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Important information

Accreditation period

Units 1–4: 1 January 2023 – 31 December 2027

Implementation of this study commences in 2023.

Other sources of information

The [*VCAA Bulletin*](https://www.vcaa.vic.edu.au/news-and-events/bulletins-and-updates/bulletin/Pages/index.aspx) is the only official source of changes to regulations and accredited studies. The Bulletin also regularly includes advice on VCE studies. It is the responsibility of each VCE teacher to refer to each issue of the Bulletin. The Bulletin is available as an e-newsletter via [free subscription](https://www.vcaa.vic.edu.au/Footer/Pages/Subscribe.aspx) on the VCAA website.

To assist teachers in developing courses, the VCAA publishes online [Support materials](https://www.vcaa.vic.edu.au/curriculum/vce/vce-study-designs/chemistry/Pages/Index.aspx) (incorporating the previously known *Advice for teachers*).

The current [*VCE Administrative Handbook*](https://www.vcaa.vic.edu.au/administration/vce-vcal-handbook/Pages/index.aspx) contains essential information on assessment processes and other procedures.

VCE providers

Throughout this study design the term ‘school’ is intended to include both schools and other VCE providers.

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Introduction

Scope of study

The study of VCE Chemistry involves investigating and analysing the composition and behaviour of matter, and the chemical processes involved in producing useful materials for society in ways that minimise adverse effects on human health and the environment. Chemistry underpins the generation of energy for use in homes and industry, the maintenance of clean air and water, the production of food, medicines and new materials, and the treatment of wastes.

An important feature of undertaking a VCE science study is the opportunity for students to engage in a range of scientific investigation methodologies, to develop key science skills, and to interrogate the links between knowledge, theory and practice. Students work collaboratively as well as independently on a range of scientific investigations involving controlled experiments, fieldwork, case studies, classification and identification, modelling, simulations, literature reviews, and the development of a product, process or system. Knowledge and application of the safety considerations, including use of safety data sheets, and ethical guidelines associated with undertaking investigations is integral to the study of VCE Chemistry.

As well as increasing their understanding of scientific processes, students develop insights into how knowledge in chemistry has changed, and continues to change, in response to new evidence, discoveries and thinking. They explore the impact of chemistry on their own lives, and on society and the environment. They develop capacities that enable them to critically assess the strengths and limitations of science, respect evidence-based conclusions and gain an awareness of the ethical contexts of scientific endeavours. Students consider how science is connected to innovation in addressing contemporary chemistry-based challenges.

Rationale

VCE Chemistry enables students to investigate a range of chemical, biochemical and geophysical phenomena through the exploration of the nature of chemicals and chemical processes. Sustainability principles, concepts and goals are used to consider how useful materials for society may be produced with the least possible adverse effects on human health and the environment. In undertaking this study, students apply chemical principles to explain and quantify the behaviour of matter, as well as undertake practical activities that involve the analysis and synthesis of a variety of materials.

In VCE Chemistry, students develop and enhance a range of inquiry skills, such as practical experimentation, research and analytical skills, problem-solving skills including critical and creative thinking, and communication skills. Students pose questions, formulate hypotheses, conduct investigations, and analyse and critically interpret qualitative and quantitative data. They assess the limitations of data, evaluate methodologies and results, justify their conclusions, make recommendations and communicate their findings. Students apply chemical knowledge, scientific skills, and critical and creative thinking to investigate and analyse contemporary chemistry-related issues and communicate their views from an informed position.

VCE Chemistry provides for continuing study pathways within the discipline and can lead to a range of careers. Branches of chemistry include organic chemistry, inorganic chemistry, analytical chemistry, physical chemistry and biochemistry. In addition, chemistry is applied in many fields of human endeavour including agriculture, bushfire research, dentistry, dietetics, education, engineering, environmental science, forensic science, forestry, horticulture, medicine, metallurgy, meteorology, nursing, pharmacy, sports science, toxicology, veterinary science and viticulture.

