGowan, C.R., *et al.* (2022) 'Community-based surveillance of infectious diseases: A systematic review of drivers of success', *BMJ Global Health*, 7(8), e009934. Available at: https://doi.org/10.1136/bmjgh-2022-009934.

Nickbakhsh, S., *et al.* (2020) 'Epidemiology of seasonal coronaviruses', *Journal of Infectious Diseases*, 222(1), pp. 17–25. Available at: https://doi.org/10.1093/infdis/jiaa185.

Saravanos, G.L., *et al.* (2024) 'Infection prevention and control programme priorities for sustainable health systems', *BMC Global and Public Health*, 2, 6. Available at: https://doi.org/10.1186/s44263-023-00031-4.

Tomczyk, S., *et al.* (2021) 'Infection prevention and control (IPC) implementation in low-resource settings', *Antimicrobial Resistance and Infection Control*, 10, 113. Available at: https://doi.org/10.1186/s13756-021-00962-3.

Olu-Abiodun, O., *et al.* (2025) 'Effectiveness and challenges of digital tools implementation for enhancing infectious disease surveillance data quality in low- and middle-income countries: A systematic review protocol', *PLOS ONE*, 20(8), e0330904. Available at: https://doi.org/10.1371/journal.pone.0330904.

Links

This unit links to the following related units:

Unit 501: Personal and Professional Development for Scientists

Unit 502: Applied Sciences Research Project (Pearson-set)

Unit 506: Medical Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 524: Immunology.

Unit 522: Histology and Haematology

Unit code: **A/652/3083**

Unit level: **5**

Credit value: **15**

Introduction

Histology and haematology underpin many areas of applied biological and biomedical science, providing essential insight into the structure and organisation of human tissues and the formation and function of blood. This unit sits within the Applied Sciences suite at Level 5 and supports students progressing towards laboratory, biomedical, healthcare science and related technical roles. It builds on foundational biological knowledge developed at Level 4 and focuses on developing a deeper understanding of how microscopic structure relates to normal physiological function.

The purpose of this unit is to develop students' understanding of tissue organisation, histological methods and blood cell biology, and to enable them to interpret microscopic information in a scientifically informed manner. Through the study of histology and haematology, students gain insight into how tissues and blood components are prepared, examined and interpreted within laboratory and investigative contexts. The unit also develops students' ability to communicate scientific findings clearly and appropriately to different audiences.

The unit covers the structural organisation and architecture of the major human tissue types, alongside the principles and techniques used in histological preparation and microscopic analysis. Students will explore the processes of haematopoiesis and the functional roles of red blood cells, white blood cells and platelets, linking structure and formation to function. The unit also introduces common histological and haematological disorders, focusing on their key diagnostic features and how investigative findings are presented rather than on clinical diagnosis or treatment.

On completion of this unit, students will be able to explain tissue structure and blood cell formation, describe the application of histological techniques and quality considerations, and present investigative findings using appropriate scientific language. The knowledge and skills developed support progression to higher-level study in biomedical science, pathology-related subjects, laboratory research or applied health sciences, as well as employment in laboratory-based and technical roles where microscopic analysis and scientific communication are required.

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Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the structural features and architectural organisation of human tissues

LO2 Explore the principles of haematopoiesis and the functional roles of blood components

LO3 Describe, using either real-world case studies or laboratory-based practice, the histological techniques used in tissue preparation and microscopic analysis

LO4 Present an investigation into the common histological and haematological disorders and their diagnostic features to an intended audience.

Essential Content

LO1 **Explain the structural features and architectural organisation of human tissues**

Structural organisation and major tissue types:

Hierarchical organisation: organisation from cells to tissues to organs e.g. cellular specialisation, tissue compartments, basement membranes, tissue boundaries, polarity, cellularity, extracellular matrix (ECM)

Architectural organisation: organisation of epithelial, connective, muscle, nervous tissues; cellular arrangement, matrix composition, layering, fibre orientation, vascularity, innervation; tissue architecture e.g. tissue orientation; planes of section, effect of sectioning on observed tissue appearance e.g. transverse and longitudinal sections of skeletal muscle, layered organisation of the gastrointestinal tract.

Structure-function relationships in human tissues:

Integrated relationships: relationship between tissue structure and physiological function e.g. surface area, diffusion distance, permeability, mechanical strength, contractility, conductivity, secretion, absorption

Effects of tissue architecture: functional capacity, adaptation to physiological demand e.g. alveolar epithelium in gas exchange, villi in absorption, intercalated discs in cardiac muscle contraction, dense connective tissue in tensile support.

Comparative tissue analysis:

Comparative analysis of major tissue types: e.g. definition of features, architectural organisation, functional specialisation, structural variation, adaptation

Interpretation of features: interpretation of histological features in relation to tissue identity, organisation and function e.g. stratified squamous epithelium compared with simple columnar epithelium, loose connective tissue compared with dense connective tissue.

LO2 **Explore the principles of haematopoiesis and the functional roles of blood components**

Principles of haematopoiesis:

Organisation: hierarchical organisation of haematopoiesis across embryonic, foetal, adult stages: haematopoietic stem cells, progenitor populations, lineage commitment, differentiation, maturation, self-renewal

Pathways and signalling: myeloid and lymphoid pathways, bone marrow microenvironment, stromal support, cytokine-mediated signalling e.g. erythropoiesis and reticulocyte maturation, granulopoiesis, lymphocyte development.

Blood components and functional roles:

Blood components: erythrocytes, leukocytes, platelets, plasma e.g. structural characteristics, physiological roles, morphology, lifespan, production rates.

Functional specialisation: e.g. contribution to homeostasis, biological variation across populations and life stages

Structure-function relationships: oxygen transport, carbon dioxide transport, immune surveillance, inflammatory response, haemostasis e.g. biconcave erythrocytes in gas exchange, neutrophils in phagocytosis, lymphocytes in adaptive immunity, platelets in primary haemostasis.

Regulation of haematopoiesis and blood cell production:

Regulatory control of blood cell production: e.g. growth factors, cytokines, transcriptional control, feedback mechanisms, physiological demand

Coordination: coordination between haematopoiesis and systemic homeostasis e.g. erythropoietin response to hypoxia, thrombopoietin regulation of platelet production, increased leukocyte production during infection, altered blood cell production in deficiency states.

LO3 **Describe, using either real-world case studies or laboratory-based practice, the histological techniques used in tissue preparation and microscopic analysis**

Principles of microscopy:

Core microscopy principles for tissue examination: light microscopy, digital microscopy, virtual microscopy in histological analysis e.g. magnification, resolution, contrast, field of view, depth of field, illumination, image quality, optical limitations, calibration, scale, image resolution

Comparative observation across magnifications: e.g. adjusting illumination to improve contrast, recognising the effect of magnification on field of view, using virtual slides to examine tissue architecture at different scales.

Preparation of tissue samples:

Histological preparation stages: fixation, processing, embedding, sectioning, staining, mounting; preservation of tissue architecture, macromolecules, cellular morphology, antigenicity, structural relationships for microscopic examination

Influence of preparation variables: influence on tissue integrity, contrast, interpretability e.g. fixation to reduce degradation, staining to improve contrast between nuclei and cytoplasm.

Microscopic analysis and application of techniques:

Application of techniques: e.g. application of histological techniques to prepared slides, photomicrographs, digital slides, virtual slides; case-study evidence and secondary data; differential staining; benefits, limitations, reliability of techniques

Selection of preparation methods: e.g. staining methods for tissue type, investigative purpose, diagnostic context; tissue components, macromolecular targets, correlation between technique choice and observable features e.g. H&E staining for general tissue structure, stains used to show collagen or nuclear detail.

Quality and reliability of microscopic observations:

Quality, reliability of microscopic observations: e.g. artefacts, technical limitations, quality control, specimen quality, sampling limitations, observer variation, reproducibility, validity, diagnostic confidence

Standardisation of preparation and observation: calibration, scale, staining consistency, section thickness, image resolution, documentation of limitations; effect of preparation, technique selection on interpretation and evidence quality e.g. folds, tearing, poor fixation, uneven staining, air bubbles, contamination, section thickness obscuring tissue detail, digital image resolution affecting feature recognition.

LO4 **Present an investigation into the common histological and haematological disorders and their diagnostic features to an intended audience**

Common histological and haematological disorders:

Selection of common disorders affecting tissues, blood components: inflammatory conditions, fibrotic change, anaemia, leukaemia, histological changes commonly associated with malignancy; scope limited to diagnostic features, investigative findings rather than clinical diagnosis or treatment

Relationships: relationship between disorder type, affected tissue or blood component; expected morphological change; investigative context e.g. inflammatory cell infiltration, fibrosis, abnormal red blood cell morphology, altered white blood cell populations, loss of normal tissue structure, increased nuclear atypia and abnormal mitotic activity associated with cancerous change.

Diagnostic features and investigative evidence:

Diagnostic features: microscopic, cellular, morphological features used in investigation of common histological, haematological disorders e.g. cell injury, cellular adaptation, cell death, changes in tissue architecture, blood cell appearance

Evidence: recognition of diagnostic features through descriptive morphology, comparison with normal findings, correlation of abnormal features with investigative evidence e.g. inflammatory change, fibrosis, necrosis, apoptosis, abnormal red blood cell morphology, altered white blood cell populations, changes commonly associated with malignancy, consideration of biological variation, reference ranges

Context: demographic context and limitations of diagnostic interpretation e.g. pleomorphism, increased nuclear to cytoplasmic ratio, hyperchromasia, loss of normal tissue organisation and abnormal mitotic activity

Haematological investigative evidence: blood cell counts, blood films, haemoglobin measures, coagulation screening, platelet function, correlation with morphology and reference ranges e.g. full and differential blood count, reticulocyte count, blood film, haemoglobin concentration, haemoglobin variants or abnormal haemoglobin findings, coagulation factors, platelet aggregation, activated partial thromboplastin time, fibrinogen

Interpretation of investigative evidence: e.g. artefact, specimen quality, sampling limitations, differential features, distinction between pathological change and preparation-related distortion.

Professional communication of investigations:

Communication: audience, purpose; scientific language, conventions; structure, visuals, annotation; traceability of evidence sources; clarity, accuracy, justification of findings; inclusive, accessible communication; avoidance of assumptions, bias and stigmatising language

Professional standards in evidence handling and reporting: e.g. specimen traceability, sample integrity, documentation, audit trail, confidentiality, ethical handling of human tissue and blood samples

Presentation of evidence: selection, organisation, explanation of diagnostic evidence for intended audience; evaluation of communication effectiveness e.g. technical poster using labelled micrographs and feature descriptors for peers; short report for a supervisor summarising key findings and limitations; presentation adapted for a non-specialist audience using simplified terminology and clear visuals.

Learning Outcomes and Assessment Criteria

Pass	Merit	Distinction
LO1 Explain the structural features and architectural organisation of human tissues		**LO1, LO2 and LO3** **D1** Critically evaluate the influence of tissue structure, haematopoietic processes and histological technique selection on the interpretation of microscopic evidence.
P1 Explain the structural organisation, defining features and architectural characteristics of major human tissue types. **P2** Explore the relationship between tissue architecture and physiological function.	**M1** Analyse the relationship between tissue architecture and specialised function in major human tissue types.	
LO2 Explore the principles of haematopoiesis and the functional roles of blood components		
P3 Explore the principles, stages and regulation of haematopoiesis in relation to blood cell development. **P4** Explain the structural characteristics and functional roles of blood components.	**M2** Analyse haematopoietic development and regulation in relation to the functional roles of blood components.	
LO3 Describe, using either real-world case studies or laboratory-based practice, the histological techniques used in tissue preparation and microscopic analysis		
P5 Describe the application of histological techniques in the preparation of tissue samples for microscopic examination. **P6** Examine microscopic observations in relation to quality factors and limitations.	**M3** Assess the effectiveness of histological techniques in producing reliable microscopic observations.	

Pass	Merit	Distinction
LO4 Present an investigation into the common histological and haematological disorders and their diagnostic features to an intended audience		**LO4**
P7 Investigate histological and haematological techniques used to identify diagnostic features of selected disorders. **P8** Present findings from an investigation into histological and haematological diagnostic features to an identified audience to obtain feedback.	**M4** Analyse diagnostic evidence from complementary histological and haematological techniques, using audience feedback.	**D2** Justify conclusions from diagnostic evidence with reference to investigative limitations and audience feedback.

Recommended Resources

Textbooks

Bain, B.J., Bates, I. and Laffan, M.A. (2017) *Dacie and Lewis Practical Haematology*. 12th edn. London: Elsevier.

Gartner, L.P. (2020) *Textbook of Histology*. 5th edn. Philadelphia: Elsevier.

Hoffman, R., *et al.* (2022) *Hematology: Basic Principles and Practice*. 8th edn. Philadelphia: Elsevier.

Howard, M.R. and Owen, M. (2026) *Haematology: An Illustrated Colour Text*. 5th edn. London: Elsevier.

McKenzie, S.B., Williams, L. and Landis-Piwowar, K. (2022) *Clinical Laboratory Hematology*. 4th edn. Harlow: Pearson.

Ross, M.H. and Pawlina, W. (2020) *Histology: A Text and Atlas: With Correlated Cell and Molecular Biology*. 8th edn. Philadelphia: Wolters Kluwer.

Young, B., O'Dowd, G. and Woodford, P. (2023) *Wheater's Functional Histology: A Text and Colour Atlas*. 7th edn. London: Elsevier.

Websites

https://histologyguide.com/slidebox/slidebox.html	Histology Guide – virtual slide box Human tissues, peripheral blood and haematopoiesis (Virtual microscopy)
https://histology.leeds.ac.uk/	University of Leeds – The Histology Guide Basic tissue types, organs, blood and quizzes (Teaching resource)
https://www.leicabiosystems.com/knowledge-pathway/sample-preparation/page-0/	Leica Biosystems – Sample Preparation Knowledge Pathway Fixation, embedding, sectioning and good histology practice (Technical guidance)
https://www.learnhaem.com/	LearnHaem Blood films, bone marrow, haemoglobinopathy and coagulation cases (Teaching resource)

https://www.gloshospitals.nhs.uk/our-services/services-we-offer/pathology/haematology/haematology-reference-ranges/	Gloucestershire Hospitals NHS Foundation Trust – Haematology reference ranges Full blood count, differential count, reticulocytes, coagulation and haematinics (Reference ranges)
https://www.blood-academy.com/students/	Blood Academy – Haematology resources for students Blood count, blood film, morphology, haemostasis and laboratory quality assurance (Student resource)

Journals and articles

Bai, B., *et al.* (2023) 'Deep learning-enabled virtual histological staining of biological samples', *Light: Science & Applications*, 12, 57. Available at: https://www.nature.com/articles/s41377-023-01104-7

Belyavsky, A., Petinati, N. and Drize, N. (2021) 'Hematopoiesis during Ontogenesis, Adult Life, and Aging', *International Journal of Molecular Sciences*, 22(17), 9231. Available at: https://doi.org/10.3390/ijms22179231

Elsaid, R., *et al.* (2020) 'Hematopoiesis: A Layered Organization Across Chordate Species', *Frontiers in Cell and Developmental Biology*, 8, 606642. Available at: https://doi.org/10.3389/fcell.2020.606642

Francis, D.V., *et al.* (2022) 'Virtual microscopy as a teaching-learning tool for histology', *Medical Journal Armed Forces India*. Available at: https://doi.org/10.1016/j.mjafi.2021.07.008

Hanna, M.G., *et al.* (2022) 'Integrating digital pathology into clinical practice', *Modern Pathology*, 35(2), pp. 152–164. Available at: https://www.modernpathology.org/article/S0893-3952(22)00326-X/fulltext

Javaeed, A., *et al.* (2021) 'Histological Stains in the Past, Present, and Future', *Cureus*, 13(10), e18486. Available at: https://doi.org/10.7759/cureus.18486

Liggett, L.A. and Sankaran, V.G. (2020) 'Unraveling hematopoiesis through the lens of genomics', *Cell*, 182(6), pp. 1384–1400. Available at: https://doi.org/10.1016/j.cell.2020.08.022

Poeschla, M. and Sankaran, V.G. (2026) 'Genetic influences on haematopoiesis', *Nature Reviews Genetics*. Available at: https://www.nature.com/articles/s41576-026-00947-1

Links

This unit links to the following related units:

Unit 401: Fundamentals of Biological Laboratory Protocols and Techniques

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 408: Human Anatomy and Physiology

Unit 501: Personal and Professional Development for Scientists

Unit 527: Clinical Chemistry.

Unit 523: Principles of Pharmacology

Unit code: D/652/3084

Unit level: 5

Credit value: 15

Introduction

Pharmacology underpins the safe and effective use of medicines across a wide range of applied science, healthcare, biomedical and pharmaceutical contexts. Professionals working in laboratory, clinical, industrial and regulatory settings require a sound understanding of how drugs interact with biological systems, how they are processed by the body, and how their use is governed to protect patient safety and public health. This unit situates pharmacology within applied scientific practice, providing students with a foundation that is relevant to roles in biomedical science, biotechnology, pharmaceutical development, diagnostics, forensic science and related sectors where pharmacological knowledge informs decision making.

The unit places emphasis on professional and responsible practice in pharmacology, recognising the importance of safety, regulation and ethical considerations in the development and application of medicines. Students will consider how pharmacological principles are applied within regulated environments and how risks associated with drug use are identified, managed and communicated. The role of regulatory frameworks, quality systems and pharmacovigilance in supporting safe medicine use is explored alongside expectations for professional judgement, accurate communication and appropriate use of digital information sources in contemporary scientific settings.

Key scientific principles relating to pharmacodynamics and pharmacokinetics are explored to enable students to understand how drugs produce their effects and how these effects vary between individuals and contexts. The unit also examines mechanisms of drug action at molecular, cellular and systemic levels, supporting students in making connections between drug behaviour, biological response and therapeutic outcomes. These principles are applied through consideration of drug safety, toxicity and interactions, allowing students to develop a coherent understanding of how pharmacological knowledge informs therapeutic use without extending into prescribing or clinical decision making beyond the scope of the unit.

On completion of this unit, students will be able to apply pharmacological principles to the investigation and communication of therapeutic applications in a manner appropriate to different audiences and professional contexts. They will be equipped to interpret pharmacological information, consider safety and regulatory implications, and present reasoned, evidence-informed explanations of drug use. The knowledge

and skills developed support progression to further study in applied or biomedical sciences, pharmaceutical and biotechnology pathways, or employment in laboratory, regulatory, quality or scientific support roles where an understanding of pharmacology is essential.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental principles of pharmacodynamics and pharmacokinetics

LO2 Discuss the mechanisms of drug action at molecular, cellular and systemic levels

LO3 Explore drug safety, toxicity and regulatory frameworks within the pharmaceutical industry

LO4 Present an investigation into the applications of pharmacology for therapeutic use to an intended audience.

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Essential Content

LO1 **Explain the fundamental principles of pharmacodynamics and pharmacokinetics**

Pharmacodynamics: drug–target interactions and response:

Pharmacodynamics (PD): receptor theory e.g. ligand binding, affinity, efficacy and intrinsic activity, agonists, partial agonists, antagonists, inverse agonists and allosteric modulators

Dose-response relationships and curve interpretation: potency and efficacy e.g. EC_{50}, ED_{50}, *E*max, threshold and ceiling effect; therapeutic index, therapeutic window and margin of safety; receptor reserve, desensitisation, tolerance and tachyphylaxis; variability in response e.g. receptor density, pharmacogenomic variation, disease state, concurrent medicines.

Pharmacokinetics: ADME and concentration-time behaviour:

Pharmacokinetics (PK): absorption, distribution, metabolism and excretion (ADME); bioavailability and bioequivalence; plasma concentration–time profiles e.g. C_{max}, T_{max} and area under the curve (AUC)

Concentration–time behaviour: half-life, clearance and volume of distribution; first-pass metabolism; protein binding and tissue distribution; phase I and phase II metabolism; enzyme induction and inhibition e.g. cytochrome P450 interactions; renal and biliary excretion; first-order and zero-order kinetics; steady state and accumulation

Routes of administration and implications for onset and duration: e.g. oral, intravenous, inhaled; factors influencing ADME e.g. age, hepatic and renal impairment, formulation, transporter effects; links between concentration-time and effect, including basic PK/PD relationships and sources of variability.

LO2 **Discuss the mechanisms of drug action at molecular, cellular and systemic levels**

Molecular and cellular mechanisms of action:

Drug targets and molecular selectivity: structure-activity relationships at principle level; receptor classes and signalling e.g. ion channels, G-protein coupled receptors (GPCRs), receptor tyrosine kinases, intracellular/nuclear receptors; enzyme inhibition and activation; transporter modulation e.g. reuptake inhibition, efflux pumps

Signal transduction pathways and downstream effects: second messenger systems e.g. cAMP, IP3, calcium ions; phosphorylation cascades and gene transcription effects; amplification, feedback and pathway cross-talk; receptor desensitisation, internalisation, down-regulation and up-regulation; mechanistic basis of adverse effects e.g. off-target binding, unintended receptor activation.

Systemic physiological effects and response patterns:

Physiological effects: translation of molecular and cellular effects to tissue, organ and system responses; relationship between target engagement, pathway modulation and physiological outcome; therapeutic effects versus side effects; on-target versus off-target effects; compensatory mechanisms and homeostatic adaptation e.g. receptor up-regulation, feedback inhibition, counter-regulatory hormone release

Dose-dependent and time-dependent systemic outcomes: tolerance, sensitisation and rebound effects; inter-individual variability in systemic response e.g. pharmacogenomic variation, co-morbidities, age-related physiological change, concurrent medicines; population diversity considerations in interpreting drug response; mechanism-effect links across body systems e.g. beta-blockade, bronchodilation, opioid receptor activation, insulin receptor activation.

LO3 **Explore drug safety, toxicity and regulatory frameworks within the pharmaceutical industry**

Drug safety and toxicity principles:

Hazard, risk and exposure concepts: dose-response relationships in toxicity; safety margins; no observed adverse effect level (NOAEL) and lowest observed adverse effect level (LOAEL) at overview level; acute, sub-acute and chronic toxicity; organ-specific toxicity e.g. hepatotoxicity, nephrotoxicity, cardiotoxicity, neurotoxicity

Toxicity principles: toxicodynamics versus toxicokinetics; idiosyncratic toxicity and hypersensitivity reactions; genotoxicity, mutagenicity, carcinogenicity and teratogenicity concepts; therapeutic index as a safety concept; exposure limits and risk thresholds; factors increasing risk e.g. polypharmacy, impaired clearance, narrow therapeutic index medicines, pregnancy, pharmacogenomic variation.

Adverse drug reactions and risk management:

Adverse drug reactions (type A and type B): e.g. predictable versus unpredictable reactions; side effects, contraindications and precautions; seriousness, severity and causality assessment at overview level

Safety signal detection and validation: therapeutic drug monitoring concepts; interactions (drug–drug, drug–food, drug–disease) and safety implications; medication error concepts and safety culture; risk minimisation measures e.g. labelling, patient information, controlled access medicines, additional monitoring; benefit-risk assessment and uncertainty in safety decisions; use of digital systems supporting safety surveillance e.g. electronic reporting, pharmacovigilance databases, electronic health records.

Regulatory and compliance frameworks in medicines:

Regulatory lifecycle concepts: discovery, preclinical evidence, clinical trial phases, marketing authorisation, post-marketing surveillance and lifecycle variation; roles of national, regional and global regulatory bodies e.g. Medicines and Healthcare products Regulatory Agency (MHRA), European Medicines Agency (EMA), Food and Drug Administration (FDA), World Health Organization (WHO); international harmonisation and standards at overview level e.g. International Council for Harmonisation (ICH), good laboratory practice (GLP), good clinical practice (GCP), good manufacturing practice (GMP), good pharmacovigilance practice (GVP)

Compliance frameworks: global pharmacovigilance and medicine safety systems e.g. adverse event reporting networks, signal detection, counterfeit and substandard medicines surveillance; quality systems and quality risk management; documentation, traceability and auditability

Data integrity: data integrity principles; pharmacovigilance and reporting obligations; ethical and legal considerations for safety monitoring e.g. informed consent, confidentiality, patient safety, data governance; inclusion and population diversity considerations in safety evidence; sustainability considerations linked to safe medicine use and waste reduction.

LO4 **Present an investigation into the applications of pharmacology for therapeutic use to an intended audience**

Therapeutic applications and clinical considerations:

Therapeutic purpose and intended outcomes: linking mechanism of action, pharmacokinetics and pharmacodynamics (PK/PD) to therapeutic effectiveness; dosing strategy concepts at principle level e.g. onset, duration, steady state

Clinical considerations: treatment individualisation factors e.g. age, co-morbidities, renal and hepatic function; benefit-risk reasoning aligned to therapeutic index and safety margins; application contexts across biomedical, biotechnology, forensic and toxicology pathways.

Interactions, variability and decision–support considerations:

Drug interaction mechanisms and implications for therapeutic use: adherence and formulation considerations; pharmacogenomic influences on response at overview level

Decision-support considerations: interpretation of evidence sources used in an investigation e.g. summaries of product characteristics, clinical guidelines, pharmacovigilance updates; appropriate use of digital decision-support tools to inform interpretation and communication at principle level.

Professional communication and audience adaptation:

Audience adaptation: audience purpose and needs analysis; inclusive and accessible communication e.g. health literacy, language clarity, cultural context, accessibility needs; clarity, accuracy and appropriate scientific language; ethical communication of uncertainty and limitations

Communication: appropriate use of visual or quantitative representations e.g. concentration-time curves, dose-response curves; structure and coherence in presenting an investigation; professional standards for referencing and data presentation; responsible practice messaging where relevant to therapeutic application.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental principles of pharmacodynamics and pharmacokinetics</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate how pharmacokinetic and pharmacodynamic principles interact with mechanisms of drug action to influence therapeutic response.</td></tr>
<tr><td>P1 Explain core pharmacodynamic principles influencing drug–target interaction and response.

P2 Explore pharmacokinetic processes influencing drug exposure over time.</td><td>M1 Analyse how pharmacokinetic parameters and pharmacodynamic relationships influence drug concentration, therapeutic response and variability between individuals.</td></tr>
<tr><td colspan="2">LO2 Discuss the mechanisms of drug action at molecular, cellular and systemic levels</td></tr>
<tr><td>P3 Discuss molecular and cellular mechanisms of drug action.

P4 Explain how drug mechanisms produce systemic physiological effects.</td><td>M2 Analyse how molecular and cellular mechanisms of drug action influence systemic physiological response.</td></tr>
<tr><td colspan="2">LO3 Explore drug safety, toxicity and regulatory frameworks within the pharmaceutical industry</td></tr>
<tr><td>P5 Explain principles of drug safety and toxicity.

P6 Explore regulatory frameworks governing the approval and safe use of medicines.</td><td>M3 Assess safety, toxicity and regulatory considerations that support responsible pharmacological practice.</td><td rowspan="4">LO3 and LO4

D2 Justify conclusions from pharmacological evidence with reference to safety, toxicity and regulatory considerations.</td></tr>
<tr><td colspan="2">LO4 Present an investigation into the applications of pharmacology for therapeutic use to an intended audience</td></tr>
<tr><td>P7 Investigate pharmacological principles used to explain therapeutic applications of selected medicines.

P8 Present findings from an investigation into pharmacological applications for therapeutic use to an intended audience.</td><td>M4 Compare pharmacological evidence from complementary sources to explain therapeutic applications of selected medicines.</td></tr>
</table>

Recommended Resources

Textbooks

Brunton, L.L., Hilal-Dandan, R. and Knollmann, B.C. (2023) *Goodman & Gilman's The Pharmacological Basis of Therapeutics*. 14th edn. New York: McGraw-Hill.

Golan, D.E., Armstrong, E.J. and Armstrong, A.W. (2026) *Principles of Pharmacology: The Pathophysiologic Basis of Drug Therapy*. 5th edn. Philadelphia: Wolters Kluwer.

Hill, R.G. and Richards, D. (2022) *Drug Discovery and Development: Technology in Transition*. 3rd edn. London: Elsevier.

Katzung, B.G. and Trevor, A.J. (2021) *Basic and Clinical Pharmacology*. 15th edn. New York: McGraw-Hill.

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Ritter, J.M., *et al.* (2008) *A Textbook of Clinical Pharmacology and Therapeutics*. 5th edn. London: CRC Press.

Tozer, T.N. and Rowland, M. (2006) *Introduction to Pharmacokinetics and Pharmacodynamics*. Philadelphia: Wolters Kluwer.

Winter, M.E. (2018) *Basic Clinical Pharmacokinetics*. 6th edn. Philadelphia: Wolters Kluwer.

Websites

https://www.gov.uk/government/publications/guidance-on-pharmacovigilance-procedures/guidance-on-pharmacovigilance-procedures	Medicines and Healthcare products Regulatory Agency (MHRA) Guidance on pharmacovigilance procedures and adverse drug reaction reporting (Regulatory guidance)
https://www.ema.europa.eu/en/human-regulatory-overview/pharmacovigilance-overview	European Medicines Agency Overview of pharmacovigilance systems and post-marketing safety monitoring (Regulatory guidance)
https://www.fda.gov/drugs/development-approval-process-drugs	U.S. Food and Drug Administration Drug development, approval and post-marketing safety processes (Regulatory guidance)

BNF (British National Formulary) | NICE	British National Formulary Drug interaction checking and safety information (General reference)
https://www.medicines.org.uk/emc/about-the-emc	Electronic Medicines Compendium (emc) Summaries of Product Characteristics and licensed medicines information (General reference)
https://who-umc.org/about-uppsala-monitoring-centre/	Uppsala Monitoring Centre (WHO Collaborating Centre) Global pharmacovigilance systems and safety signal detection (General reference)
https://www.vigiaccess.org/	World Health Organization Public access to global adverse drug reaction data (VigiBase summaries) (Datasets)

Journals and articles

Aronson, J.K. and Ferner, R.E. (2003) 'Joining the DoTS: new approach to classifying adverse drug reactions', *BMJ*, 327, p. 1222. Available at: https://doi.org/10.1136/bmj.327.7425.1222.

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Pirmohamed, M. (2023) 'Pharmacogenomics: current status and future perspectives', *Nature Reviews Genetics*, 24(6), pp. 350–362. Available at: https://doi.org/10.1038/s41576-022-00572-8.

Stielow, M., *et al.* (2023) 'The Bioavailability of Drugs – The Current State of Knowledge', *Molecules*, 28(24), 8038. Available at: https://doi.org/10.3390/molecules28248038.

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Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 412: Organic Chemistry

Unit 414: Introduction to Chemistry

Unit 521: Infectious Disease Epidemiology and Control

Unit 522: Histology and Haematology

Unit 524: Immunology

Unit 527: Clinical Chemistry.

Unit 524: Immunology

Unit code: **F/652/3085**

Unit level: **5**

Credit value: **15**

Introduction

Immunology plays a central role across applied science disciplines, particularly in biomedical, clinical, pharmaceutical and research-focused laboratory settings. Understanding how the immune system is organised and regulated is essential for work in health-related sciences, biotechnology, diagnostics and research environments. This unit introduces the immune system as an integrated network of cells, tissues, receptors and signalling processes that protect the body from biological threats and support physiological balance.

Students explore the functional organisation of innate and adaptive immunity, including the roles of major immune cells, lymphoid organs and immune communication. The unit considers how immune components recognise non-self material, initiate activation and coordinate controlled responses. Emphasis is placed on regulation and control, including how immune activation is amplified, limited and resolved to support effective defence while reducing the risk of inappropriate or excessive responses.

The unit also develops understanding of pathogen recognition, antigen processing and presentation, immune signalling, humoral immunity and cellular immune responses. Students examine how antibodies, lymphocytes and effector mechanisms contribute to immune control, and how immune memory supports faster and more effective secondary responses. These concepts are explored at a systems level, supporting analytical understanding of immune function across different immunological contexts rather than a diagnostic or treatment-led focus.

On completion of the unit, students will be able to apply immunological principles to the investigation of immune disorders and associated clinical conditions, interpret appropriate evidence and communicate findings for a defined audience. The unit supports progression to further study in biomedical science, immunology, biotechnology, clinical science, pharmaceutical science or related applied science disciplines. It is also relevant to employment or progression in biomedical, diagnostic, laboratory research, clinical research coordination, medical science liaison and research and development roles, where understanding immune mechanisms and evidence-based scientific communication is important.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the organisation and functional roles of the human immune system

LO2 Discuss the mechanisms of pathogen recognition and immune activation

LO3 Describe the humoral and cellular immune responses involved in immune control

LO4 Present an investigation into immune disorders and associated clinical conditions for an intended audience.

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Essential Content

LO1 **Explain the organisation and functional roles of the human immune system**

Functional organisation of the immune system:

Innate and adaptive immunity as integrated systems: barriers and internal defence; immune components by function e.g. recognition, signalling, effector, regulation

Primary and secondary lymphoid organisation by function: lymphoid tissues and organs as sites of immune development, activation and coordination e.g. bone marrow and thymus for immune cell development; lymph nodes and spleen for antigen encounter and activation

Major immune cell types and functional roles: leukocyte categories and interactions e.g. phagocytes for early clearance; lymphocytes for specificity and memory.

Coordination of innate and adaptive defence:

Communication and coordination between immune components: e.g. cellular cooperation in immune defence, regulation of immune activation and resolution

Functional relationships across cells and compartments: recruitment and trafficking; local and systemic immune responses e.g. tissue-resident immune surveillance versus circulating responses

Immune homeostasis: tolerance and controlled activation; consequences of dysregulation e.g. inappropriate activation leading to tissue damage; failure of tolerance leading to self-reactivity.

LO2 **Discuss the mechanisms of pathogen recognition and immune activation**

Recognition of non-self and initiation of activation:

Pathogen recognition principles: pattern recognition and innate response initiation; receptor–ligand interactions underpinning detection e.g. pattern recognition receptors (PRRs) recognising pathogen-associated molecular patterns (PAMPs) such as lipopolysaccharide (LPS) or viral RNA

Antigen recognition: antigen specificity and recognition pathways e.g. innate recognition compared with adaptive antigen recognition

Antigen processing and presentation: e.g. as a bridge between innate and adaptive responses; antigen-presenting cells (APC) roles and functional consequences of presentation e.g. dendritic cells presenting antigen to initiate T-cell activation.

Immune activation signalling and regulation:

Core activation signalling: cellular signalling pathways linked to immune activation; effector instruction and amplification e.g. cytokine-mediated communication supporting activation and differentiation

Signal integration and immune response regulation: receptor signalling, cytokine networks and co-stimulatory signals in activation strength, differentiation and effector function e.g. PRR and cytokine signalling shaping inflammatory and adaptive responses

Co-stimulation and checkpoints as activation regulators: activation thresholds; response magnitude and duration e.g. co-stimulatory requirements for full lymphocyte activation

Constraints, uncertainty and limitations in immune activation: context- and host-dependent variation e.g. altered activation in immunocompromised states; immune evasion as a constraint on effective activation.

LO3 **Describe the humoral and cellular immune responses involved in immune control**

Humoral and cellular effector responses:

Humoral immunity components: B-cell activation; antibody structure-function relationships; antibody effector functions e.g. neutralisation; opsonisation

B-cell selection, clonal expansion and antibody diversification: e.g. class switching, affinity maturation, plasma cells and memory B-cells; specificity, strength and duration of humoral responses

Cell-mediated immunity components: T-cell functional roles and subsets; cytotoxic mechanisms; helper functions and immune regulation e.g. cytotoxic T-cell killing of infected cells; helper T-cell support for B-cell responses

T-cell activation and differentiation: e.g. major histocompatibility complex (MHC) restriction, antigen-specific clonal expansion, effector T-cell functions, memory T-cell formation in immune control

Immune control: innate effector contribution to immune control; early containment and shaping of adaptive responses e.g. phagocytosis supporting antigen availability for presentation.

Coordination of responses in immune control:

Coordination: e.g. functional coordination between humoral and cellular responses, sequencing and reinforcement of immune defence, signalling, effector action and regulation

Immune memory: primary and secondary response characteristics; protective immunity principles e.g. memory responses generating faster and stronger secondary responses

Immune control: comparative immune control across immunological contexts: response variation by pathogen type and tissue context without disease pathway focus e.g. intracellular pathogens favouring cellular responses; extracellular pathogens favouring antibody-mediated control.

LO4 **Present an investigation into immune disorders and associated clinical conditions for an intended audience**

Immune disorders and associated clinical conditions:

Immune dysregulation categories: hypersensitivity, autoimmunity, immunodeficiency; immunological principles underpinning disorder features e.g. immediate hypersensitivity linked to inappropriate effector activation; autoimmunity linked to loss of tolerance

Immunodeficiency: primary and secondary immunodeficiency principles; immune consequences and vulnerabilities e.g. impaired cellular immunity increasing susceptibility to certain infections

Clinical associations at an immunological level: immune dysfunction and associated clinical features without diagnostic workflow emphasis e.g. autoimmune-mediated tissue targeting; immune complex-mediated effects.