Aims

This study enables students to:

* develop knowledge and understanding of matter and its interaction with energy, as well as key factors that affect chemical systems, to explain the properties, structures, reactions and related applications of materials in society
* understand and use the language and methodologies of chemistry to solve qualitative and quantitative problems in familiar and unfamiliar contexts
* develop knowledge and understanding of how chemical systems can be controlled to develop greener and more sustainable processes for the production of chemicals and energy while minimising any adverse effects on human health and the environment, with consideration of wastes as underutilised resources and/or feedstock for another process or product

and more broadly to:

* develop attitudes that include curiosity, open-mindedness, creativity, flexibility, integrity, attention to detail and respect for evidence-based conclusions
* develop an understanding of the cooperative, cumulative, iterative and interdisciplinary nature of science as a human endeavour, including its possibilities, limitations and sociocultural, economic, political and legal influences and consequences
* develop a range of individual and collaborative science inquiry skills through a variety of investigation methodologies in the laboratory and field, refining investigations to improve data quality
* understand the research, ethical and safety guidelines that govern the study and practice of the discipline and apply these guidelines to generate, collate, analyse, critically evaluate and report data
* analyse and interpret qualitative and quantitative data to provide evidence, recognising patterns, relationships and limitations of data
* develop an informed and critical perspective, as local and global citizens, on contemporary science-based issues
* develop knowledge and understanding of key models, concepts, theories and laws of science to explain scientific processes and phenomena, and apply this understanding in familiar and unfamiliar situations, including personal, sociocultural, environmental and technological contexts
* communicate clearly and accurately an understanding of the discipline, using appropriate terminology, conventions and formats.

Structure

The study is made up of four units.

* Unit 1: How can the diversity of materials be explained?
* Unit 2: How do chemical reactions shape the natural world?
* Unit 3: How can design and innovation help to optimise chemical processes?
* Unit 4: How are carbon-based compounds designed for purpose?

Each unit deals with specific content contained in areas of study and is designed to enable students to achieve a set of outcomes for that unit. Each outcome is described in terms of key knowledge and key skills.

Entry

There are no prerequisites for entry to Units 1, 2 and 3. Students must undertake Unit 3 and Unit 4 as a sequence. Units 1–4 are designed to the equivalent standard of the final two years of secondary education. All VCE studies are benchmarked against comparable national and international curriculum.

Duration

Each unit involves at least 50 hours of scheduled classroom instruction.

Changes to the study design

During its period of accreditation minor changes to the study will be announced in the [*VCAA Bulletin*](https://www.vcaa.vic.edu.au/news-and-events/bulletins-and-updates/bulletin/Pages/index.aspx). The Bulletin is the only source of changes to regulations and accredited studies. It is the responsibility of each VCE teacher to monitor changes or advice about VCE studies published in the Bulletin.

Monitoring for quality

As part of ongoing monitoring and quality assurance, the VCAA will periodically undertake an audit of VCE Chemistry to ensure the study is being taught and assessed as accredited. The details of the audit procedures and requirements are published annually in the [*VCE Administrative Handbook*](https://www.vcaa.vic.edu.au/administration/vce-vcal-handbook/Pages/index.aspx). Schools will be notified if they are required to submit material to be audited.

Safety and wellbeing

The study may involve the handling of potentially hazardous substances and the use of potentially hazardous equipment. It is the responsibility of the school to ensure that duty of care is exercised in relation to the health and safety of all students undertaking the study. Teachers and students should observe appropriate safety precautions when undertaking practical activities. Risk assessment should be undertaken for all chemicals used in practical investigations. All laboratory work should be supervised by the teacher. It is the responsibility of schools to ensure that they comply with health and safety requirements.

Relevant acts and regulations include:

* Occupational Health and Safety Act 2004 (Vic.)
* Electrical Safety Act 1998 (Vic.)
* Occupational Health and Safety Regulations 2017 (Vic.)
* Dangerous Goods (Storage and Handling) Regulations 2022 (Vic.)
* Code of Practice for the Storage and Handling of Dangerous Goods 2013 (WorkSafe Victoria)
* Compliance Code: Hazardous Substances, Edition 2, 2019 (WorkSafe Victoria)
* ‘Occupational Health and Safety Management Systems’ (AS/NZS ISO 45001:2018).

Teachers should ensure they access up-to-date versions of all Acts, regulations and codes.

Employability skills

This study offers a number of opportunities for students to develop employability skills. The [Support materials](https://www.vcaa.vic.edu.au/curriculum/vce/vce-study-designs/chemistry/Pages/Index.aspx) provide specific examples of how students can develop employability skills during learning activities and assessment tasks.

Legislative compliance

When collecting and using information, the provisions of privacy and copyright legislation, such as the Victorian *Privacy and Data Protection Act 2014* and *Health Records Act 2001*, and the federal *Privacy Act 1988* and *Copyright Act 1968*, must be met.