Investigation, evidence synthesis and audience-appropriate communication:

Evidence sources for immunological investigation: scientific literature, case-based evidence, laboratory-reported findings or datasets; credibility and limitation awareness e.g. primary research articles; clinical summaries; curated datasets

Evidence appraisal and synthesis: e.g. validity, reliability, relevance and limitations of immunological evidence; comparison of source types to support justified conclusions

Equity and inclusion in immunological investigation: e.g. population diversity, under-representation or bias in evidence sources, inclusive communication for an intended audience

Immunological principles in evidence interpretation: coherent and defensible links between mechanism and disorder features; uncertainty and constraints e.g. limitations of evidence quality; alternative interpretations

Reasoned conclusions: e.g. immunological mechanisms supporting alternative interpretations, recognition of uncertainty, justified conclusions for the intended audience

Communication and presentation for an intended audience: structure and clarity of investigation outputs; appropriate scientific language and formats; use of responsible digital tools e.g. digital visualisation of immune pathways; reference management tools; accuracy and integrity of sourced information.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the organisation and functional roles of the human immune system</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate how immune organisation, pathogen recognition and activation coordinate humoral and cellular immune control.</td></tr>
<tr><td>P1 Explain the functional organisation of the human immune system.

P2 Examine the roles of major immune cells and lymphoid organs in immune defence.</td><td>M1 Assess the functional relationships between immune system components in coordinating immune defence.</td></tr>
<tr><td colspan="2">LO2 Discuss the mechanisms of pathogen recognition and immune activation</td></tr>
<tr><td>P3 Explain mechanisms of pathogen recognition.

P4 Discuss mechanisms of immune activation.</td><td>M2 Analyse the role of immune signalling pathways in coordinating immune activation.</td></tr>
<tr><td colspan="2">LO3 Describe the humoral and cellular immune responses involved in immune control</td></tr>
<tr><td>P5 Describe humoral immune responses involved in immune control.

P6 Explain cellular immune responses involved in immune control.</td><td>M3 Analyse the coordination between humoral and cellular immune responses in immune control.</td></tr>
<tr><td colspan="2">LO4 Present an investigation into immune disorders and associated clinical conditions for an intended audience</td><td rowspan="2">LO4

D2 Justify conclusions from analytical immunological evidence, recognising evidence limitations, uncertainty and incorporating audience feedback.</td></tr>
<tr><td>P7 Investigate immunological principles used to explain immune disorders and associated clinical conditions.

P8 Present findings from an investigation into immune disorders and associated clinical conditions to an intended audience to obtain feedback.</td><td>M4 Analyse immunological evidence from complementary sources to explain immune disorders and associated clinical conditions, using audience feedback.</td></tr>
</table>

Recommended Resources

Textbooks

Abbas, A.K., *et al.* (2026) *Cellular and Molecular Immunology*. 11th edn. Philadelphia: Elsevier.

Delves, P.J., *et al.* (2017) *Roitt's Essential Immunology*. 13th edn. Hoboken: Wiley-Blackwell.

Juris, S.J. (2025) *Immunology*. 2nd edn. Oxford: Oxford University Press.

Murphy, K.M., Weaver, C. and Berg, L.J. (2022) *Janeway's Immunobiology*. 10th edn. New York: W. W. Norton & Company.

Parham, P. (2021) *The Immune System*. 5th edn. New York: W. W. Norton & Company.

Sompayrac, L.M. (2022) *How the Immune System Works*. 7th edn. Hoboken: Wiley-Blackwell.

Websites

https://www.immunology.org/public-information/bitesized-immunology	British Society for Immunology Student-friendly overview of immunology, immune system organisation and immune function (General reference)
https://www.who.int/health-topics/vaccines-and-immunization/	World Health Organization Overview of vaccines, immunisation and immune memory (General reference)
https://esid.org/	European Society for Immunodeficiencies (ESID) Overview of primary immunodeficiency disorders and immune system dysfunction (General reference)
https://www.immunodeficiencyuk.org/	Immunodeficiency UK Explanation of primary immunodeficiency disorders and immune system failure (General reference)

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https://www.nature.com/nri/journal-information	Nature Reviews Immunology Research reviews covering immune mechanisms, signalling and immune regulation (Research)
https://www.frontiersin.org/journals/immunology	Frontiers in Immunology Peer-reviewed research articles on immune mechanisms and immune disorders (Research)

Journals and articles

Abraham, C., Abreu, M.T. and Turner, J.R. (2022) 'Pattern Recognition Receptor Signaling and Cytokine Networks in Microbial Defenses and Regulation of Intestinal Barriers: Implications for Inflammatory Bowel Disease', *Gastroenterology*, 162(6), pp. 1602–1616. e6. Available at: https://doi.org/10.1053/j.gastro.2021.12.288

Chen, R., *et al.* (2025) 'Pattern recognition receptors: function, regulation and therapeutic potential', *Signal Transduction and Targeted Therapy*, 10, 216. Available at: https://doi.org/10.1038/s41392-025-02264-1

Duan, T., *et al.* (2022) 'Toll-Like Receptor Signaling and Its Role in Cell-Mediated Immunity', *Frontiers in Immunology*, 13, 812774. Available at: https://doi.org/10.3389/fimmu.2022.812774

Hundt, J.E., *et al.* (2023) 'Editorial: Autoimmune pre-disease', *Frontiers in Immunology*, 14, 1159396. Available at: https://doi.org/10.3389/fimmu.2023.1159396

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Vultaggio, A., *et al.* (2021) 'How to Prevent and Mitigate Hypersensitivity Reactions to Biologicals Induced by Anti-Drug Antibodies?', *Frontiers in Immunology*, 12, 765747. Available at: https://doi.org/10.3389/fimmu.2021.765747

Xiang, Y., *et al.* (2023) 'The role of inflammation in autoimmune disease: a therapeutic target', *Frontiers in Immunology*, 14, 1267091. Available at: https://doi.org/10.3389/fimmu.2023.1267091

Yasmeen, F., *et al.* (2024) 'Understanding Autoimmunity: Mechanisms, Predisposing Factors, and Cytokine Therapies', *International Journal of Molecular Sciences*, 25(14), 7666. Available at: https://doi.org/10.3390/ijms25147666

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 503: Applied Molecular Biology

Unit 506: Medical Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 521: Infectious Disease Epidemiology and Control.

Unit 525: Genomics and Proteomics

Unit code: H/652/3086

Unit level: 5

Credit value: 15

Introduction

Advances in genomics and proteomics have fundamentally changed how biological systems are studied across applied science, healthcare and biotechnology. The ability to analyse genetic information alongside protein structure and function now underpins much of modern biomedical research, diagnostics and therapeutic development. These disciplines provide complementary perspectives on biological organisation, enabling scientists to explore variation, regulation and function at multiple levels of complexity.

The aim of this unit is to develop higher-level understanding of the principles that underpin genomics and proteomics, and how these approaches are used to generate, analyse and interpret biological data. Students will examine genome organisation, sequencing principles and annotation frameworks, alongside the foundations of proteome characterisation and analytical workflows. The unit emphasises critical understanding of how different data types are produced and the constraints that influence interpretation.

The unit covers core genomic concepts such as genome structure, variation and sequencing strategies, together with protein structure, proteomic methodologies and data interpretation challenges. Students will apply bioinformatic approaches to selected genomic and proteomic datasets, developing the ability to evaluate data quality, suitability and analytical outcomes. The unit culminates in an integrated multiomic study where students synthesise and present findings to a defined audience, reflecting current practice in research and applied laboratory contexts.

On successful completion of this unit, students will be able to integrate and communicate genomic and proteomic evidence in a structured and methodologically robust manner. These skills support progression into roles where biological data interpretation and analysis are central, including Bioinformatics Analyst, Research Scientist, Clinical Data Analyst, Biotechnology Research Associate and Laboratory Scientist, as well as progression to further study within molecular biology and data-driven bioscience pathways.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core concepts of genome organisation, sequencing principles and annotation frameworks

LO2 Describe the fundamental principles of proteome characterisation, protein structure and analytical workflows

LO3 Implement a bioinformatic analysis on a selection of genomic and proteomic datasets for an identified scenario

LO4 Present the results of the multiomic study to an identified audience.

Essential Content

LO1 **Explain the core concepts of genome organisation, sequencing principles and annotation frameworks**

Genome organisation and variation:

Genome organisation: genome structure e.g. prokaryotic genomes, eukaryotic genomes; chromosomal organisation e.g. linear chromosomes, circular chromosomes; coding sequences e.g. protein-coding genes, exons; non-coding sequences e.g. introns, regulatory regions; gene structure features e.g. promoters, untranslated regions; regulatory sequence organisation e.g. operons, enhancer elements

Architecture: genome architecture concepts e.g. gene-dense regions, gene-sparse regions; functional organisation implications e.g. co-regulated genes, dispersed loci; biological constraints e.g. genome size, organisational complexity

Variation: genome variation types e.g. single nucleotide variants, base substitutions; insertion and deletion events e.g. indels, frameshifts; structural variation e.g. inversions, translocations; copy number variation e.g. duplications, deletions

Population: population and reference concepts e.g. haplotypes, linkage groups; population variation e.g. allele frequency differences, shared variants; reference genome concepts e.g. consensus genomes, standard references; reference limitations e.g. reference bias, incomplete representation.

Sequencing and annotation principles:

Sequencing: sequencing data generation concepts e.g. short-read sequencing, long-read sequencing; read characteristics e.g. read length, coverage depth; accuracy considerations e.g. sequencing errors, base-calling accuracy; quality scoring e.g. Phred scores, quality thresholds

Strategy selection: sequencing strategy selection: e.g. whole-genome sequencing, targeted sequencing; platform considerations e.g. throughput capacity, resolution capability; purpose alignment e.g. variant detection, structural characterisation

Annotation: annotation frameworks: e.g. structural annotation, functional annotation; annotation evidence sources e.g. experimental evidence, computational prediction; annotation outputs e.g. gene models, functional assignments

Revisions: annotation confidence and revision: e.g. curated databases, automated pipelines; annotation uncertainty e.g. predicted features, limited evidence; annotation versioning e.g. database updates, revised interpretations; biological interpretation constraints e.g. hypothetical proteins, incomplete functional characterisation.

LO2 **Describe the fundamental principles of proteome characterisation, protein structure and analytical workflows**

Proteome characterisation and protein structure:

Proteome characterisation: proteome concepts e.g. complete protein complement, expressed proteins; biological context e.g. tissue specificity, condition dependence; proteome complexity e.g. isoforms, proteoforms; post-translational modifications e.g. phosphorylation, glycosylation; dynamic range e.g. high-abundance proteins, low-abundance proteins

Genome–proteome relationships: e.g. gene–protein correspondence, transcript-protein variation; regulation effects e.g. alternative splicing, differential expression; biological variability e.g. temporal variation, environmental influence

Structure: protein structure fundamentals e.g. primary structure, amino acid sequence; secondary structure e.g. alpha helices, beta sheets; tertiary structure e.g. three-dimensional folding, domain organisation; quaternary structure e.g. protein complexes, subunit interactions

Structure-function relationships: e.g. active sites, binding regions; functional domains e.g. conserved motifs, catalytic domains; stability factors e.g. folding energetics, molecular interactions; detection constraints e.g. membrane proteins, intrinsically disordered regions

Proteomic workflows and interpretation constraints:

Workflow: proteomic workflow stages e.g. sample preparation, protein extraction; separation principles e.g. chromatographic separation, electrophoretic separation; detection concepts e.g. mass spectrometry signals, peptide spectra; identification outputs e.g. peptide identification, protein inference; quantification approaches e.g. relative quantification, absolute quantification

Comparison: comparative proteomics principles e.g. condition comparison, differential abundance; experimental design considerations e.g. controls, biological replicates; workflow selection factors e.g. sensitivity requirements,

Constraints: interpretation constraints e.g. peptide-to-protein inference ambiguity, shared peptides; data completeness issues e.g. missing values, stochastic sampling; variability sources e.g. technical variation, biological variation; normalisation concepts e.g. signal scaling, variance reduction

Confidence: confidence and uncertainty handling e.g. false discovery rate, confidence thresholds; reproducibility considerations e.g. replicate concordance, workflow consistency; analytical limitations e.g. detection bias, incomplete proteome coverage

LO3 **Implement a bioinformatic analysis on a selection of genomic and proteomic datasets for an identified scenario**

Scenario definition and dataset selection:

Definition: scenario framing e.g. biological context, applied research question; problem definition e.g. investigation aim, analysis objectives; scenario boundaries e.g. scope limitations, assumptions

Selection: dataset selection criteria e.g. genomic datasets, proteomic datasets; dataset relevance e.g. biological appropriateness, analytical fit; inclusion logic e.g. required features, relevant variables; exclusion logic e.g. unsuitable platforms, incomplete datasets

Metadata: dataset metadata requirements e.g. sample descriptors, experimental conditions; comparator selection e.g. control groups, baseline datasets; data provenance e.g. source repositories, dataset origin

Suitability: dataset suitability factors e.g. sample size, representativeness; dataset limitations e.g. missing data, batch effects; platform differences e.g. sequencing platforms, proteomics technologies

Ethics: responsible data handling e.g. secure storage, ethical use; sustainability considerations e.g. reuse of existing datasets, avoidance of unnecessary data generation.

Bioinformatic analysis of genomic datasets:

Data handling stages: genomic data handling stages e.g. data acquisition, data pre-processing; data formats e.g. FASTQ, BAM, VCF; quality control outputs e.g. read quality, coverage summaries

Analysis: alignment and mapping concepts e.g. read alignment, reference mapping; variant detection e.g. variant calling, indel identification; annotation processes e.g. variant annotation, functional assignment

Interpretation: interpretation outputs e.g. variant consequence categories, gene-level summaries; comparative analysis e.g. case-control comparison, population-level patterns

Limitations: analysis limitations e.g. mapping ambiguity, reference bias; uncertainty sources e.g. low coverage, false positives; reproducibility considerations e.g. parameter documentation, reference versioning

Bioinformatic analysis of proteomic datasets and cross–dataset comparison:

Data handling stages: proteomic data handling stages e.g. spectrum processing, database searching; identification outputs e.g. peptide matches, protein inference; quantification outputs e.g. abundance measures, relative change

Interpretation: data interpretation concepts e.g. differential abundance, functional enrichment; analytical constraints e.g. shared peptides, incomplete proteome coverage

Comparison: cross-dataset comparison concepts e.g. genomic–proteomic concordance, discordance patterns; mapping relationships e.g. genotype to protein effect, variant impact on expression

Limitations: integration limitations e.g. transcript-protein discordance, post-translational modification effects; inference constraints e.g. correlation versus causation, methodological compatibility.

Real-world examples:

A range of real-world genomics and proteomics analysis tool examples: genomics analysis tools; sequencing data analysis tools e.g. BWA, Bowtie2, Minimap2; variant analysis tools e.g. GATK, FreeBayes, SAMtools; genome assembly and annotation tools e.g. Prokka, MAKER, NCBI Genome Annotation Pipeline

Proteomics analysis tools: mass spectrometry data analysis tools e.g. MaxQuant, Proteome Discoverer, OpenMS; peptide and protein identification tools e.g. Mascot, Sequest, Andromeda; quantitative proteomics tools e.g. Skyline, Perseus

Functional interpretation resources: gene and protein functional databases e.g. UniProt, Gene Ontology, KEGG; pathway and enrichment analysis tools e.g. Reactome, DAVID, g:Profiler

Integrated genomics-proteomics resources: proteogenomics tools e.g. Proteome Generator, Peppy; cross-omics reference databases e.g. Ensembl, UniProt Proteomes; cancer and disease focused resources e.g. CPTAC, COSMIC.

LO4 **Present the results of the multiomic study to an identified audience**

Multiomics integration approaches:

Purpose: integration purposes e.g. combined biological insight, complementary evidence; data complementarity e.g. genomic variation, protein expression; systems-level reasoning e.g. pathway analysis, network interpretation; integration strategies e.g. sequential analysis, parallel analysis

Methods: synthesis methods e.g. pathway-level integration, functional enrichment; evidence triangulation e.g. cross-validation of findings, corroborating datasets; analytical alignment e.g. question–method matching, dataset suitability

Confidence: strength of inference e.g. consistency across omics layers, corroborated signals; inference limitations e.g. indirect associations, incomplete coverage; interpretation boundaries e.g. correlation versus causation, model assumptions.

Synthesis and communication for intended audiences:

Communication: investigation structure and narrative coherence; logical sequencing of evidence; clear linkage between datasets and conclusions; appropriate scientific language for technical audiences and accessible explanation for non-technical audiences; visual communication principles e.g. annotated pathway diagrams and summary tables that link genomic changes to proteomic effects

Digital tools: appropriate use of digital tools to support investigation outputs; data visualisation tools; reference management; responsible use of AI/digital assistance with attention to accuracy, traceability and source integrity.

Ethical, legal and data-governance considerations:

Ethical considerations: privacy risks e.g. informed consent, appropriate data use e.g. identifiable genomic data, sensitive information; equity considerations e.g. dataset bias, population representation

Legal considerations: legal frameworks e.g. data protection legislation, regulatory compliance; governance controls e.g. access restrictions, usage permissions; ownership considerations e.g. intellectual property, data stewardship

Data management: data governance practices e.g. provenance documentation, version control; FAIR-aligned principles e.g. findable data, reusable data; data lifecycle management e.g. secure storage, retention and deletion

Risk management: accountability mechanisms e.g. audit trails, compliance review; data sharing e.g. cross-organisation data sharing, controlled access.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core concepts of genome organisation, sequencing principles and annotation frameworks</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate, using a selection of real-world examples, the significance of genomic and proteomic approaches in advancing biological research across identified biological contexts.</td></tr>
<tr><td>P1 Explain, using a selection of real-world examples, the core principles of genome organisation and sequencing.

P2 Explore, using a selection of real-world examples, the core concepts of sequencing and annotation frameworks.</td><td>M1 Analyse, using a selection of real-world examples, how genome organisation, sequencing principles and annotation frameworks influence the interpretation of genomic information.</td></tr>
<tr><td colspan="2">LO2 Describe the fundamental principles of proteome characterisation, protein structure and analytical workflows</td></tr>
<tr><td>P3 Describe, using a selection of real-world examples, the fundamental principles of proteome characterisation and protein structure.

P4 Explain, using a selection of real-world examples, how proteomic workflow stages and interpretation constraints contribute to efficient biological research.</td><td>M2 Assess, using a selection of real-world examples, the benefits and limitations of proteome characterisation and analytical workflows in different biological research contexts.</td></tr>
</table>

Pass	Merit	Distinction
LO3 Implement a bioinformatic analysis on a selection of genomic and proteomic datasets for an identified scenario		**LO3 and LO4** **D2** Justify the decisions made in the selection of multiomic datasets, tools and analytical methods used to generate valid conclusions for the identified scenario.
P5 Implement a bioinformatic analysis on a selection of genomic datasets for an identified scenario. **P6** Apply a bioinformatic analysis on a selection of proteomic datasets for an identified scenario. **P7** Review the quality of data generated with internal stakeholders to identify strengths and limitations.	**M3** Evaluate the strengths and limitations of the chosen bioinformatic analysis techniques and datasets, explaining why certain options were rejected.	
LO4 Present the results of the multiomic study to an identified audience		
P8 Interpret the generated bioinformatics data using appropriate methods to obtain meaningful integrated multiomic insights for an identified scenario. **P9** Present the findings of the integrated multiomic study to an identified external audience and obtain feedback on the results.	**M4** Analyse, using the findings of the multiomic study, the internal stakeholder and external audience feedback, the effectiveness of the results for an identified scenario.	

Recommended Resources

Textbooks

Alkhateeb, A. and Rueda, L. (eds.) (2024) *Machine Learning Methods for Multi-Omics Data Integration.* Cham: Springer.

Cecconi, D. (ed.) (2021) *Proteomics Data Analysis.* New York: Springer.

Lesk, A. (2025) *Introduction to Genomics.* 4th edn. Oxford: Oxford University Press.

Link, A.J. and LaBaer, J. (eds.) (2022) *Proteomics: A Cold Spring Harbor Laboratory Course Manual.* Cold Spring Harbor: Cold Spring Harbor Laboratory Press.

Marcus, K., Eisenacher, M. and Sitek, B. (eds.) (2021) *Quantitative Methods in Proteomics.* New York: Humana Press (Springer).

Ning, K. (ed.) (2023) *Methodologies of Multi-Omics Data Integration and Data Mining: Techniques and Applications.* Singapore: Springer.

Owens, R.J. (ed.) (2021) *Structural Proteomics: High-throughput Methods.* 3rd edn. New York: Humana Press.

Srivastava, S. (2022) *From Proteins to Proteomics: Basic Concepts, Techniques and Applications.* Boca Raton, FL: CRC Press.

Websites

https://mart.ensembl.org/info/genome/genebuild/index.html	Ensembl Detailed explanation of how genes and transcripts are annotated onto genome assemblies, including automated and curated annotation workflows. (General reference)
https://beta.ensembl.org/help/articles/gene-annotation	Ensembl Overview of genome and gene annotation processes, evidence sources, and limitations used in large-scale genomic databases. (General reference)

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https://www.ebi.ac.uk/training/online/courses/proteomics-an-introduction/	EMBL-EBI Introductory tutorial explaining proteomics concepts, core databases, and typical analytical workflows used in protein analysis (Tutorial)
https://pdb101.rcsb.org/learn/guide-to-understanding-pbd-data/introduction	RCSB PDB-101 Guide to Understanding PDB Data (Tutorial)
https://www.ebi.ac.uk/training/online/courses/alphafold/accessing-and-predicting-protein-structures-with-alphafold/	EMBL-EBI Tutorial explaining access to predicted protein structures and confidence assessment using AlphaFold resources. (Tutorial)
https://www.ebi.ac.uk/training/materials/introduction-to-multiomics-data-integration-and-visualisation-materials/	EMBL-EBI Structured learning materials covering principles, challenges, and tools for multiomics data integration and visualisation. (Training)
https://omicstutorials.com/introduction-to-multi-omics-data-integration-from-concepts-to-applications/	Omics Conceptual and applied introduction to multiomics integration strategies, data interpretation, and reporting considerations. (Tutorial)
https://www.ebi.ac.uk/training/materials/proteomics-bioinformatics-materials/course-content/	EMBL-EBI Teaching materials covering bioinformatic processing, identification, quantification, and functional annotation of proteomics datasets. (Training)

https://informatics.fas.harvard.edu/resources/tutorials/how-to-annotate-a-genome/	Harvard FAS Informatics Genome Annotation Tutorial (Tutorial)
https://omicstutorials.com/exploring-protein-information-and-analysis-with-uniprot/	Omics Tutorials Exploring Protein Information and Analysis with UniProt (Tutorial)

Journals and articles

Baião, A.R., *et al.* (2025) 'A technical review of multi-omics data integration methods: from classical statistical to deep generative approaches', *Briefings in Bioinformatics*, 26(4), bbaf355. Available at: https://doi.org/10.1093/bib/bbaf355.

Graw, S., *et al.* (2021) 'Multi-omics data integration considerations and study design for biological systems and disease', *Molecular Omics*, 17, pp. 170–185. Available at: https://doi.org/10.1039/D0MO00041H.

Stanojević, S., *et al.* (2022) 'Computational Methods for Single-Cell Multi-Omics Integration and Alignment', *Genomics, Proteomics & Bioinformatics*, 20(5), pp. 836–849. Available at: https://doi.org/10.1016/j.gpb.2022.11.013.

Steen, H. and Mann, M. (2004) 'The abc's (and xyz's) of peptide sequencing', *Nature Reviews Molecular Cell Biology*, 5(9), pp. 699–711. Available at: https://doi.org/10.1038/nrm1468.

Tumienė, B., Adams, D.R., Allaway, R., *et al.* (2026) 'Translating multi-omics into healthcare: requisites for scalable and equitable implementation', *Human Genomics*, 20, Article 71. Available at: https://doi.org/10.1186/s40246-025-00902-x.

Zhang, T., *et al.* (2025) 'Computational Tools and Resources for Long-read Metagenomic Sequencing Using Nanopore and PacBio', *Genomics, Proteomics & Bioinformatics*, 23(4), qzaf075. Available at: https://doi.org/10.1093/gpbjnl/qzaf075.

Zheng, Y., *et al.* (2023) 'Multi-omics data integration using ratio-based quantitative profiling with Quartet reference materials', *Nature Biotechnology*, 42, pp. 1133–1149. Available at: https://www.nature.com/articles/s41587-023-01934-1.

Zubair, M., *et al.* (2022) 'Proteomics approaches: A review regarding an importance of proteome analyses in understanding the pathogens and diseases', *Frontiers in Veterinary Science*, 9, 1079359. Available at: https://doi.org/10.3389/fvets.2022.1079359.

Links

This unit links to the following related units:

Unit 503: Applied Molecular Biology

Unit 506: Medical Microbiology

Unit 508: Diagnostics for the Biomedical Sciences

Unit 530: Plant Biotechnology.

Unit 526: Further Analytical Chemistry

Unit code: J/652/3087

Unit level: 5

Credit value: 15

Introduction

Analytical chemistry is central to reliable scientific decision making in areas such as pharmaceutical development, environmental monitoring, materials testing, food analysis, forensic investigation and quality control. As analytical methods become more sensitive, automated and data-rich, scientists and technicians need to understand not only the operation of advanced instruments, but also the factors that affect the validity, reliability and interpretation of analytical results.

This unit develops students' understanding of further analytical chemistry techniques, including atomic and molecular spectroscopy, X-ray methods, electron microscopy, mass spectrometry and advanced nuclear magnetic resonance (NMR) spectroscopy. Students will review the principles, instrumentation, outputs and limitations of these techniques, considering how method selection is influenced by the analyte, sample matrix, detection requirements and purpose of the analysis.

Students will also explore the core principles that support robust analytical measurement, including calibration, detection capability, instrument performance, optimisation, validation, error and uncertainty. The unit emphasises the importance of sampling, sample preparation, quality control and quality assurance in producing defensible data. Students will apply these principles to an identified analytical scenario, using evidence to judge the suitability, reliability and credibility of analytical methods and results.

On completion of this unit, students will be able to select, apply and justify analytical techniques and supporting quality processes for realistic laboratory contexts. The knowledge and skills developed support progression to further study in analytical chemistry, chemistry, forensic science, biomedical science, pharmaceutical science, environmental science, materials science or related laboratory-based degrees. They also support career paths in analytical laboratories, quality assurance, environmental monitoring, pharmaceutical analysis, forensic services, regulatory testing, materials characterisation and scientific technical support roles.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Review techniques of further analytical chemistry

LO2 Explain the core principles of further analytical chemistry

LO3 Discuss appropriate sampling, sample preparation techniques and quality assurance principles

LO4 Apply sampling, sample preparation techniques and quality assurance principles used in analytical chemistry methodologies for an identified scenario.

Essential Content

LO1 **Review techniques of further analytical chemistry**

Advanced atomic techniques:

Advanced atomic spectroscopy: excitation and ionisation processes e.g. inductively coupled plasma optical emission spectroscopy (ICP-OES), inductively coupled plasma mass spectrometry (ICP-MS); plasma physics; spectral interferences, atomisation efficiency, ionisation suppression; collision/reaction cell chemistry e.g. isotope ratio measurement

Detection limits: matrix effects; method optimisation e.g. selecting ICP-MS with a collision cell to reduce polyatomic interference in trace metal analysis.

X-ray methods:

X-ray methods: X-ray fluorescence (XRF) e.g. characteristic X-ray emission, inner-shell ionisation, elemental identification, quantitative calibration, matrix correction; X-ray diffraction (XRD) e.g. crystalline order, lattice spacing, Bragg's law, instrument components e.g. X-ray tube, monochromator, goniometer and solid-state detector.

Electron microscopy:

Techniques: scanning electron microscopy (SEM) principles and instrumentation e.g. focused electron beam, electron-sample interactions, secondary electrons, backscattered electrons; energy-dispersive X-ray spectroscopy (EDX) e.g. electron gun, electromagnetic lenses, vacuum chamber; detector selection e.g. using secondary electron imaging to examine surface topography

Analytical outputs: high-resolution surface morphology e.g. particle size and shape, compositional contrast, elemental microanalysis, spatial distribution of elements; semi-quantitative EDX spectra e.g. comparing metal oxide particles in a contaminated soil sample

Practical considerations: sample conductivity, conductive coating, vacuum compatibility, charging artefacts, beam damage, sample preparation, resolution limits; operator settings e.g. lowering accelerating voltage to reduce beam damage in sensitive materials.

Advanced molecular spectroscopy:

Raman spectroscopy: inelastic scattering, monochromatic laser excitation, Raman shift, vibrational modes, polarisability change, fluorescence interference, complementary use with infrared spectroscopy, qualitative identification; mapping applications e.g. distinguishing polymorphs in a pharmaceutical solid.

Advanced mass spectrometry:

Mass spectrometry principles and instrumentation: ionisation mode, electron ionisation (EI), chemical ionisation (CI), electrospray ionisation (ESI), matrix-assisted laser desorption ionisation (MALDI); mass-to-charge ratio, mass analyser, quadrupole, time-of-flight (TOF); Orbitrap, ion trap; detector type e.g. selecting ESI for polar thermally labile compounds

Analytical outputs: molecular ion, fragment ion, exact mass, isotope pattern, mass accuracy; tandem mass spectrometry (MS/MS) fragmentation pathway; precursor ion, product ion, quantitative response; internal standardisation e.g. using a deuterated internal standard in liquid chromatography–tandem mass spectrometry (LC–MS/MS) quantification

Practical considerations: ionisation efficiency, matrix effects, ion suppression, mass calibration, resolving power, collision energy, sample purity, carryover; calibration drift e.g. checking mass accuracy with a reference compound before reporting exact-mass data.

Advanced nuclear magnetic resonance spectroscopy:

Advanced nuclear magnetic resonance (NMR) spectroscopy: two-dimensional NMR, correlation spectroscopy (COSY), heteronuclear single quantum coherence (HSQC), heteronuclear multiple bond correlation (HMBC), proton–proton correlation, proton–heteronucleus correlation, chemical shift, coupling pattern, structural elucidation, alternative NMR-active nuclei e.g. ^{19}F, ^{31}P and ^{15}N for compound identification.

LO2 **Explain the core principles of further analytical chemistry**

Calibration and measurement reliability:

Calibration reliability: e.g. calibration model, working range, linearity, residual analysis, calibration curve, external calibration, internal standardisation, standard addition, matrix-matched calibration

Measurement reliability: precision, repeatability, reproducibility, trueness, bias, instrumental error, method error, operator error, environmental error e.g. using standard additions to compensate for matrix effects in complex samples.

Uncertainty, error and reporting:

Uncertainty and error: e.g. sampling error, preparation error, calibration error, instrument drift, contamination, transcription error, random error, systematic error, uncertainty component, combined uncertainty, expanded uncertainty, coverage factors

Reporting: reporting tolerance, decision rule, traceability, digital audit trail e.g. reporting a result as concentration ± expanded uncertainty at a stated coverage level.

Instrumentation performance and optimisation:

Instrumentation performance: e.g. source function, sample introduction, separation interface, detector response, data system, autosampler carryover, detector saturation, limit of detection, limit of quantification, signal-to-noise ratio

Optimisation: baseline correction, integration settings, method robustness, sensitivity, selectivity, resolution, throughput e.g. adjusting integration parameters to avoid overestimating a poorly resolved peak.

Monitoring, validation and improvement:

Monitoring: method performance characteristics e.g. accuracy, trueness, precision, linearity, range, selectivity, robustness, sensitivity

Validation: e.g. verification, validation, standard method, in-house method, change control, control chart, warning limit, action limit, trend detection

Improvement: corrective action, digital dashboard e.g. using a Shewhart chart to identify instrument drift before results are released.

LO3 **Discuss appropriate sampling, sample preparation techniques and quality assurance principles**

Sampling and sample preparation techniques:

Sampling and sample preparation techniques: dissolution, extraction, filtration, particulate separation, purification, clean-up, concentration, dilution, derivatisation, drying, reconstitution, homogenisation, preservation; chain of custody e.g. solvent evaporation followed by reconstitution to a defined volume before instrumental analysis

Impact on data quality: e.g. impact of analyte recovery, transfer loss, contamination, matrix effect, selectivity, sensitivity, representativeness, analyte stability, solvent waste, repeatability, reproducibility e.g. poor homogenisation causing variation between replicate soil subsamples; sustainability considerations.

Quality control in sampling and sample preparation:

Quality control in sampling and preparation: method blank, field blank, reagent blank, recovery check, replicate preparation, certified reference material, acceptance criterion, preparation log, traceability record, fitness for purpose, spiked sample, e.g. using a matrix spike to check analyte recovery after extraction

Internal quality control measures: blank analysis, known-concentration sample, spiked sample, duplicate sample, calibration verification, control sample, method validation, sampling method, sampling plan, batch acceptance e.g. rejecting a batch when recovery falls outside the agreed acceptance range

External quality control measures: inter-laboratory comparison, proficiency testing, assigned value, performance score, *z*-score, E_n number, *Q* score, external assurance, method comparability e.g. reviewing a proficiency testing z-score to identify potential bias.

Quality assurance:

Quality assurance features: staff competence, training record, document control, record keeping, data management, laboratory environment, sample storage, material storage, sample receipt, traceability, calibration, maintenance, validated method, statistical review, audit trail e.g. using controlled templates and authorised procedures to support defensible reporting

Control charts: control sample, mean, standard deviation, confidence limit, warning limit, action limit, Shewhart chart, moving average chart, cumulative sum (CUSUM) chart, trend, out-of-control signal; corrective action e.g. investigating reagent deterioration when control values drift towards an action limit.

LO4 **Apply sampling, sample preparation techniques and quality assurance principles used in analytical chemistry methodologies for an identified scenario.**

Sampling strategy and application:

Sampling strategy: sampling plan, analytical scenario, representative sample, sampling frequency, sampling location, preservation, temperature control, additive selection, field blank, chain of custody, risk-based decision threshold, auditability e.g. selecting more frequent sampling near a known contamination source

Sample preparation: targeted preparation, interference removal, homogenisation, digestion, extraction, dilution, clean-up, over-processing risk, recovery check, matrix compatibility e.g. using microwave acid digestion for trace metals in soil before ICP-MS analysis.

Analytical techniques and method selection:

Analytical technique selection: e.g. analytical question, target analyte, matrix compatibility, sensitivity, selectivity, throughput, detection capability

Method selection: inductively coupled plasma mass spectrometry (ICP-MS), atomic absorption spectroscopy (AAS), gas chromatography–mass spectrometry (GC–MS), liquid chromatography-tandem mass spectrometry (LC-MS/MS), scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM–EDX), X-ray fluorescence (XRF); method limitation e.g. selecting LC-MS/MS for polar pharmaceuticals in wastewater

Tandem and hyphenated techniques: chromatographic separation, definitive identification, tandem mass spectrometry (MS/MS) confirmation, high-resolution mass spectrometry, isobaric interference, structural confirmation, regulatory decision, forensic decision, selectivity improvement e.g. using gas chromatography–tandem mass spectrometry (GC–MS/MS) for complex volatile organic mixtures where single-stage mass spectrometry lacks specificity.

Quality control, error sources and uncertainty reporting:

Quality control: e.g. method blank, matrix spike, duplicate sample, calibration verification, batch control, proficiency testing, uncertainty budget

Error and uncertainty reporting: error source, acceptance criterion, corrective action, result qualification e.g. flagging results where matrix spike recovery is outside the agreed acceptance range.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Review techniques of further analytical chemistry</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate the suitability, reliability and effectiveness of analytical techniques, calibration approaches, sample preparation strategies and quality assurance measures for analytical chemistry applications.</td></tr>
<tr><td>P1 Review the operation of atomic, X-ray and electron microscopy techniques.

P2 Explain the operation of molecular and mass spectrometry and advanced magnetic resonance methods.</td><td>M1 Analyse the selection of further analytical chemistry techniques for different analytical problems, considering their principles, strengths and limitations.</td></tr>
<tr><td colspan="2">LO2 Explain the core principles of further analytical chemistry</td></tr>
<tr><td>P3 Explore calibration models and detection capability concepts used in analytical chemistry.

P4 Explain sources of error and uncertainty concepts used to support reliable analytical measurement.</td><td>M2 Assess the influence of instrument performance, optimisation strategies and validation concepts on the reliability and suitability of analytical methods.</td></tr>
<tr><td colspan="2">LO3 Discuss appropriate sampling, sample preparation techniques and quality assurance principles</td></tr>
<tr><td>P5 Discuss appropriate sampling and sample preparation techniques and their impact on analytical data quality.

P6 Explain quality control and quality assurance principles relevant to sampling and sample preparation.</td><td>M3 Assess the influence of sampling strategy, sample preparation choices and quality assurance measures on analytical data quality and reliability.</td></tr>
<tr><td colspan="2">LO4 Apply sampling, sample preparation techniques and quality assurance principles used in analytical chemistry methodologies for an identified scenario</td><td rowspan="2">LO4

D2 Critically evaluate the reliability and credibility of analytical results for an identified scenario, using evidence from sampling, sample preparation, quality control and quality assurance activities.</td></tr>
<tr><td>P7 Apply appropriate sampling methods and sample preparation techniques for an identified analytical scenario.

P8 Demonstrate quality control and quality assurance measures during sampling and sample preparation for an identified analytical scenario.</td><td>M4 Analyse the effectiveness of the sampling, sample preparation, quality control and quality assurance measures used in the identified analytical scenario.</td></tr>
</table>

Recommended Resources

Textbooks

Dean, J.R., Langford, A.M., Holmes, D.A., Reed, R., Weyers, J. and Jones, A. (2017) *Practical Skills in Chemistry*. 3rd edn. Harlow: Pearson.