Child Safe Standards

Schools and education and training providers are required to comply with the Child Safe Standards made under the Victorian *Child Wellbeing and Safety Act 2005*. Registered schools are required to comply with *Ministerial Order No. 1359 Implementing the Child Safe Standards – Managing the Risk of Child Abuse in Schools and School Boarding Premises*. For further information, consult the websites of the [Victorian Registration and Qualifications Authority](https://www.vrqa.vic.gov.au/childsafe/Pages/Home.aspx), the [Commission for Children and Young People](https://ccyp.vic.gov.au/) and the [Department of Education and Training](https://www2.education.vic.gov.au/pal/child-safe-standards/policy).

Assessment and reporting

Satisfactory completion

The award of satisfactory completion for a unit is based on the teacher’s decision that the student has demonstrated achievement of the set of outcomes specified for the unit. Demonstration of achievement of outcomes and satisfactory completion of a unit are determined by evidence gained through the assessment of a range of learning activities and tasks.

Teachers must develop courses that provide appropriate opportunities for students to demonstrate satisfactory achievement of outcomes.

The decision about satisfactory completion of a unit is distinct from the assessment of levels of achievement. Schools will report a student’s result for each unit to the VCAA as S (satisfactory) or N (not satisfactory).

Levels of achievement

Units 1 and 2

Procedures for the assessment of levels of achievement in Units 1 and 2 are a matter for school decision. Assessment of levels of achievement for these units will not be reported to the VCAA. Schools may choose to report levels of achievement using grades, descriptive statements or other indicators.

Units 3 and 4

The VCAA specifies the assessment procedures for students undertaking scored assessment in Units 3 and 4. Designated assessment tasks are provided in the details for each unit in VCE study designs.

The student’s level of achievement in Units 3 and 4 will be determined by School-assessed Coursework (SAC) as specified in the VCE study design, and external assessment.

The VCAA will report the student’s level of achievement on each assessment component as a grade from   
A+ to E or UG (ungraded). To receive a study score the student must achieve two or more graded assessments in the study and receive an S for both Units 3 and 4. The study score is reported on a scale of 0–50; it is a measure of how well the student performed in relation to all others who took the study. Teachers should refer to the current [*VCE Administrative Handbook*](https://www.vcaa.vic.edu.au/administration/vce-vcal-handbook/Pages/index.aspx) for details on graded assessment and calculation of the study score. Percentage contributions to the study score in VCE Chemistry are as follows:

* Unit 3 School-assessed Coursework: 20 per cent
* Unit 4 School-assessed Coursework: 30 per cent
* End-of-year examination: 50 per cent.

Details of the assessment program are described in the sections on Units 3 and 4 in this study design.

Authentication

Work related to the outcomes of each unit will be accepted only if the teacher can attest that, to the best of their knowledge, all unacknowledged work is the student’s own. Teachers need to refer to the current [*VCE Administrative Handbook*](https://www.vcaa.vic.edu.au/administration/vce-vcal-handbook/Pages/index.aspx) for authentication rules and strategies.

Cross-study specifications

Key science skills

The key science skills are a core component of the study of VCE Chemistry and apply across Units 1 to 4 in all areas of study. In designing teaching and learning programs for each unit and in assessing student learning for each outcome, teachers should ensure that students are given the opportunity to develop, use and demonstrate these skills in a variety of contexts, including when undertaking their own investigations and when evaluating the research of others. As the complexity of key knowledge increases from Unit 1 to 4, and as opportunities are provided to undertake scientific investigations, students should aim to demonstrate the key science skills at a progressively higher level.

The key science skills are common to all VCE science studies and have been contextualised in the following table for VCE Chemistry.

|  |  |
| --- | --- |
| **Key science skill** | **VCE Chemistry Units 1–4** |
| Develop aims and questions, formulate hypotheses and make predictions | * identify, research and construct aims and questions for investigation * identify independent, dependent and controlled variables in experiments * formulate hypotheses to focus investigations * predict possible outcomes of investigations |
| Plan and conduct investigations | * determine appropriate investigation methodology: case study; classification and identification; controlled experiment; fieldwork; literature review; modelling; product, process or system development; simulation * design and conduct investigations; select and use methods appropriate to the selected investigation methodology, including consideration of sampling technique and size, equipment and procedures, taking into account potential sources of error and causes of uncertainty; determine the type and amount of qualitative and/or quantitative data to be generated or collated * work independently and collaboratively as appropriate and within identified research constraints, adapting or extending processes as required and recording such modifications in a logbook |
| Comply with safety and ethical guidelines | * demonstrate safe laboratory practices when planning and conducting investigations by using risk assessments that are informed by safety data sheets (SDS), and accounting for risks * apply relevant occupational health and safety guidelines while undertaking practical investigations * demonstrate ethical conduct when undertaking and reporting investigations |
| Generate, collate and record data | * systematically generate and record primary data, and collate secondary data, appropriate to the investigation, including use of databases and reputable online data sources * record and summarise both qualitative and quantitative data, including use of a logbook as an authentication of generated or collated data * organise and present data in useful and meaningful ways, including schematic diagrams, flow charts, tables, bar charts, line graphs and calibration curves |