Feinberg, M. and Rudaz, S. (2024) *Quantification, Validation and Uncertainty in Analytical Sciences: An Analyst's Companion*. Weinheim: Wiley-VCH.

Ham, B.M. and MaHam, A. (2024) *Analytical Chemistry: A Toolkit for Scientists and Laboratory Technicians*. 2nd edn. Hoboken: Wiley.

Harris, D.C. (2020) *Quantitative Chemical Analysis*. 10th edn. New York: W.H. Freeman and Company.

Langman, L.J. and Snozek, C.L.H. (eds.) (2019) *LC-MS in Drug Analysis: Methods and Protocols*. 2nd edn. New York: Springer.

Locatelli, M. and Kaya, S. (2024) *Green Analytical Chemistry: Current Status and Future Perspectives in Sample Preparation*. Amsterdam: Elsevier.

Magnusson, B. and Örnemark, U. (eds.) (2014) *Eurachem Guide: The Fitness for Purpose of Analytical Methods - A Laboratory Guide to Method Validation and Related Topics*. 2nd edn. Teddington: Eurachem.

Soffiantini, V.A. (2021) *Analytical Chemistry: Principles and Practice*. Berlin: De Gruyter.

Thomas, R. (2023) *Practical Guide to ICP-MS and Other Atomic Spectroscopy Techniques: A Tutorial for Beginners*. 4th edn. Boca Raton: CRC Press.

Worsfold, P., Townshend, A. and Poole, C. (eds.) (2019) *Encyclopedia of Analytical Science*. 3rd edn. Amsterdam: Elsevier.

Websites

https://chem.libretexts.org/Bookshelves/Analytical_Chemistry	Chemistry LibreTexts Analytical Chemistry bookshelf (General reference)
https://eurachem.org/index.php/publications/guides	Eurachem Guides Guide to method validation; uncertainty in measurement (Standards)

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https://goldbook.iupac.org	IUPAC Compendium of Chemical Terminology (Gold Book) Online reference to chemical terminology (General reference)
https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html	ISO/IEC 17025:2017 General requirements for the competence of testing and calibration laboratories (Standards)
https://www.nist.gov/analytical-chemistry	National Institute of Standards and Technology (NIST) Standard Reference Materials for chemical measurement (Standards)
https://www.chromacademy.com/	Chromacademy Chromatography learning resources (Training)
https://pubs.acs.org/journal/ancham	American Chemical Society Analytical Chemistry journal resources (Research)
https://www.rsc.org/publishing/journals/analyst	Royal Society of Chemistry Analyst journal resource (Research)

Journals and articles

Guillarme, D., *et al.* (2025) 'Fundamental and Applied Reviews in Analytical Chemistry 2025', *Analytical Chemistry*, 97. Available at: https://doi.org/10.1021/acs.analchem.5c03181

Meher, A.K. and Zarouri, A. (2025) 'Green Analytical Chemistry—Recent Innovations', *Analytica*, 6(1), p. 10. Available at: https://doi.org/10.3390/analytica6010010

Mehta, M., Mehta, D. and Mashru, R. (2024) 'Recent application of green analytical chemistry: eco-friendly approaches for pharmaceutical analysis', *Future Journal of Pharmaceutical Sciences*, 10, p. 83. Available at: https://doi.org/10.1186/s43094-024-00658-6

Nichols, Z.E. and Geddes, C.D. (2021) 'Sample Preparation and Diagnostic Methods for a Variety of Settings: A Comprehensive Review', *Molecules*, 26(18), p. 5666. Available at: https://doi.org/10.3390/molecules26185666

Pollard, C. and Rapp-Wright, H. (2026) 'Sustainable analytical chemistry laboratories: the critical role of education', *RSC Sustainability*. Available at: https://doi.org/10.1039/D5SU00921A

Poojarya, H., *et al.* (2025) 'Current advances in solid-phase microextraction as a green analytical sample preparation approach', *Green Chemistry Letters and Reviews*, 18(1). Available at: https://doi.org/10.1080/17518253.2025.2486135

Shinde, S.S. and Khulbe, P. (2025) 'Analytical Method Validation: A Comprehensive Review of Current Practices', *South Eastern European Journal of Public Health*, 21, pp. 244–254. Available at: https://doi.org/10.70135/seejph.vi.6516

Links

This unit links to the following related units:

Unit 423: Analytical Chemistry

Unit 512: Solid State and Transition Metal Chemistry

Unit 513: Aromatic and Carbonyl Compounds

Unit 514: Spectroscopy, Surface Chemistry and Equilibria

Unit 515: Green Chemistry.

Unit 527: Clinical Chemistry

Unit code: **K/652/3088**

Unit level: **5**

Credit value: **15**

Introduction

Clinical chemistry is a core discipline within laboratory medicine, underpinning the screening, diagnosis and monitoring of a wide range of medical conditions across healthcare settings. This unit sits within the applied sciences pathway and reflects the central role of clinical chemistry laboratories in modern patient care, where high-throughput analytical testing, digital systems and quality frameworks are used to generate reliable biochemical data to support clinical decision making.

The purpose of this unit is to develop students' understanding of the principles, methodologies and professional practices that underpin clinical chemistry testing. Students will explore how biochemical tests are selected, performed and evaluated in response to clinical questions, and how laboratory processes are designed to ensure accuracy, reliability, validity and fitness for purpose. Emphasis is placed on the total testing process, including pre-analytical, analytical and post-analytical stages, and the impact that variation at each stage can have on reported results.

The unit covers key topics, including the scope of clinical chemistry testing, specimen and analyte types, analytical methodologies and instrumentation, calibration, performance characteristics and methodological limitations. Students will examine how reference information, patterns, relationships and trends in biochemical results support interpretation in relation to pathological conditions for identified clinical scenarios. Quality assurance and quality control procedures are also explored, highlighting their role in supporting result validity, patient safety, reporting decisions, continuous improvement and efficient and sustainable laboratory practice.

On completion of this unit, students will have developed the knowledge and analytical skills required to interpret clinical chemistry data within an identified clinical context, evaluate sources of error and variability, and review the application of quality systems in laboratory environments. The unit is particularly relevant to students preparing for roles in biomedical science, medical laboratory science, healthcare science and related diagnostic services. It will support progression to more specialised study and provide a strong foundation for employment or further training in those areas, where analytical judgement, digital competence and quality-focused practice are essential.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain, using either real-world case studies or laboratory-based practice, the principles and methodologies of clinical chemistry testing

LO2 Explore the pre-analytical, analytical and post-analytical variables that can influence clinical chemistry results

LO3 Analyse biochemical test results in relation to pathological conditions for an identified clinical scenario

LO4 Review, using either real-world case studies or laboratory-based practice, the application of quality assurance and quality control procedures within clinical chemistry laboratories.

Essential Content

LO1 **Explain, using either real-world case studies or laboratory-based practice, the principles and methodologies of clinical chemistry testing**

Scope of clinical chemistry testing:

Screening, diagnosis and monitoring: specimen types selected for clinical questions: e.g. serum, plasma, urine; analyte categories e.g. metabolites, enzymes, electrolytes, proteins

Reporting conventions: units, reference information e.g. mmol/L for electrolytes, IU/L for enzyme activity, g/L for proteins.

Methodologies and instrumentation used in clinical chemistry:

Core analytical principles: e.g. photometric and colorimetric measurement, enzyme activity assays, ion-selective electrode measurement, immunochemical methods

Automated analysers and middleware: sample tracking, result processing; automation concepts e.g. sample handling, reagent handling, throughput, carryover controls

Method selection factors: analyte properties, sensitivity, specificity, turnaround time, clinical risk, resource efficiency, sustainability, fitness for purpose, diagnostic pathway impact e.g. point-of-care testing versus central laboratory analysers, immunoassay versus enzymatic methods, urgent electrolyte testing vs routine monitoring.

Calibration, performance and methodological limitations:

Calibration approaches: e.g. single-point calibration, multi-point calibration, calibration curves, calibrators, standards, traceability

Analytical performance characteristics: e.g. accuracy, precision, bias, linearity, limit of detection, limit of quantitation, uncertainty

Methodological limitations: interference, matrix effects, sample integrity effects, haemolysis, lipaemia, jaundice e.g. pseudohyperkalaemia from haemolysis, lipaemia affecting photometric assays.

LO2 **Explore the pre-analytical, analytical and post-analytical variables that can influence clinical chemistry results.**

Pre-analytical variables:

Pre-analytical variables: patient preparation and biological variation e.g. fasting status, posture, diurnal variation; patient identification and sample labelling; sample type and container selection e.g. serum versus plasma, ethylenediaminetetraacetic acid (EDTA) vs lithium heparin

Sample handling: collection, transport, processing, storage conditions; sample acceptability and integrity indicators e.g. haemolysed samples, insufficient volume, delayed separation.

Analytical and post-analytical variables:

Analytical sources of variation: instrument calibration stability and drift, reagent performance, lot variation, maintenance status, operator factors, carryover, interferences, matrix effects; digital quality monitoring tools and analyser software

Post-analytical sources of error: verification, authorisation, transcription errors, unit errors, reference information, digital reporting systems, audit trails e.g. incorrect unit conversion, incorrect reference interval applied.

Reliability in an identified scenario:

Reliability and validity of results: influence of pre-analytical, analytical and post-analytical factors on confidence in reporting; source and direction of error

Reliability improvement actions: repeat analysis, recollection, add-on tests, alternative method, interpretive notes; repeat testing reduction and waste reduction.

LO3 **Analyse biochemical test results in relation to pathological conditions for an identified clinical scenario**

Reference information and comparability:

Reference information: reference intervals, decision limits, critical values, therapeutic ranges, biological variation, population-specific interpretation

Interpretation factors: age, sex, pregnancy status, population group, clinical context, analytical method e.g. method-dependent differences in creatinine, paediatric vs adult reference intervals, critical potassium values.

Patterns, relationships and trends in biochemical results:

Relationships across related analytes and profiles: concordant and discordant findings; organ-system patterns e.g. renal, liver, endocrine, cardiac, metabolic and inflammatory profiles

Trends: acute and chronic trends over time; monitoring and pathway significance; digital data visualisation and trending tools e.g. renal function and electrolytes, liver profile, lipid profile, glucose and HbA1c, troponin time-series in suspected myocardial injury, C-reactive protein trends in inflammation.

Pathology links and interpretation confidence:

Interpretation: pathophysiological rationale for abnormal results; support, refutation or refinement of interpretation; differential interpretation, borderline, conflicting or non-specific findings

Confidence: interpretation confidence limitations e.g. data quality issues, plausibility checks, delta checks, quality control (QC), quality assurance (QA); context for result validity e.g. unexpected critical results requiring confirmation, discordant results requiring repeat or alternative testing, abnormal liver enzyme patterns requiring clinical correlation.

LO4 **Review, using either real-world case studies or laboratory-based practice, the application of quality assurance and quality control procedures within clinical chemistry laboratories**

Quality control in practice, internal quality control (IQC):

Quality control: purpose of internal quality control (IQC), control materials, target values, frequency and placement of controls, quality control (QC) charting; random error, systematic error, shifts and trends

Acceptance criteria: e.g. method validation and verification links, out-of-control responses; escalation, documentation, investigation; digital quality control (QC) software and data management systems e.g. Levey–Jennings charts, Westgard rule breaches, repeat QC, recalibration triggers, lot-to-lot verification.

Quality assurance in practice, external quality assurance (EQA) and the quality system:

Quality assurance: e.g. purpose and operation of external quality assurance (EQA) and proficiency testing, standard operating procedures (SOPs), staff training, competency, equipment maintenance schedules, audits, risk management, sustainable laboratory practices, quality assurance (QA)

EQA performance reports: comparability, bias, peer-group performance, trend monitoring; digital records and traceability e.g. document control, traceability records, reagent lot verification records, audit trails for amendments, non-conformance logs.

Using QA and QC information to support result validity:

QA and QC outputs: confidence in reported results, non-conformances, corrective and preventive actions, links between QA and QC evidence and result validity

Risk-based decision making: e.g. patient safety implications, continuous improvement, service quality; impact on reporting decisions e.g. root cause analysis, corrective and preventive actions (CAPA), review of impacted patient results, temporary suspension of affected assays.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain, using either real-world case studies or laboratory-based practice, the principles and methodologies of clinical chemistry testing</td><td rowspan="5">LO1 and LO2

D1 Critically evaluate the suitability of clinical chemistry methodologies for an identified testing purpose, considering pre-analytical, analytical and post-analytical variables and methodological limitations.</td></tr>
<tr><td>P1 Explain the scope and principles of clinical chemistry testing.

P2 Explore common clinical chemistry methodologies, instrumentation and performance characteristics.</td><td>M1 Analyse the selection and application of clinical chemistry methodologies in relation to fitness for purpose, performance characteristics and methodological limitations.</td></tr>
<tr><td colspan="2">LO2 Explore the pre-analytical, analytical and post-analytical variables that can influence clinical chemistry results</td></tr>
<tr><td>P3 Discuss pre-analytical variables that influence clinical chemistry results.

P4 Explore analytical and post-analytical variables that influence clinical chemistry results.</td><td>M2 Assess the impact of pre-analytical, analytical and post-analytical variables on the reliability and validity of clinical chemistry results for an identified scenario.</td></tr>
</table>

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO3 Analyse biochemical test results in relation to pathological conditions for an identified clinical scenario</td><td rowspan="5">LO3 and LO4

D2 Justify an evidence-based interpretation of biochemical test results for an identified clinical scenario, using quality control and quality assurance evidence to support result validity.</td></tr>
<tr><td>P5 Review biochemical test results against relevant reference information for an identified clinical scenario.

P6 Discuss patterns and relationships within biochemical test results to support interpretation for an identified clinical scenario.</td><td>M3 Analyse biochemical test results to support an evidence-based interpretation for an identified clinical scenario.</td></tr>
<tr><td colspan="2">LO4 Review, using either real-world case studies or laboratory-based practice, the application of quality assurance and quality control procedures within clinical chemistry laboratories</td></tr>
<tr><td>P7 Review the application of quality control procedures within clinical chemistry laboratories.

P8 Discuss the application of quality assurance procedures within clinical chemistry laboratories.</td><td>M4 Evaluate quality control and quality assurance information to support the validity of clinical chemistry results.</td></tr>
</table>

Recommended Resources

Textbooks

Dasgupta, A. and Wahed, A. (2021) *Clinical Chemistry, Immunology and Laboratory Quality Control: A Comprehensive Review for Board Preparation, Certification and Clinical Practice*. 2nd edn. London: Elsevier.

Guder, W.G., *et al.* (2014) *Diagnostic Samples: From the Patient to the Laboratory: The Impact of Preanalytical Variables on the Quality of Laboratory Results*. 4th updated edn. Weinheim: Wiley-Blackwell.

McPherson, R.A. and Pincus, M.R. (2021) *Henry's Clinical Diagnosis and Management by Laboratory Methods*. 24th edn. Philadelphia: Elsevier.

Rifai, N. (ed.) (2023) *Tietz Fundamentals of Clinical Chemistry and Molecular Diagnostics*. 9th edn. St Louis: Elsevier.

Rifai, N. (ed.) (2022) *Tietz Textbook of Laboratory Medicine*. 7th edn. St Louis: Elsevier.

Wu, A.H.B. (ed.) (2006) *Tietz Clinical Guide to Laboratory Tests*. 4th edn. St Louis: Saunders Elsevier.

Websites

https://www.england.nhs.uk/pathology/resources/	NHS England Pathology and laboratory medicine resources and guidance (General reference)
https://www.eflm.eu/site/page/a/1145	European Federation of Clinical Chemistry and Laboratory Medicine (EFLM) Green and sustainable laboratories resources (General reference)
https://diagnostics.roche.com/global/en/products/product-category/lab-type/core-lab/clinical-chemistry-immunoassay.html	Roche Diagnostics Clinical chemistry and immunoassay analyser information (General reference)
https://www.rcpath.org/profession/guidelines.html	Royal College of Pathologists Laboratory quality and governance guidance (General reference)

https://www.rsc.org/policy-and-campaigning/sustainability/sustainable-laboratories	Royal Society of Chemistry Sustainable laboratory practice resources (General reference)

Journals and articles

Blatter, T.U., *et al.* (2022) 'Big Data in Laboratory Medicine—FAIR Quality for AI?', *Diagnostics*, 12(8), article 1923. Available at: https://doi.org/10.3390/diagnostics12081923

Glover, R.T., *et al.* (2023) 'Sustainability in Laboratory Medicine', *Clinical Chemistry*, 69(11), pp. 1212–1219. Available at: https://doi.org/10.1093/clinchem/hvad156

Padoan, A. and Plebani, M. (2022) 'Flowing through laboratory clinical data: the role of artificial intelligence and big data', *Clinical Chemistry and Laboratory Medicine*, 60(12), pp. 1875–1880. Available at: https://doi.org/10.1515/cclm-2022-0653

Plebani, M. (2023) 'Quality in laboratory medicine and the *Journal*: walking together', *Clinical Chemistry and Laboratory Medicine*, 61(5), pp. 713–720. Available at: https://doi.org/10.1515/cclm-2022-0755

Thakur, A., Mukhopadhyay, T. and Ahirwar, A.K. (2024) 'Approaching sustainability in Laboratory Medicine', *Clinical Chemistry and Laboratory Medicine*, 62(9), pp. 1787–1794. Available at: https://doi.org/10.1515/cclm-2023-0973

Wheeler, S.E., *et al.* (2022) 'Clinical Laboratory Informatics and Analytics: Challenges and Opportunities', *Clinical Chemistry*, 68(11), pp. 1361–1367. Available at: https://doi.org/10.1093/clinchem/hvac157

Links

This unit links to the following related units:

Unit 407: Fundamentals of Biochemistry

Unit 506: Medical Microbiology

Unit 507: Pathophysiology and Applied Diagnostics

Unit 508: Diagnostics for the Biomedical Sciences

Unit 522: Histology and Haematology

Unit 524: Immunology.

Unit 528: Manage Forensic Investigations at Scenes

Unit code: L/652/3089

Unit level: 5

Credit value: 15

Introduction

Effective management of forensic investigations at scenes is essential to the integrity, legality and credibility of the wider investigative process. Decisions made at the scene influence the quality of forensic activity, compliance with regulatory and professional requirements, admissibility of evidence and public confidence in investigative practice. This unit is designed for students progressing within forensic and applied science pathways who are developing the judgement, organisational awareness and management skills needed to oversee forensic investigations at scenes.

The unit focuses on the principles and frameworks that underpin at scene forensic investigation management, rather than the technical execution of forensic techniques. Students explore how investigations are planned, coordinated and controlled, including allocation of roles and responsibilities, decision-making authority, governance arrangements and forensic readiness. Emphasis is placed on proportionality of response, accountability for decisions, risk assessment, dynamic decision making and structured management from deployment through to formal handover.

Students also examine how governance, assurance and accreditation frameworks shape at scene forensic investigation processes. This includes legal, ethical and regulatory requirements, professional conduct, disclosure, data protection, confidentiality and human rights considerations. The unit highlights the importance of transparent, traceable and defensible management practice, including audit trails, documentation systems, competence and authorisation of personnel, digital case management, sustainable use of resources, and fair, unbiased decision making that takes account of equality, diversity and inclusion.

On completion of this unit, students will have applied at scene forensic investigation management processes within a virtual crime scene scenario. This enables them to demonstrate professional practice skills in a controlled, simulated environment, including coordination of activity, documentation and record control, compliance monitoring and evaluation of management decisions. Successful completion supports

progression into roles involving the management or oversight of forensic investigations at scenes, as well as further study in forensic science, criminal investigation or related professional practice areas.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Discuss the principles of managing at scene forensic investigations

LO2 Explain how at scene forensic investigation processes are governed and assured for use

LO3 Examine the legal, ethical and regulatory frameworks governing at scene forensic investigative practice

LO4 Apply at scene forensic investigation management processes to a virtual crime scene scenario.

Essential Content

LO1 **Discuss the principles of managing at scene forensic investigations**

Management principles for at scene forensic investigations:

Management principles: management principles for at scene forensic investigations e.g. purpose, scope control, proportionality, accountability, defensibility

Role allocation: responsibility structures e.g. scene manager responsibilities, investigator responsibilities, decision-making authority, personnel coordination e.g. authority levels based on scene complexity and risk, command interfaces, risk assessment; dynamic decision making e.g. adapting management decisions to changing scene conditions

Sustainable forensic practice: proportionate resource use e.g. reduced unnecessary resource use; avoidance of duplication e.g. avoidance of repeated scene attendance; delay reduction; waste minimisation; operational prioritisation e.g. efficient deployment, proportionate deployment of personnel.

Forensic investigation lifecycle and readiness:

Resource planning: pre-incident forensic readiness e.g. pre-defined response models, accredited personnel

Documentation: documentation preparedness e.g. management documentation prepared before scene deployment, personnel authorisation confirmation, authorisation checks

At scene: response models, scene control, formal handover.

Governance and coordination at forensic scenes:

Governance and coordination at forensic scenes: management controls e.g. command structures; communication pathways e.g. structured briefings; documentation requirements e.g. documented lines of authority

Investigative objectives: organisational expectations, regulatory expectations, inter-agency coordination e.g. controlled communication between agencies.

LO2 **Explain how at scene forensic investigation processes are governed and assured for use**

Governance of at scene forensic investigation processes:

Governance of at scene forensic investigation processes: authorisation, control, monitoring; organisational policies, approved procedural frameworks e.g. formally approved investigation frameworks

Management controls: deviation management e.g. documented authorisation for deviations; escalation routes e.g. defined escalation routes; competence, training, personnel authorisation e.g. authorised and competent personnel matched to scene requirements.

Assurance and auditability of forensic investigations:

Assurance and auditability: controlled processes; traceability e.g. traceable approvals; suitability for use

Documentation systems: decision records, audit trails, management documentation e.g. recorded management decisions; Manual of Guidance (MG) forms e.g. audit-ready documentation of scene activity

Digital case management and documentation systems: version control, access control, record integrity, traceability e.g. traceable updates to case records; audit readiness; secure records e.g. secure electronic records; documentation accountability e.g. controlled access to scene documentation.

Accreditation and quality frameworks:

Accreditation and quality frameworks: ISO/IEC 17020 or equivalent national frameworks, ISO/IEC 17025 distinctions

Scene-based accreditation: e.g. crime scene investigation (CSI) accreditation for governance and scene processes

Laboratory accreditation: e.g. laboratory requirements for analytical testing; management oversight, assurance responsibilities, accountability.

LO3 **Examine the legal, ethical and regulatory frameworks governing at scene forensic investigative practice**

Legal and regulatory frameworks:

Legal and regulatory frameworks: admissibility e.g. management decisions affecting admissibility; continuity e.g. continuity records; compliance obligations, scene-level decisions; disclosure e.g. disclosure-sensitive information; data protection, confidentiality e.g. controlled access to personal or confidential data; human rights considerations

Legal requirements, regulatory standards or equivalent national frameworks; documented continuity systems e.g. documented handling of scene-level decisions.

Ethical and professional obligations:

Ethical and professional obligations: integrity, impartiality e.g. avoidance of bias in management direction; transparency, accountability, professional conduct, operational pressure, uncertainty; professional independence e.g. professional independence under investigative or organisational pressure; ethical judgement

Fair and inclusive management practice: fairness; accessibility e.g. accessible communication routes; avoidance of bias e.g. unbiased allocation of investigative attention; equality, diversity and inclusion considerations; community impact; individual impact e.g. fair treatment of affected individuals and communities; investigative outcomes.

Management implications of frameworks:

Management implications of legal, ethical and regulatory frameworks: risk identification e.g. exclusion of evidence due to governance failures; escalation, documentation, control of investigative activity, non-compliance

Organisational accountability e.g. accountability for unmanaged compliance risks; criminal justice consequences; regulatory action e.g. regulatory intervention.

LO4 **Apply at scene forensic investigation management processes to a virtual crime scene scenario**

Application of management processes:

At scene forensic investigation management processes: scene control e.g. control structures, allocation of responsibilities to authorised personnel; management responsibilities; coordination of investigative activity

Documentation management: e.g. coordinated activity logs, regulatory compliance, organisational requirements.

Documentation, control and compliance:

Documentation, records and management controls: e.g. traceability, accountability, audit readiness, version control e.g. controlled versioning of scene records

Decision records: e.g. documented justification for management decisions; streamlined forensic reporting MG forms, oversight of forensic activity, digital case management systems.

Evaluation and improvement of management practice:

Evaluation of management practice: limitations; risks e.g. gaps in documentation control; strengths, management effectiveness e.g. review of decision rationale, decision quality, review of management decisions

Requirements: regulatory requirements, accreditation requirements e.g. governance, assurance, control arrangements; justified recommendations e.g. improvements to escalation routes, strengthened assurance processes.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Discuss the principles of managing at scene forensic investigations</td><td rowspan="8">LO1, LO2 and LO3

D1 Critically evaluate how management principles, governance and assurance mechanisms, and legal, ethical and regulatory frameworks collectively support compliant and defensible at scene forensic investigation management.</td></tr>
<tr><td>P1 Discuss key principles that underpin the management of at scene forensic investigations.

P2 Explain how roles, responsibilities, and decision-making authority are structured within at scene forensic investigation management.</td><td>M1 Analyse how management principles affect coordination, control and decision making in at scene forensic investigation management.</td></tr>
<tr><td colspan="2">LO2 Explain how at scene forensic investigation processes are governed and assured for use</td></tr>
<tr><td>P3 Explain how governance mechanisms control and authorise at scene forensic investigation processes.

P4 Discuss how assurance mechanisms are used to demonstrate traceability, auditability and suitability for use.</td><td>M2 Assess the effectiveness of governance and assurance mechanisms in maintaining compliance, traceability, auditability and suitability for use in at scene forensic investigation processes.</td></tr>
<tr><td colspan="2">LO3 Examine the legal, ethical and regulatory frameworks governing at scene forensic investigative practice</td></tr>
<tr><td>P5 Examine legal and regulatory frameworks that govern the management of at scene forensic investigations.

P6 Discuss ethical and professional obligations that influence management decisions at forensic scenes.</td><td>M3 Analyse how legal, ethical and regulatory frameworks influence management decisions in at scene forensic investigative practice.</td></tr>
</table>

Pass	Merit	Distinction
LO4 Apply at scene forensic investigation management processes to a virtual crime scene scenario		**LO4**
P7 Apply at scene forensic investigation management processes to control and coordinate activity within a virtual crime scene scenario. **P8** Demonstrate documentation and record controls to support traceability and accountability within the virtual crime scenario.	**M4** Analyse the effectiveness of at scene forensic investigation management processes in demonstrating coordinated control, documentation and compliance in a virtual crime scene scenario.	**D2** Critically evaluate the effectiveness of at scene forensic investigation management processes in a virtual crime scene scenario, making justified recommendations for improvement.

Recommended Resources

Textbooks

Bell, S. (2025) *Forensic Science: An Introduction to Scientific and Investigative Techniques*. 6th edn. Boca Raton, FL: CRC Press.

Fisher, B. A. J. and Fisher, D. R. (2022) *Techniques of Crime Scene Investigation*. 9th edn. Boca Raton, FL: CRC Press.

Hald, C., Tilstone, W. J. and Hastrup, M. L. (2019) *Fisher's Techniques of Crime Scene Investigation*. Boca Raton, FL: CRC Press.

Hammer, L. (2019) *Footwear and Tire Track Evidence Collection Manual*. Boca Raton, FL: CRC Press.

Jackson, A. R. W., *et al.* (2016) *Forensic Science*. 4th edn. Harlow: Pearson Education.

Langford, A. (2019) *Practical Skills in Forensic Science*. 3rd edn. Harlow: Pearson.

Mozayani, A. and Parish-Fisher, C. (eds.) (2017) *Forensic Evidence Management: From the Crime Scene to the Courtroom*. Boca Raton, FL: CRC Press.

NicDaeid, N. and White, P. C. (2024) *Crime Scene to Court: The Essentials of Forensic Science*. 5th edn. Cambridge: Royal Society of Chemistry.

Pfefferli, P. (2015) *Forensic Evidence Field Guide: A Collection of Best Practices*. Amsterdam: Academic Press.

Reiber, L. (2019) *Mobile Forensic Investigations: A Guide to Evidence Collection, Analysis, and Presentation*. 2nd edn. New York: McGraw-Hill Education.

Sutton, R., Trueman, K. and Moran, C. (eds.) (2018) *Crime Scene Management: Scene Specific Methods*. 2nd edn. Chichester: Wiley.

Wallace, E. (2016) *Crime Scene Unit Management: A Path Forward*. London: Routledge.

Websites

https://www.college.police.uk/	College of Policing Scene strategy (Training)
https://www.cps.gov.uk	Crown Prosecution Service (UK) Prosecution guidance on expert evidence and disclosure (Professional guidance)
https://enfsi.eu/	European Network of Forensic Science Institutes (ENFSI) Scenes of Crime Examination Best Practice Manual (General resources)
https://www.gov.uk/government/organisations/forensic-science-regulator	Forensic Science Regulator (UK) Codes of practice and regulatory guidance for forensic science (Regulatory guidance)
https://www.iso.org/home.html	International Organization for Standardization (ISO) International forensics standards (Standards)
https://www.lawcom.gov.uk	Law Commission of England and Wales Law reform publications relevant to expert evidence (General reference)
https://nij.ojp.gov	National Institute of Justice (NIJ) Forensic training and guidance on reporting and courtroom testimony (Training)
https://www.nist.gov	National Institute of Standards and Technology (NIST) Forensic science standards and communication of findings (Standards)

Journals and articles

Almazrouei, M. A., Dror, I. E. and Morgan, R. M. (2019) 'The forensic disclosure model: What should be disclosed *to*, and *by*, forensic experts?', *International Journal of Law, Crime and Justice*, 59, article 100330. Available at: https://doi.org/10.1016/j.ijlcj.2019.05.003.

Ballantyne, K. N., *et al.* (2024) 'A transparent approach: Openness in forensic science reporting', *Forensic Science International: Synergy*, 8, article 100474. Available at: https://doi.org/10.1016/j.fsisyn.2024.100474.

Dror, I. E. and Pierce, M. L. (2020) 'ISO Standards Addressing Issues of Bias and Impartiality in Forensic Work', *Journal of Forensic Sciences*, 65(3), pp. 800–808. Available at: https://doi.org/10.1111/1556-4029.14265.

Knes, A. S., *et al.* (2024) 'CSI-CSI: Comparing several investigative approaches toward crime scene improvement', *Science & Justice*, 64(1), pp. 63–72. Available at: https://doi.org/10.1016/j.scijus.2023.11.009.

Mousseau, V., Morelato, M. and Roux, C. (2025) 'The Quest for Regulating Crime Scene Investigation in Forensic Science: Can We Learn About Discretion and Standardization From Other Fields?', *WIREs Forensic Science*. Available at: https://doi.org/10.1002/wfs2.70010.

Neuteboom, W., *et al.* (2020) 'Quality management in forensic science: A closer inspection', *Forensic Science International: Synergy*, 2, pp. 275–283. Available at: https://doi.org/10.1016/j.forsciint.2023.111779.

Links

This unit links to the following related units:

Unit 402: Fundamentals of Forensic Laboratory Protocols and Techniques

Unit 409: Fundamentals of Forensic Science

Unit 410: Criminal Investigation

Unit 501: Personal and Professional Development for Scientists

Unit 509: Forensic Evidence Collection at Crime Scenes

Unit 529: Conservation and Biodiversity

Unit code: T/652/3090

Unit level: 5

Credit value: 15

Introduction

Conservation and biodiversity are central to addressing many of the environmental challenges facing societies today, including habitat loss, species decline and ecosystem degradation. Professionals working in environmental science, conservation, ecology and related fields are increasingly required to understand how biodiversity is structured, why it is important and how it is affected by natural and human-driven pressures. This unit situates conservation biology within applied scientific and environmental contexts, supporting students who are preparing for roles that involve environmental analysis, conservation support and evidence-informed decision making across a range of ecosystems.

The unit develops students' understanding of the principles that underpin conservation practice, including the value of biodiversity, sustainability-focused approaches, and the precautionary principle. Students explore how biodiversity can be described and assessed using established concepts and indicators, and how threats to biodiversity operate at different biological levels. Emphasis is placed on developing a structured understanding of conservation challenges rather than on specialist field techniques, ensuring that the unit remains accessible while still reflecting real-world conservation contexts.

Building on this foundation, the unit examines a range of conservation strategies and management approaches used to protect biodiversity in terrestrial, freshwater and marine ecosystems. Students consider how conservation actions are shaped by ecological context, governance frameworks and sustainability objectives, and how different approaches are applied to support biodiversity protection and ecosystem resilience. The unit also introduces the role of digital information sources in conservation, including the use of biodiversity datasets and policy documentation to support understanding and informed practice.

By the end of the unit, students will be able to apply biodiversity assessment methods to an identified scenario and use evidence to inform conservation decision making. Students develop skills in interpreting biodiversity information, using digital data sources appropriately and communicating evidence clearly to support conservation priorities. The knowledge and skills developed in this unit support progression to

further study in environmental and conservation sciences, as well as entry-level roles that require an understanding of biodiversity, sustainability and evidence-based environmental practice.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core principles of conservation biology and biodiversity assessment

LO2 Discuss a range of threats to biodiversity at different biological levels

LO3 Explore a range of conservation strategies and management approaches for different ecosystems

LO4 Apply biodiversity assessment methods to an identified scenario to inform conservation decision making.

Essential Content

LO1 **Explain the core principles of conservation biology and biodiversity assessment**

Principles of conservation biology:

Key principles underpinning conservation biology: biodiversity value, intrinsic value, instrumental value

Conservation prioritisation: e.g. prioritising species at risk; sustainable use e.g. balancing conservation with human activity; intergenerational equity; precautionary principle e.g. applying precaution where ecological outcomes are uncertain; ecological integrity, ecosystem services; biodiversity hotspots, biogeographical regions

Ethics: conservation ethics, global conservation priorities e.g. recognising tropical forests, coral reefs and wetlands as globally significant habitats, evidence-informed practice.

Concepts underpinning biodiversity assessment:

Main components of biodiversity: genetic diversity, species diversity e.g. genetic diversity supporting population adaptability; functional diversity, ecosystem diversity, species richness, species evenness e.g. species evenness affecting community balance

Habitat heterogeneity: e.g. habitat heterogeneity supporting varied ecological niches

Ecosystem stability: ecosystem resilience, adaptive capacity, endemism, global habitat variation, biogeographical patterns e.g. island endemism.

Use and interpretation of biodiversity metrics:

Common biodiversity metrics and indicators: species richness, species abundance e.g. species richness not reflecting population decline; species evenness, diversity indices

Indicators: indicator species e.g. indicator species signalling ecosystem change; keystone species, endemic species

Conservation status: e.g. conservation status supporting prioritisation; ecosystem condition measures, habitat quality indicators, contextual interpretation of biodiversity measures

Digital biodiversity datasets and repositories: international monitoring frameworks; biodiversity records e.g. occurrence records from global biodiversity databases; species occurrence data, species distribution data, ecosystem condition data e.g. mapped habitat condition; spatial data, temporal trends, global datasets, data quality, geographic sampling bias, under-recorded regions, uneven data coverage e.g. under-recorded regions, data limitations, data interpretation e.g. trend data over time.

LO2 **Discuss a range of threats to biodiversity at different biological levels**

Threats to biodiversity at genetic, species and ecosystem levels:

Genetic-level threats: genetic bottlenecks, reduced gene flow, inbreeding depression e.g. overexploitation reducing breeding individuals; genetic drift e.g. loss of adaptive capacity; population isolation e.g. habitat fragmentation isolating populations

Species-level threats: population decline, species range shifts e.g. climate-related range shifts; local extinction e.g. overexploitation, disease, reduced population viability; invasive species impacts e.g. invasive predators affecting island species

Ecosystem-level threats: habitat loss, habitat fragmentation, habitat degradation e.g. tropical deforestation reducing habitat availability; pollution, eutrophication e.g. nutrient enrichment affecting freshwater systems; land-use change, climate change e.g. coral bleaching linked to ocean warming; trophic imbalance, ecosystem degradation, reduced ecosystem resilience.

Interactions between threats across biological levels:

Connections between biological levels: genetic diversity e.g. reduced genetic diversity increasing vulnerability; population viability, species populations e.g. species loss altering food webs; metapopulations

Community structure: trophic relationships, ecosystem function, ecosystem services e.g. ecosystem degradation affecting flood regulation.

Global and regional variation in biodiversity threats:

Variation in threat intensity across global habitats and regions: tropical forests e.g. tropical deforestation; coral reefs e.g. coral bleaching; islands, freshwater systems, drylands, polar ecosystems, regional vulnerability e.g. invasive species affecting island ecosystems, desertification in drylands; global drivers of biodiversity loss

Interactions between biodiversity threats: cumulative pressures, compounding pressures e.g. climate change increasing invasive species spread; synergistic effects, temporal change, spatial scale, ecological thresholds, intensified biodiversity impacts e.g. habitat fragmentation increasing sensitivity to pollution

Digital evidence sources for biodiversity threats: published datasets, scientific reviews; threat assessments e.g. invasive species records, species distribution records; land-cover data e.g. satellite-derived land-cover change

Climate projections: global monitoring data e.g. mapped habitat change; uncertainty in evidence.