|  |  |
| --- | --- |
| **Key science skill** | **VCE Chemistry Units 1–4** |
| Analyse and evaluate data and investigation methods | * process quantitative data using appropriate mathematical relationships and units, including calculations of ratios, percentages, percentage change and mean * use appropriate numbers of significant figures in calculations * plot graphs involving two variables that show linear and non-linear relationships * identify and analyse experimental data qualitatively, handling, where appropriate, concepts of: accuracy, precision, repeatability, reproducibility, resolution, and validity of measurements; and errors (random and systematic) * identify outliers, and contradictory, provisional or incomplete data * repeat experiments to evaluate the precision of data * evaluate investigation methods and suggest ways to improve precision, and to reduce the likelihood of errors |
| Construct evidence-based arguments and draw conclusions | * distinguish between opinion, anecdote and evidence, and between scientific and non-scientific ideas * evaluate data to determine the degree to which the evidence supports the aim of the investigation, and make recommendations, as appropriate, for modifying or extending the investigation * evaluate data to determine the degree to which the evidence supports or refutes the initial prediction or hypothesis * use reasoning to construct scientific arguments, and to draw and justify conclusions consistent with evidence and relevant to the question under investigation * identify, describe and explain the limitations of conclusions, including identification of further evidence required * discuss the implications of research findings and proposals |
| Analyse, evaluate and communicate scientific ideas | * use appropriate chemical terminology, representations and conventions, including standard abbreviations, graphing conventions, algebraic equations, units of measurement and significant figures * discuss relevant chemical information, ideas, concepts, theories and models and the connections between them * analyse and explain how models and theories are used to organise and understand observed phenomena and concepts related to chemistry, identifying limitations of selected models/theories * critically evaluate and interpret a range of scientific and media texts (including journal articles, mass media communications and opinions in the public domain), processes, claims and conclusions related to chemistry by considering the quality of available evidence * apply sustainability concepts (green chemistry principles, development goals and the transition from a linear towards a circular economy) to analyse and evaluate responses to chemistry-based scenarios, case studies, issues and challenges * identify and explain when judgements or decisions associated with chemistry-related issues may be based on sociocultural, economic, political, legal and/or ethical factors and not solely on scientific evidence * use clear, coherent and concise expression to communicate to specific audiences and for specific purposes in appropriate scientific genres, including scientific reports and posters * acknowledge sources of information and assistance, and use standard scientific referencing conventions |

Scientific investigation

Students undertake scientific investigations across Units 1 to 4 of this study. Scientific investigations may be undertaken in groups, but all work for assessment must be completed individually.

All VCE science studies include scientific investigations that are student-designed. In approving student-designed investigation topics, teachers and schools must ensure that an investigation proposed by a student for a VCE Chemistry assessment task is not able to be presented as an assessment task in another VCE study at the school.

Scientific investigation methodologies

Scientific investigations can be undertaken in a variety of ways depending on the aim of the investigation and the question under investigation. For the purposes of VCE Chemistry, the planning and conducting of scientific investigations will require consideration of the following scientific investigation methodologies:

* **Case study:** An investigation of a particular event or problem that contains a real or hypothetical situation and includes the complexities that would be encountered in the real world. Case studies can take various forms: historical, involving the analysis of causes and consequences, and discussion of knowledge learned from the situation; a real situation or a role-play of an imagined situation, where plausible recommendations are to be made; or problem-solving, where developing a new design, methodology or method is required.
* **Classification and identification:** Classification is the arrangement of phenomena, objects or events into manageable sets, whereas identification is a process of recognition of phenomena as belonging to particular sets or possibly being part of a new or unique set. The classification of organic compounds into families, for example, enables predictions of how designed molecules may behave under different physical and chemical conditions.
* **Controlled experiment:** An experimental investigation of the relationship between an independent variable and a dependent variable, controlling all other variables as is realistic. This may also include setting up a set of ‘controls’: for example, to plot a standard curve in colorimetry experiments.
* **Fieldwork:** Fieldwork involves students undertaking their own investigation to solve a problem or to investigate an issue at a specific location. Students may note the context of the site and the relevance of the site to an investigation, prediction and/or hypothesis prior to recording site data for later processing. The generation of site-specific data should be recorded in the student’s logbook.
* **Literature review:** Involves the collation and analysis of secondary data related to other people’s scientific findings and/or viewpoints in order to answer a question or provide background information to help explain observed events, or as preparation for an investigation to generate primary data.
* **Modelling:** Involves the construction of a physical model, such as a small-scale or large-scale representation of an object; a conceptual model, which represents a system involving concepts that help people know, understand or simulate the system; or a mathematical model, which describes a system using mathematical equations that involve relationships between variables and that can be used to make predictions.
* **Product, process or system development:** Design of an artefact, process or system to meet a need, which may involve technological applications in addition to scientific knowledge and procedures.
* **Simulation:** A process of using a model to study the behaviour of a real or theoretical system. The modelling and manipulation of variables in a real system is useful because often the variables cannot be controlled as the system may be too complex, too large or small, too fast or slow, not accessible or too dangerous.

Logbooks

Students undertaking this study must maintain a logbook of practical work in each of Units 1 to 4 for recording, authentication and assessment purposes. All items in the logbook must be dated and clearly documented.

The logbook is submitted as a requirement for satisfactory completion in each of Units 1 to 4. Teachers must regularly sight and monitor the logbook, particularly for the student-designed practical and/or research investigations in Outcome 3 of Units 1 and 2 and Outcome 3 of Unit 4.

The logbook may be maintained in hard-copy or electronic form.

Unit 4 scientific poster

In Unit 4, Area of Study 3, students demonstrate their science communication skills by presenting the findings of a student-designed scientific investigation and the significance of these findings to both technical and non-technical audiences as a poster. The poster may be produced electronically or in hard-copy format and should not exceed 600 words. Supporting text, such as in tables, graphs, image captions, references and acknowledgements, is not included in the word count.

Posters are not limited to a particular paper size (or number of panels). The priorities for the communication should be conciseness, clarity and legibility.

Students will use the following scientific poster format when reporting on their investigation.

|  |  |  |  |
| --- | --- | --- | --- |
|  | Title Student name | |  |
| Introduction  Methodology and methods  Results | Communication statement reporting the key finding  of the investigation as a one-sentence summary | Discussion  Conclusion | |
| References and acknowledgements | | | |

The centre of the poster will occupy between 20 to 25 per cent of the poster space and will be a one-sentence summary of the major finding of the investigation that answers the investigation question.

The presentation format of the poster will include the following sections.

|  |  |  |
| --- | --- | --- |
| **Poster section** | **Content** | |
| Title | Question under investigation | |
| Introduction | Brief explanation or reason for undertaking the investigation, including a clear aim, a hypothesis and/or prediction and relevant background chemical concepts | |
| Methodology and methods | Brief outline of the selected methodology used to address the investigation question | |
| Summary of data generation method(s) and data analysis method(s) | |
| Results | Presentation of generated data/evidence in appropriate format to illustrate trends, patterns and/or relationships | |
| Discussion | Interpretation and evaluation of analysed primary data | |
| Identification of limitations in data and methods, and suggested improvements | |
| Cross-referencing of results to relevant chemical concepts | |
| Linking of results to investigation question and to the aim to explain whether the investigation data and findings support the hypothesis | |
| Conclusion | | Conclusion that provides a response to the investigation question |
| Identification of the extent to which the analysis has answered the investigation question, with no new information being introduced |
| References and acknowledgements | | Referencing and acknowledgement of all quotations and sourced content relevant to the investigation |

Students record in their logbooks all elements of their investigation planning, comprising identification and management of relevant risks, recording of raw data, and preliminary analysis and evaluation of results, including identification of outliers and their subsequent treatment. Both the students’ poster and logbook entries are assessed as part of Unit 4, Area of Study 3.

Critical and creative thinking

Responding effectively to environmental, social and economic challenges requires young people to be creative, innovative, enterprising and adaptable, with the motivation, confidence and skills to use critical and creative thinking purposefully.

Critical and creative thinking are embedded in the key science skills and applied across the VCE sciences during learning experiences where students develop questions and hypotheses, design and undertake investigations, make reasoned predictions, generate and evaluate knowledge, clarify concepts and ideas, seek possibilities, consider alternatives and consequences, make evidence-based decisions, devise real or imagined solutions, and solve problems.

Students may engage in scientific investigations involving both primary and secondary data after they identify an aim and methodology, and develop a specific investigation method that includes consideration of a relevant procedure and equipment. A commitment to accuracy, precision and integrity in observation is an important precursor to critical thinking when generating primary data.

Problem-solving of any kind requires initial deconstruction to identify an appropriate methodology, followed by consideration of potential risks, and perseverance in adopting different strategies to develop a solution or to reach a conclusion.

In VCE Chemistry, students also consider how critical and creative thinking has been applied by others in the development of knowledge and applications related to addressing chemical challenges. Green chemistry principles, for example, apply innovative scientific solutions to address health and environmental issues associated with the production of useful materials for society.

Ethical understanding

Ethical understanding is applied across Units 1 to 4 of the VCE sciences. Students apply ethical understanding when they undertake their own investigations, analyse their own and others’ data, and identify and investigate issues relating to the application of scientific knowledge in society. Applying the knowledge and skills of ethical understanding enables students to:

* consider the implications of their own and others’ investigations of living and non-living things and the environment
* apply integrity when recording and reporting the outcomes of their own investigations, and when using their own and others’ data
* reach a position about science-related ethical issues based on an understanding of ethical concepts and scientific knowledge and skills, considering current and future needs
* recognise the importance of values, and social, economic, political and legal factors in responsible science-related decision-making.

Individual and collaborative scientific endeavour

Scientific endeavour is commonly a collaborative, and often global, undertaking that draws on the knowledge and skills of individuals. Units 1 to 4 of VCE Chemistry provide students with opportunities to manage their time effectively, work safely, make responsible decisions and constructively handle challenging situations.

When working with others, students are expected to actively participate, share ideas, and offer viewpoints and suggestions while respecting the perspectives of others. In group work, students should identify collective goals and make use of strategies to work effectively as a group member to complete tasks and solve problems.

Students learn to seek, value and act on feedback when undertaking both individual and collaborative endeavours.

Aboriginal and Torres Strait Islander knowledge, cultures and histories

Aboriginal and Torres Strait Islander peoples have diverse cultures, social structures and a history of unique and complex knowledge systems. In VCE Chemistry, students consider how scientific thinking can be informed and enhanced by considering how Aboriginal and Torres Strait Islander peoples have developed and refined their own knowledge about the world through: observation, using all the senses; prediction and hypothesis testing, including trial-and-error; and making generalisations within specific contexts, including the use of plants as medicine and the use and modification of natural materials for useful purposes.

Teachers are encouraged to include Aboriginal and Torres Strait Islander knowledge and perspectives in the design and delivery of teaching and learning programs related to VCE Chemistry. Many local Aboriginal and Torres Strait Islander communities have protocols that they have developed in relation to education. The Victorian Koorie community-preferred education model enables teachers to focus on inclusively supporting students to consider Victorian Koorie education matters, and systematically support students to learn about local, regional, state and national Indigenous perspectives. VCE studies involve a focused extension of this model and include a broader application of national and international perspectives.

*Protocols for Koorie Education in Victorian Primary and Secondary Schools*, developed through the Yalca policy, and other resources relating to the inclusion of Aboriginal and Torres Strait Islander knowledge and perspectives can be accessed on the [Victorian Aboriginal Education Association (VAEAI) website](http://www.vaeai.org.au/documents/).

Terms used in this study

For the purposes of this study design and associated assessment, the following definitions will apply. The [Support materials](https://www.vcaa.vic.edu.au/curriculum/vce/vce-study-designs/chemistry/Pages/Index.aspx) provide additional information and should be used in conjunction with this study design.

Data and measurement

A major aim of science is to develop explanations that are supported by evidence for natural phenomena and events. This involves considering the quality and quantity of evidence and, before conclusions are drawn from data, considering questions such as ‘Can I rely on the data I have generated when drawing conclusions?’ and ‘Does the difference between one measurement and another indicate a real change in what is being measured?’.