LO3 **Explore a range of conservation strategies and management approaches for different ecosystems**

Conservation strategies:

Common conservation strategies: in situ conservation, ex situ conservation e.g. captive breeding; protected areas e.g. nature reserves; ecological networks, wildlife corridors e.g. ecological corridors

Species recovery programmes: habitat restoration, ecological restoration, rewilding e.g. wetland restoration; assisted migration, conservation translocation e.g. species reintroduction; conservation planning.

Ecosystem–specific management approaches:

Conservation and management approaches across ecosystem types: ecosystem-based management e.g. adaptive management, landscape-scale management, catchment management, habitat connectivity, invasive species control, restoration ecology, biodiversity conservation

Ecosystems: terrestrial ecosystems: e.g. catchment-based management, landscape-scale habitat management; freshwater ecosystems; marine ecosystems e.g. marine protected areas; tropical forests, coral reefs; mangroves e.g. mangrove restoration; savannahs e.g. grassland management; wetlands; temperate woodlands e.g. woodland restoration; polar ecosystems.

Policy, governance, and management context:

Policy, governance and management frameworks: national biodiversity strategies e.g. regulatory measures; protected area designation e.g. protected area management plans

Stakeholder involvement: community engagement e.g. community-led conservation initiatives, local ecological knowledge, indigenous knowledge systems

Ecosystem services evaluation: sustainability-focused objectives, monitoring requirements, conservation targets, international conservation agreements, conservation activity guidance, regional conservation priorities

Digital policy portals and conservation documents: conservation governance, management contexts, policy evidence, monitoring reports; site management plans e.g. biodiversity action plans; conservation status information; publicly available guidance e.g. protected area guidance, Red List assessments.

LO4 **Apply biodiversity assessment methods to an identified scenario to inform conservation decision making**

Biodiversity assessment methods:

Biodiversity assessment methods: biodiversity indicators; species abundance data e.g. population counts; species distribution data e.g. species presence or absence data; species richness, species evenness, diversity indices, quadrat sampling, transect sampling, habitat surveys e.g. habitat quality indicators

Remote sensing: e.g. remote sensing of forest cover and coastal habitats; ecosystem condition measures, international sampling comparability, cross-habitat comparison e.g. mapped habitat extent.

Selection and interpretation of biodiversity evidence:

Factors influencing selection and interpretation of biodiversity assessment methods: relevance e.g. selecting appropriate indicators for a habitat; scale, sampling design, sample size, data availability, data reliability, uncertainty, limitation

Baseline data: e.g. comparing current findings with baseline data; temporal trends e.g. recognising limits of short-term datasets

Context: conservation context, evidence use, geographic coverage e.g. considering uneven sampling between well-studied and under-recorded regions; global sampling bias, local ecological knowledge

Digital datasets and online biodiversity databases: biodiversity evidence; species records e.g. online species records, species occurrence data; habitat condition data e.g. habitat maps; ecosystem data; spatial mapping e.g. mapped protected area information; metadata, data quality; global biodiversity databases, open-access datasets; data interpretation e.g. global occurrence data.

Using biodiversity assessment to inform conservation decisions:

Biodiversity assessment outcomes for conservation decision making: conservation priorities e.g. prioritising restoration activity; ecological risks, species vulnerability, habitat condition e.g. identifying habitats of concern

Management decisions: options, uncertainty, trade-offs, evidence-based recommendations, regional conservation priorities, global conservation significance, informed management choices e.g. informing invasive species control, recognising uncertainty in recommendations, comparing conservation needs across contrasting habitats

Digital formats for presenting biodiversity evidence: summary tables e.g. table of species records; annotated maps e.g. map of habitat condition; graphs, simple visual representations e.g. graph showing biodiversity trends; indicator summaries, evidence summaries, clear communication of findings.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core principles of conservation biology and biodiversity assessment</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate how conservation principles, biodiversity threats and conservation approaches interrelate across contrasting ecosystem contexts.</td></tr>
<tr><td>P1 Explain core principles of conservation biology in relation to biodiversity conservation.

P2 Describe key concepts, indicators and metrics used in biodiversity assessment.</td><td>M1 Analyse how conservation biology principles inform the selection and interpretation of biodiversity assessment approaches.</td></tr>
<tr><td colspan="2">LO2 Discuss a range of threats to biodiversity at different biological levels.</td></tr>
<tr><td>P3 Discuss a range of threats to biodiversity at genetic, species and ecosystem levels.

P4 Explain the effects, interactions and variation of biodiversity threats across genetic, species and ecosystem levels.</td><td>M2 Assess how biodiversity threats operate and interact across genetic, species and ecosystem levels.</td></tr>
<tr><td colspan="2">LO3 Explore a range of conservation strategies and management approaches for different ecosystems</td></tr>
<tr><td>P5 Review conservation strategies used to protect biodiversity.

P6 Explore management approaches for conservation across different ecosystem types.</td><td>M3 Analyse the suitability of conservation approaches for contrasting ecosystem contexts.</td></tr>
<tr><td colspan="2">LO4 Apply biodiversity assessment methods to an identified scenario to inform conservation decision making</td><td>LO4

D2 Critically evaluate the use of biodiversity assessment evidence to inform conservation decision making for an identified scenario.</td></tr>
<tr><td>P7 Apply appropriate biodiversity assessment methods to an identified scenario.

P8 Present biodiversity assessment outcomes to inform conservation decision making for the identified scenario.</td><td>M4 Interpret biodiversity assessment evidence to inform conservation decision making.</td></tr>
</table>

Recommended Resources

Textbooks

Ausden, M. (2007) *Habitat Management for Conservation: A Handbook of Techniques*. Oxford: Oxford University Press. Available at: Habitat Management for Conservation: A Handbook of Techniques | Oxford Academic

Bowman, W.D. and Hacker, S.D. (2023) *Ecology*. 6th edn. Cary, NC: Sinauer Publishing. Available at: Ecology 6th edition | 9780197614044, 9780197614082 | VitalSource

Hambler, C. and Canney, S. (2013) *Conservation*. 2nd edn. Cambridge: Cambridge University Press. Available at: https://www.cambridge.org/core/books/conservation/EACADEC6E338F3CC084F4F6C52E10117

Jeffries, M.J. (2006) *Biodiversity and Conservation*. 2nd edn. London: Routledge. Available at: Biodiversity and Conservation | Michael J. Jeffries | Taylor & Francis

Lame, M. and Marcantonio, R. (2022) *Environmental Management: Concepts and Practical Skills*. Cambridge: Cambridge University Press. Available at: Environmental Management | Cambridge University Press & Assessment

Perrings, C. and Kinzig, A. (2021) *Conservation: Economics, Science and Policy*. Oxford: Oxford University Press. Available at: Conservation: Economics, Science, and Policy | Oxford Academic

Sutherland, W.J., Dicks, L.V., Ockendon, N. and Smith, R.K. (2020) *What Works in Conservation*. Cambridge: Open Book Publishers. Available at: What Works in Conservation 2020 - Open Book Publishers

Wich, S.A. and Piel, A.K. (2021) *Conservation Technology*. Oxford: Oxford University Press. Available at: Conservation Technology | Oxford Academic

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Websites

https://jncc.gov.uk/our-work/uk-biodiversity-indicators/	Joint Nature Conservation Committee (JNCC) UK Biodiversity Indicators and trends (Datasets)
https://www.cbd.int/gbf/monitoring	Convention on Biological Diversity Global biodiversity indicators and monitoring framework (Standards/policy)
https://www.iucnredlist.org/assessment/process	International Union for Conservation of Nature (IUCN) Red List assessment process and criteria (Standards/methods)
https://www.iucnrle.org	International Union for Conservation of Nature (IUCN) Red List of Ecosystems categories and assessment guidance (Standards/methods)
NBN Atlas - UK's largest collection of biodiversity information	National Biodiversity Network (NBN) Accessing and using UK biodiversity datasets (Datasets)
https://publications.naturalengland.org.uk/publication/6049804846366720	Natural England Statutory biodiversity metric supporting guidance and case studies (Guidance)
https://www.gbif.org/what-is-gbif	Global Biodiversity Information Facility (GBIF) Using global biodiversity occurrence data (Datasets)
https://cieem.net/resource/guidelines_for_accessing_and_using_biodiversity_data	Chartered Institute of Ecology and Environmental Management (CIEEM) Guidance on accessing and using biodiversity data (Guidance)

Journals and articles

Cardinale, B.J., *et al.* (2012) 'Biodiversity loss and its impact on humanity', *Nature*, 486, pp. 59–67. Available at: https://doi.org/10.1038/nature11148

Dalongeville, A., *et al.* (2022) 'Benchmarking eleven biodiversity indicators based on environmental DNA surveys: More diverse functional traits and evolutionary lineages inside marine reserves', *Journal of Applied Ecology*. Available at: https://doi.org/10.1111/1365-2664.14276

Díaz, M. (2023) 'Dealing with global threats to biodiversity: A pressing but realistic challenge', *Frontiers in Conservation Science*, 4, 1147470. Available at: https://doi.org/10.3389/fcosc.2023.1147470

Hochkirch, A., *et al.* (2023) 'A multi-taxon analysis of European Red Lists reveals major threats to biodiversity', *PLoS ONE*, 18(11), e0293083. Available at: https://doi.org/10.1371/journal.pone.0293083

Kitikidou, K., et al. (2024) 'Using biodiversity indices effectively: Considerations for forest management', *Ecologies*, 5(1), pp. 42–51. Available at: https://doi.org/10.3390/ecologies5010003

Lahoz-Monfort, J.J. and Magrath, M.J.L. (2021) 'A Comprehensive Overview of Technologies for Species and Habitat Monitoring and Conservation', *BioScience*, 71(10), pp. 1038–1062. Available at: https://doi.org/10.1093/biosci/biab073

Sutherland, W.J., *et al.* (2020) 'Building a tool to overcome barriers in research-implementation spaces', *Conservation Biology*, 34(5), pp. 1172–1183. Available at: https://doi.org/10.1111/cobi.13443

Links

This unit links to the following related units:

Unit 417: Principles of Ecology

Unit 418: Managing Environmental Resources

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 531: Soil Science and Geochemical Processes.

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Unit 530: Plant Biotechnology

Unit code: **Y/652/3091**

Unit level: **5**

Credit value: **15**

Introduction

Plant biotechnology is an important area of applied biological science, supporting innovation in agriculture, horticulture, conservation, environmental management and plant-derived products. It uses knowledge of plant cell structure, growth, regeneration and genetic potential to develop practical solutions to real-world challenges, including crop quality, disease resistance, sustainable production and biodiversity conservation. The unit introduces students to plant-specific biotechnology in a global context, drawing on examples from model plants and crop species used in research, production and case studies.

Students will explore the core principles of plant cell biology that underpin biotechnology, including plant cell organisation, totipotency, differentiation, regeneration, growth regulation and cell cycle control. They will consider how these principles support approaches such as plant transformation, genetic modification, genome editing awareness, plant improvement, propagation and the production of plant-derived materials. The emphasis is on developing a clear understanding of plant systems and their applications rather than on highly specialised molecular detail.

The unit also enables students to review plant tissue culture and micropropagation techniques through applied laboratory practice or real-world case studies. Students will examine explant selection, culture media, aseptic technique, growth regulators, culture conditions, quality control and common limitations that affect tissue culture outcomes. This supports the development of analytical skills needed to assess the effectiveness and suitability of techniques for specific plant biotechnology applications.

On completion of this unit, students will be able to apply knowledge of plant cell biology, biotechnology and tissue culture to evaluate plant-based applications and communicate evidence-based conclusions to an intended audience. This will support progression to further study in areas such as applied biology, plant science, agricultural science, environmental science, biotechnology, horticulture and crop science. It will also support career pathways in laboratory science, plant production, crop improvement, conservation, environmental consultancy, biotechnology support roles and other plant-related scientific or technical occupations.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the core principles of plant cell biology

LO2 Explore the principles of plant biotechnology

LO3 Review plant-specific tissue culture and micropropagation techniques using applied laboratory practice or real-world case studies

LO4 Deliver a presentation on the applications and implications of plant biotechnology to an intended audience.

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Essential Content

LO1 **Explain the core principles of plant cell biology**

Plant cell structure and organisation:

Cell structures: cell walls e.g. structure, function, rigidity; vacuoles e.g. storage, turgor, waste management; plastids e.g. chloroplasts, chromoplasts, amyloplasts; plasmodesmata e.g. cell-to-cell communication

Plant–animal cell differences: e.g. photosynthetic capacity, large central vacuole, cell wall; organisation of tissues and meristematic regions; model plant examples e.g. *Arabidopsis thaliana*, tobacco; labelled images, diagrams, digital microscopy resources.

Totipotency, differentiation and regeneration:

Totipotency: cellular totipotency e.g. significance for regeneration, propagation; differentiation and dedifferentiation in plant tissues

Factors influencing totipotency: e.g. explant source, tissue type, meristematic versus differentiated tissues, developmental stage; regeneration competence; callus formation and organogenesis.

Plant growth regulation and cell cycle control:

Cell cycle control: plant cell cycle e.g. role in cell division, growth; meristem activity

Plant growth regulators e.g. auxins, cytokinins, gibberellins; influence of hormone balance on cell division, differentiation and regeneration; environmental cues affecting growth responses e.g. light, temperature, nutrient availability; simple diagrams, digital visualisations.

LO2 **Explore the principles of plant biotechnology**

Core principles and scope of plant biotechnology:

Purpose and scope: purpose and scope of plant biotechnology e.g. applied discipline; use of plant biological properties e.g. propagation, improvement, production

Typical aims: e.g. enhanced yield, improved quality traits, increased stress tolerance, plant-derived products; digital and scientific sources.

Plant transformation, genetic modification and genome editing:

Genetic modification and plant transformation: genetic modification in plants e.g. trait selection, intended outcomes, application contexts; biological and physical delivery approaches e.g. *Agrobacterium*–mediated transformation, particle bombardment

Principles and applied contexts of genome editing: e.g. CRISPR-Cas9 as a targeted editing approach; selection and screening e.g. identification of plants expressing desired traits; model and crop examples e.g. *Arabidopsis thaliana*, tobacco, rice, maize, tomato; regulatory and ethical awareness.

Plant improvement, propagation and bioproduct applications:

Plant improvement and propagation: selection for desired traits; maintenance of uniformity, trait stability and performance

Applications: applications in crop quality, stress tolerance, disease resistance, biofortification and plant-derived products e.g. secondary metabolites, pharmaceuticals, industrial materials

Effectiveness: factors influencing effectiveness e.g. species characteristics, growth behaviour, regenerative capacity; feasibility, practical limitations.

LO3 **Review plant-specific tissue culture and micropropagation techniques using applied laboratory practice or real-world case studies**

Plant tissue culture systems and micropropagation techniques:

Plant tissue culture and micropropagation: in vitro culture e.g. purpose; main micropropagation stages e.g. explant selection, initiation, multiplication, rooting, acclimatisation/hardening

Common approaches: e.g. shoot culture, embryo-based systems, callus culture; model and applied examples e.g. tobacco, orchid, banana, potato, strawberry

Applications: typical applications e.g. clonal propagation, disease-free plant production, conservation; laboratory examples, images, case studies.

Culture conditions, media and growth regulation:

Aseptic practice: contamination sources and control measures; culture media components e.g. basal salts, carbon source, vitamins, gelling agents; pH, temperature, light intensity and photoperiod

Plant growth regulators: e.g. auxins, cytokinins; auxin:cytokinin ratios and growth responses; records, data summaries.

Quality control, limitations and troubleshooting:

Monitoring culture progress: contamination, browning, vitrification/hyperhydricity, abnormal development, somaclonal variation; genetic fidelity and uniformity

Acclimatisation challenges: e.g. survival rates and practical outcomes; troubleshooting using laboratory observations, records, data summaries or case study evidence.

LO4 **Deliver a presentation on the applications and implications of plant biotechnology to an intended audience**

Applications of plant biotechnology:

Applications of plant biotechnology: applications in agriculture, horticulture, conservation, environmental management and industrial contexts across different global regions e.g. crop improvement, large-scale propagation, disease-free stock, conservation of rare species, phytoremediation, production of plant-derived materials

Case studies: illustrative plant and case study examples e.g. rice, maize, potato, banana, disease-resistant papaya, Bt cotton, Golden Rice

Benefits and limitations in different contexts: e.g. case studies, reputable digital information sources.

Ethical, regulatory and sustainability implications:

Implications: ethical and social considerations e.g. public perception, access, responsible innovation; environmental and sustainability considerations e.g. biodiversity, gene flow, resource use, food security, balanced use of evidence

Regulation: regulatory frameworks and risk assessment in different jurisdictions e.g. UK Genetic Technology (Precision Breeding) Act 2023, Genetically Modified Organisms (Deliberate Release) Regulations 2002, EU Directive 2001/18/EC, EFSA risk assessment framework, Cartagena Protocol on Biosafety.

Communicating evidence-based conclusions to an intended audience:

Communication: communication to different audiences e.g. non-specialist stakeholders, technical teams, decision makers; selecting relevant evidence; adapting scientific language

Digital tools: use of digital tools, reputable online sources and simple data visuals; acknowledging different viewpoints; presenting informed, balanced and evidence-based conclusions.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the core principles of plant cell biology</td><td rowspan="4">LO1 and LO2

D1 Critically evaluate the application of plant cell biology principles in plant biotechnology.</td></tr>
<tr><td>P1 Discuss key structural features of plant cells relevant to growth and regeneration.

P2 Explain how cellular totipotency, differentiation and growth regulation support plant regeneration.</td><td>M1 Analyse how plant cell structure, totipotency and growth regulation underpin biotechnological applications.</td></tr>
<tr><td colspan="2">LO2 Explore the principles of plant biotechnology</td></tr>
<tr><td>P3 Explain the purpose, scope and core principles of plant biotechnology.

P4 Explore how plant biotechnology approaches are used to develop desired plant traits or products.</td><td>M2 Analyse how plant biotechnology approaches are applied to develop desired plant traits, propagation systems or plant-derived products.</td></tr>
<tr><td colspan="2">LO3 Review plant-specific tissue culture and micropropagation techniques using applied laboratory practice or real-world case studies</td><td rowspan="5">LO3 and LO4

D2 Critically evaluate the suitability of plant tissue culture and micropropagation techniques for specific plant biotechnology applications.</td></tr>
<tr><td>P5 Review plant tissue culture and micropropagation techniques using applied laboratory practice or case study evidence.