When analysing and discussing investigations of a quantitative nature, the following terms require consideration:

* **True value:** The value that would be found if the quantity could be measured perfectly.
* **Accuracy:** A measurement value is considered to be accurate if it is judged to be close to the true value of the quantity being measured. Accuracy is a qualitative term; a measurement value or measurement result may be described, for example, as being ‘less accurate’ or ‘more accurate’ when compared with a true value.
* **Precision**: A measure of the repeatability or reproducibility of scientific measurements and refers to how close two or more measurements are to each other. A set of precise measurements will have values very close to the mean value of the measurements. Precision gives no indication of how close the measurements are to the true value and is therefore a separate consideration to accuracy.
* **Measurement result**: Refers to a final result, usually the average of several measurement values. In the (unusual) case where only one value has been measured, then measurement result also applies to that single measurement value.
* **Repeatability:** The closeness of the agreement between the results of successive measurements of the same quantity being measured, carried out under the same conditions of measurement. These conditions include the same observer, the same measurement procedure, the same measuring instrument used under the same conditions, the same location, and replicate measurements on the same or similar objects over a short period of time. Experiments that use subjective human judgement(s) or that involve small sample sizes may yield results that may not be repeatable. Repeatability can be used to evaluate the quality of data in terms of the precision of measurement results. Ideally, measurements should be repeated where possible to produce a measurement result.
* **Reproducibility:** The closeness of the agreement between the results of measurements of the same quantity being measured, carried out under changed conditions of measurement. These changed conditions, involving replicate measurements on the same or similar objects, include a different observer, different method of measurement, different measuring instrument, different location, different conditions of use and different time. The purposes of reproducing experiments include checking of claimed precision and uncovering of any systematic errors that may affect accuracy from one or other experiments/groups. Experiments that use subjective human judgement(s) or that involve small sample sizes or insufficient measurements may also yield results that may not be reproducible. Reproducibility links closely to the accuracy of an experiment. Reproducibility can also be used to evaluate the quality of data in terms of the precision of measurement results.
* **Resolution:** The smallest change in the quantity being measured that causes a perceptible change in the value indicated on the measuring instrument. This has implications for determining the number of decimal places to which a quantity may be quoted. For example, if the measurement scale on a 50 mL burette is at 0.1 mL intervals, the resolution of the burette is said to be 0.1 mL. In a titration, the user must estimate the volume between the two marked intervals on the burette so that the value reported will be to two decimal places. For example, measurement readings of 10.50 mL or 10.55 mL are possible, but a measurement reading of 10.53 mL cannot be claimed. The meniscus of the liquid will either be on the burette line marking, in which case the reading would be 10.50, or it will lie between 10.50 and 10.60, in which case it is measured as 10.55 mL.
* **Validity:** A valid experiment investigates what it sets out and/or claims to investigate. Both experimental design and the implementation should be considered when evaluating validity. An experiment and its associated data may not be valid, for example, if the investigation is flawed and controlled variables have been allowed to change. Data may not be valid, for example, if there is observer bias.

Measurement errors, uncertainty, significant figures and outliers

Measurements of quantities are made with the aim of finding the true value of that quantity. In reality, it is impossible to obtain the true value of any quantity since there will always be variations and errors.

For the purposes of this study, the term **‘measurement error**’ is used to describe the difference between a measurement result and the true value.

* **Random errors**: Affect the precision of a measurement and may be present in all measurements. Random errors are unpredictable variations in the measurement process and result in a spread of readings.
* **Systematic errors**: Cause readings to differ from the true value in a systematic manner so that when a particular value is measured repeatedly, the error is the same. Systematic errors result from limitations in the instrument itself or incorrect calibration, or inappropriate methods (including parallax).
* **Repeated measurements**: Are made to reduce the effect of random errors (and reduce the likelihood of mistakes).
* **Mistakes**: Sometimes called personal errors. Mistakes should not be included in reporting and analysis as part of the ethical consideration of data handling. Rather, the experiment should be repeated correctly.
* **Uncertainty**: The uncertainty of the result of a measurement reflects the lack of exact knowledge of the value of the quantity being measured. VCE Chemistryrequires only a qualitative treatment of uncertainty.
* **Significant figures**: Should be considered in all calculations. The following guidelines apply to   
  VCE Chemistry:
* all digits in numbers expressed in standard form are significant: for example, 4.320 x 10-6 has four significant figures
* all non-zero numbers are significant: for example, 42.3 has three significant figures
* zeros between two non-zero numbers are significant: for example, 4.302 has four significant figures
* leading zeros are not significant: for example, 0.0043 has two significant figures
* trailing zeros to the right of a decimal point are significant: for example, 42.00 has four significant figures
* for numbers less than one, 0.4 has one significant figure and 0.04 also has one significant figure, whereas 0.40 has two significant figures and 0.400 has three significant figures
* whole numbers written without a decimal point will have the same number of significant figures as the number of digits, with the assumption that the decimal point occurs at the end of the number: for example, 400 has three significant figures. Therefore, a stated volume of ‘400 mL’ will be considered as having three significant figures.
* **Outliers**: Data points or observations that differ significantly from other data points or observations are sometimes called outliers. Outliers in data must be further analysed and accounted for, rather than being automatically dismissed, as an ethical approach to dealing with data. Repeating readings may be useful in further examining an outlier: for example, to determine whether the outlier is a personal mistake.
* **Data evaluation**: When evaluating personally sourced or provided data, students should be able to identify contradictory, provisional and incomplete data including possible sources of personal bias.