P6 Explain how culture conditions, growth regulation and quality control affect plant tissue culture and micropropagation outcomes.</td><td>M3 Assess the effectiveness and limitations of plant tissue culture and micropropagation techniques using laboratory practice or case study evidence.</td></tr>
<tr><td colspan="2">LO4 Deliver a presentation on the applications and implications of plant biotechnology to an intended audience</td></tr>
<tr><td>P7 Investigate the applications and implications of plant biotechnology.

P8 Present findings from an investigation into the applications and implications of plant biotechnology to an intended audience.</td><td>M4 Analyse different viewpoints on the applications and implications of plant biotechnology for an intended audience.</td></tr>
</table>

Recommended Resources

Textbooks

George, E.F., Hall, M.A. and De Klerk, G.-J. (2008) *Plant Propagation by Tissue Culture. Volume 1: The Background*. 3rd edn. Dordrecht: Springer. Available at: https://link.springer.com/book/10.1007/978-1-4020-5005-3.

Neumann, K.-H., Kumar, A. and Imani, J. (2020) *Plant Cell and Tissue Culture – A Tool in Biotechnology: Basics and Application*. 2nd edn. Cham: Springer. Available at: https://link.springer.com/book/10.1007/978-3-030-49098-0.

Ricroch, A., Chopra, S. and Kuntz, M. (2021) *Plant Biotechnology: Experience and Future Prospects*. 2nd edn. Cham: Springer. Available at: https://link.springer.com/book/10.1007/978-3-030-68345-0.

Stewart, C.N. (ed.) (2025) *Plant Biotechnology and Genetics: Principles, Techniques, and Applications*. 3rd edn. Hoboken, NJ: Wiley. Available at: https://www.wiley.com/en-us/shop/general-introductory-life-sciences/plant-biotechnology-and-genetics-principles-techniques-and-applications-3rd-edition-p-9781394217212.

Trigiano, R.N. and Gray, D.J. (eds.) (2016) *Plant Tissue Culture, Development, and Biotechnology*. Boca Raton, FL: CRC Press. Available at: https://www.taylorfrancis.com/books/mono/10.1201/9781439896143/plant-tissue-culture-development-biotechnology-dennis-gray-robert-trigiano.

Wayne, R.O. (2024) *Plant Cell Biology: From Astronomy to Zoology*. 3rd edn. London: Academic Press. Available at: https://shop.elsevier.com/books/plant-cell-biology/wayne/978-0-443-21469-1.

Websites

https://www.efsa.europa.eu/en/topics/genetically-modified-organisms	European Food Safety Authority Information on genetically modified organisms, risk assessment and regulatory considerations relevant to plant biotechnology (General resource)
https://www.fao.org/biotechnology/en/	Food and Agriculture Organization of the United Nations Overview of agricultural biotechnologies and their applications in crops, food production and sustainable development (General resource)

https://pmc.ncbi.nlm.nih.gov/	National Center for Biotechnology Information Open access biomedical and life science literature database for plant cell biology, tissue culture and biotechnology research articles (Dataset)
https://royalsociety.org/current-topics/genetic-technologies/	Royal Society Accessible information on genetic technologies, public engagement, ethics and policy debates relevant to plant biotechnology (General resource)

Journals and articles

Abdalla, N., *et al*. (2022) 'An Academic and Technical Overview on Plant Micropropagation Challenges', *Horticulturae*, 8(8), p. 677. Available at: https://doi.org/10.3390/horticulturae8080677.

Chen, C., *et al.* (2024) 'Plant regeneration in the new era: from molecular mechanisms to biotechnology applications', *Science China Life Sciences*, 67(7), pp. 1338–1367. Available at: https://doi.org/10.1007/s11427-024-2581-2.

Long, Y., *et al.* (2022) 'New Insights Into Tissue Culture Plant-Regeneration Mechanisms', *Frontiers in Plant Science*, 13, 926752. Available at: https://doi.org/10.3389/fpls.2022.926752.

Morinaka, H., *et al.* (2023) 'Molecular Mechanisms of Plant Regeneration from Differentiated Cells: Approaches from Historical Tissue Culture Systems', *Plant and Cell Physiology*, 64(3), pp. 297–304. Available at: https://doi.org/10.1093/pcp/pcac172.

Van Esse, H.P., Reuber, T.L. and van der Does, D. (2020) 'Genetic modification to improve disease resistance in crops', *New Phytologist*, 225(1), pp. 70–86. Available at: https://doi.org/10.1111/nph.15967.

Wolt, J.D., *et al.* (2016) 'Regulatory aspects of genome-edited crops', *In Vitro Cellular & Developmental Biology - Plant*, 52, pp. 510–518. Available at: https://doi.org/10.1007/s11627-016-9784-3.

Links

This unit links to the following related units:

Unit 406: Fundamentals of Cell and Molecular Biology

Unit 407: Fundamentals of Biochemistry

Unit 503: Applied Molecular Biology

Unit 504: Industrial Microbiology

Unit 505: Ethics and Biotechnology

Unit 519: Science Laboratory Management

Unit 520: Stem Cell Biology

Unit 524: Immunology

Unit 525: Genomics and Proteomics.

Unit 531: Soil Science and Geochemical Processes

Unit code: A/652/3092

Unit level: 5

Credit value: 15

Introduction

Soils play a fundamental role in supporting natural ecosystems, food production, water regulation and wider environmental systems. For students studying applied and environmental sciences, an understanding of soil properties and processes is essential for interpreting how soils behave under different conditions and how they respond to natural and human influences. This unit introduces soil science and geochemical processes within an applied scientific context, supporting students to develop the knowledge and analytical skills needed for further study or work in environmental, agricultural and laboratory-based science roles.

The unit focuses on the physical, chemical and biological properties that define soils and explores how these properties interact to influence soil behaviour. Students examine key geochemical processes involved in soil formation, transformation and weathering, developing an understanding of how soils evolve over time within natural systems. Attention is given to the mechanisms that control nutrient and contaminant behaviour in soils, helping students to understand how substances are retained, transformed or transported within soil environments.

Building on this theoretical foundation, the unit develops students' ability to work with soil survey and analytical data in relation to an identified soil-related scenario. Delivery may involve fieldwork activities, analysis of soil samples brought into the laboratory, the use of secondary data sources, or a combination of these approaches. Students apply quantitative methods to classify and interpret soil data, drawing on primary or secondary evidence as appropriate to the context. Emphasis is placed on using data to describe soil characteristics and behaviour, while also considering data quality, suitability and limitations in reaching evidence-based conclusions.

On successful completion of this unit, students will have acquired a thorough understanding of soil properties, geochemical processes and the behaviour of nutrients and contaminants within soil systems. They will be able to explain soil characteristics and processes, assess nutrient and contaminant behaviour, and interpret soil survey and analytical data in relation to an identified soil-related

scenario. These skills are directly applicable to further study in environmental science, chemistry and applied biology, and to roles involving soil analysis, environmental monitoring, land management and laboratory-based scientific work.

Learning Outcomes

By the end of this unit a student will be able to:

LO1 Explain the fundamental physical, chemical and biological properties of soils and how these properties influence soil behaviour

LO2 Discuss the geochemical processes that govern soil formation, transformation and weathering within natural soil systems

LO3 Assess the behaviour and movement of nutrients and contaminants within soil systems

LO4 Apply quantitative methods to classify and interpret soil survey and analytical data for an identified soil-related scenario.

Essential Content

LO1 **Explain the fundamental physical, chemical and biological properties of soils and how these properties influence soil behaviour**

Physical, chemical and biological soil properties:

Properties: physical, chemical and biological soil properties e.g. texture, structure, porosity, pH, mineral composition, organic matter, soil biota e.g. bacteria, fungi, mycorrhizal fungi, earthworms; water retention, aeration, nutrient availability, soil stability

Examples: soil type examples e.g. sandy, clay, loamy, peaty/organic-rich, calcareous soils; effective soil functioning over time e.g. sandy soils draining rapidly, clay soils retaining water more effectively, calcareous soils influencing nutrient availability through pH, microbial activity supporting nutrient cycling.

Interactions influencing soil behaviour:

Soil behaviour: combined effects of physical, chemical and biological properties, response to environmental conditions e.g. water movement, nutrient retention, aggregation, resistance to degradation

Influence of combined properties: e.g. influence of clay content and organic matter on cation exchange capacity and water-holding capacity, high water retention of peaty soils linked to organic matter content, lower nutrient retention of sandy soils because of coarse texture and rapid drainage.

LO2 **Discuss the geochemical processes that govern soil formation, transformation and weathering within natural soil systems**

Soil-forming and transformation processes:

Soil processes: soil-forming and transformation processes e.g. additions, losses, transformations, translocations, pedogenic processes, profile development, horizon differentiation, eluviation, illuviation, leaching, accumulation

Soil profiles: development of soil profiles within natural soil systems e.g. horizon development through leaching and accumulation.

Mineral weathering and geochemical cycling:

Weathering: mineral weathering and geochemical cycling e.g. physical weathering, chemical weathering, dissolution, hydrolysis, oxidation, reduction, carbonation, acidification, precipitation, mineral breakdown, secondary minerals, clay formation, soil colloids

Geochemical cycling: carbon cycling, nitrogen cycling, phosphorus cycling, element storage, transformation and movement within soils; geochemical cycling influencing soil composition and function.

Process interactions in soil development:

Processes: process interactions in soil development e.g. weathering, transformation, nutrient cycling, cation exchange, organic matter decomposition, humification, complexation/chelation, horizon differentiation, profile development, mineral inputs, clay formation, organic matter inputs, interacting soil processes

Multiple processes: operating together in shaping soil properties over time e.g. mineral weathering supplying ions that contribute to clay formation, influence of organic matter decomposition and humification, nutrient cycling and horizon differentiation.

LO3 **Assess the behaviour and movement of nutrients and contaminants within soil systems**

Geochemical mechanisms controlling behaviour:

Mechanisms: geochemical mechanisms controlling behaviour e.g. ion exchange, adsorption, complexation, precipitation, redox processes, pH effects, metal binding, organic matter interactions

Mineral phases: e.g. iron, aluminium and manganese oxides/hydroxides; clay minerals e.g. kaolinite, illite and smectite groups; carbonates e.g. calcite; sulfides such as pyrite; phosphate minerals e.g. apatite

Influences: effects on nutrient and contaminant retention, release, mobility and bioavailability e.g. phosphate adsorption to iron and aluminium oxides, pH buffering by carbonates, redox-related metal release from iron and manganese oxides.

Mobility of nutrients and contaminants:

Mobility, transport and speciation e.g. solubility, soil structure, water flow pathways, chemical form, mobility, transport, bioavailability, permeable soils, redox conditions, nutrient movement, contaminant movement

Influencing factors: factors influencing relative mobility and bioavailability within soil systems e.g. nitrate movement in permeable soils, differences in metal mobility under contrasting redox conditions.

Mechanistic assessment within soil systems:

Mechanistic assessment: mechanistic assessment within soil systems e.g. nutrient retention, contaminant behaviour, soil heterogeneity, changing soil conditions, variability, structured soils, poorly structured soils, organic matter content

Assessment of nutrient and contaminant behaviour: assessment based on underlying soil geochemical mechanisms e.g. contrasting nutrient retention in structured versus poorly structured soils, differences in contaminant behaviour where organic matter content varies across a site.

LO4 **Apply quantitative methods to classify and interpret soil survey and analytical data for an identified soil-related scenario**

Soil survey and analytical data:

Survey data: soil survey and analytical data e.g. quantitative soil survey information, laboratory analytical outputs, particle size distribution and percentages, texture class, pH values, organic matter content, moisture content, bulk density, permeability or drainage indicators, nutrient concentrations, contaminant concentrations, mineralogical indicators, soil profile or horizon descriptions, soil survey records, digital datasets

Analysis of data: e.g. use of data to describe soil characteristics for an identified soil-related scenario.

Soil classification and data interpretation:

Classification: soil classification e.g. quantitative data, soil classification, texture triangles, established descriptors, classification frameworks, basic calculations, descriptive statistics, tabulation, graphing, comparison with standards or threshold values, pattern identification

Soil behaviour: e.g. for identified soil-related scenario, informed judgement, drainage behaviour, nutrient retention

Analytical data interpretation: interpretation of data to describe soil characteristics and behaviour e.g. relating texture, organic matter content and pH to likely drainage behaviour, nutrient retention or suitability for an identified land use.

Sources of data:

Fieldwork sample collection e.g. sampling materials, collection tools, sampling locations, site conditions, sampling strategy, risk assessment, legislation, compliance requirements, field support, chain of custody

Data from laboratory analysis of soil samples: laboratory methods e.g. analytical testing, sample logging, sample preparation, sample source, sample provenance, storage history, handling records, analytical outputs, quality control

Secondary data sources: dataset sources e.g. survey records, database records, metadata, version control, data tracking, data quality, traceability, record keeping.

Evaluation of data use and limitations:

Evaluation of data use and limitations: interpretation of identified scenario e.g. data quality, uncertainty, limitations, quantitative methods, soil behaviour

Digital tools: e.g. use of digital tools for data summarising, data comparison, analytical outputs.

Learning Outcomes and Assessment Criteria

<table>
<tr><th>Pass</th><th>Merit</th><th>Distinction</th></tr>
<tr><td colspan="2">LO1 Explain the fundamental physical, chemical and biological properties of soils and how these properties influence soil behaviour</td><td rowspan="6">LO1, LO2 and LO3

D1 Critically evaluate how soil properties and geochemical processes collectively influence nutrient, contaminant and overall soil behaviour within soil systems.</td></tr>
<tr><td>P1 Describe key physical, chemical and biological soil properties.

P2 Explain how interactions between soil properties influence soil behaviour.</td><td>M1 Analyse how relationships between physical, chemical and biological soil properties influence soil behaviour.</td></tr>
<tr><td colspan="2">LO2 Discuss the geochemical processes that govern soil formation, transformation and weathering within natural soil systems</td></tr>
<tr><td>P3 Discuss the main geochemical processes involved in soil formation, transformation and weathering within natural soil systems.</td><td>M2 Assess how geochemical processes interact to influence soil development within natural soil systems.</td></tr>
<tr><td colspan="2">LO3 Assess the behaviour and movement of nutrients and contaminants within soil systems</td></tr>
<tr><td>P4 Explain the geochemical mechanisms controlling the behaviour of nutrients and contaminants within soil systems.

P5 Assess factors influencing the movement of nutrients and contaminants through soils.</td><td>M3 Analyse how geochemical mechanisms influence the movement of nutrients and contaminants within soil systems.</td></tr>
<tr><td colspan="2">LO4 Apply quantitative methods to classify and interpret soil survey and analytical data for an identified soil-related scenario</td><td rowspan="2">LO4

D2 Critically evaluate the suitability and limitations of the applied quantitative methods in supporting interpretation of the identified soil-related scenario.</td></tr>
<tr><td>P6 Apply appropriate quantitative methods to classify soil survey and analytical data for an identified soil-related scenario.

P7 Describe soil characteristics indicated by soil survey and analytical data for the identified scenario.</td><td>M4 Interpret soil survey and analytical data to explain soil behaviour relevant to the identified scenario.</td></tr>
</table>

Recommended Resources

Textbooks

Alloway, B.J. (ed.) (2013) *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*. 3rd edn. Dordrecht: Springer.

Amundson, R. (2021) *Introduction to the Biogeochemistry of Soils*. Cambridge: Cambridge University Press.

Blanco-Canqui, H. and Lal, R. (2023) *Soil Conservation and Management*. 2nd edn. Cham: Springer.

Brady, N.C. and Weil, R.R. (2022) *The Nature and Properties of Soils*. 15th edn. Harlow: Pearson.

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Kabata-Pendias, A. (2010) *Trace Elements in Soils and Plants*. 4th edn. Boca Raton, FL: CRC Press.

Lal, R. and Stewart, B.A. (eds.) (2021) *Soil and Climate*. Boca Raton, FL: CRC Press.

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White, R.E. (2006) *Principles and Practice of Soil Science: The Soil as a Natural Resource*. 4th edn. Oxford: Blackwell Publishing.

Websites

https://www.isric.org/explore/soilgrids	International Soil Reference and Information Centre (ISRIC) SoilGrids global soil property maps and data access (Datasets)
https://www.fao.org/soils-portal/soil-survey/soil-classification/en/	Food and Agriculture Organization of the United Nations (FAO) World Reference Base (WRB) soil classification system (Standards/Reference)
https://data.worldbank.org/indicator/AG.LND.PRCP.MM	World Bank Climate and precipitation datasets relevant to soil processes (Datasets)
Soil Science | Natural Resources Conservation Service	United States Department of Agriculture (USDA) Soil properties, formation processes and soil survey resources (General reference)
https://www.bgs.ac.uk/geology-projects/soil-geochemistry/	British Geological Survey (BGS) UK soil geochemistry maps and analytical datasets (Datasets)
Home :: Soil Health	University of California, Davis Soil physical properties and soil behaviour explanations (General reference)

Journals and articles

Bünemann, E.K., *et al.* (2018) 'Soil quality – A critical review', *Soil Biology and Biochemistry*, 120, pp. 105–125. Available at: https://doi.org/10.1016/j.soilbio.2018.01.030.

Cepeda-Salgado, B., *et al.* (2022) 'A simulation study of in-situ NAPL remediation treatment by using surfactant and foam processes in a military base South Korea', *Journal of Contaminant Hydrology*, 247, 103982. Available at: https://doi.org/10.1016/j.jconhyd.2022.103982.

Kirk, G.J.D., *et al.* (2020) 'Redox dynamics and nutrient cycling in soils', *Soil Systems*, 4(4), p. 65. Available at: https://doi.org/10.3390/soilsystems4040065.

Laveuf, C. and Cornu, S. (2009) 'A review on the potentiality of Rare Earth Elements to trace pedogenetic processes', *Geoderma*, 154(1-2), pp. 1–12. Available at: https://doi.org/10.1016/j.geoderma.2009.10.002.

Radulov, I. and Berbecea, A. (2024) 'Nutrient Management for Sustainable Soil Fertility', in *Sustainable Agroecosystems: Principles and Practices*. London: IntechOpen. Available at: https://doi.org/10.5772/intechopen.1006692.

Sharma, N., *et al.* (2022) 'Dynamic Responses of Trace Metal Bioaccessibility to Fluctuating Redox Conditions in Wetland Soils and Stream Sediments', *ACS Earth and Space Chemistry*, 6(5), pp. 1226–1237. Available at: https://doi.org/10.1021/acsearthspacechem.2c00031.

Links

This unit links to the following related units:

Unit 417: Principles of Ecology

Unit 418: Managing Environmental Resources

Unit 423: Analytical Chemistry

Unit 515: Green Chemistry

Unit 516: Sources, Impact and Control of Pollution

Unit 517: Environmental Monitoring and Analysis

Unit 526: Further Analytical Chemistry

Unit 529: Conservation and Biodiversity.

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