Data book

The VCE Data Book available on the VCAA website should be considered to be an integral part of the study design and not just reserved for use during the external examination. The data book contains useful data, chemical relationships and equations, physical constants and standard values, representations and formulas of organic molecules, spectroscopy data and tables of information. It is recommended that the data book be used in teaching and learning and for school-based assessments.

Sustainability

In VCE Chemistry, sustainability is considered in terms of three perspectives: sustainable development, green chemistry principles and the move from a linear economy towards a circular economy.

Sustainable development

Based on *Our Common Future,* the Brundtland Report (World Commission on Environment and Development [WCED], 1987), the term ‘sustainable development’is defined as that which meets the needs of the present without compromising the ability of future generations to meet their own needs. This has led to the [United Nations’ Sustainable Development Goals](https://sdgs.un.org/goals) – 17 goals that address current global challenges as part of the 2030 Agenda for Sustainable Development.

While chemistry is involved in all 17 of the sustainable development goals, nine are particularly relevant to the study of VCE Chemistry:

* Goal 2: Zero hunger
* Goal 6: Clean water and sanitation
* Goal 7: Affordable and clean energy
* Goal 9: Industry, innovation and infrastructure
* Goal 11: Sustainable cities and communities
* Goal 12: Responsible consumption and production
* Goal 13: Climate action
* Goal 14: Life below water
* Goal 15: Life on land.

Green chemistry principles

Society relies on the chemical industry for a variety of products through various chemical processes and pathways. To improve the life cycle management of manufactured goods and their associated processes, a broad and global transformation towards a safe and more sustainable chemical future is required. The creation, use, re-use, disposal and elimination of chemicals should be achieved with the least possible adverse effects on human health and the environment while still providing economic and social benefits.

Green chemistry is the design of new chemical products and manufacturing processes that are safer and more sustainable than traditionally used products and processes. It is underpinned by a set of 12 principles that aim to minimise the impact of the product or process on the environment, Earth’s resources, human health and the viability of other living organisms. These principles are based on reducing risk, minimising the production of unwanted by-products and wastes, and limiting the amount of energy used and raw materials (particularly non-renewable raw materials) consumed. Creativity and innovation are required to apply green chemistry principles to chemical manufacturing as new products are designed and produced.

Paul T Anastas and John C Warner developed the 12 Principles of Green Chemistry in 1991. Of these, seven principles are particularly relevant to the study of VCE Chemistry.

* **Atom economy**: Processes/pathways should be designed to maximise incorporation of all reactant materials used in the process into the final product.
* **Catalysis:** Catalysts should be selected to generate the same desired product(s) with less waste and using less energy and reagents in reaction processes/pathways.
* **Design for degradation**: Chemical products should be designed so that at the end of their use they break down into harmless degradation products and do not persist in the environment.
* **Design for energy efficiency**: Processes/pathways should be designed for maximum energy efficiency and with minimal negative environmental and economic impacts.
* **Designing safer chemicals**: Chemical products should be designed to achieve their intended function while minimising toxicity.
* **Prevention of wastes**: It is better to prevent waste than to treat or clean up waste after it has been produced.
* **Use of renewable feedstocks**: Raw materials or feedstocks should be made from renewable (mainly plant-based) materials, rather than from fossil fuels, whenever practicable.

Linear and circular economies

Resources are at risk of becoming scarce due to a growing global population and rising prosperity levels. Available resources must therefore be used as efficiently as possible. A transition from a linear economy towards a circular economy is increasingly being adopted by society and industry as a strategy to achieve more sustainable development.

**Linear economy:** Operates on a ‘take-make-dispose’ model, making use of resources to produce products that will be discarded after use. A simple representation is shown below.

Logo

Description automatically generated

**Circular economy:** A continuous cycle that focuses on the optimal use and re-use of resources from the extraction of raw materials through to production of new materials, followed by consumption and re-purposing of unused and waste materials. A simple representation is shown below.

Diagram

Description automatically generated

Unit 1: How can the diversity of materials be explained?

The development and use of materials for specific purposes is an important human endeavour. In this unit students investigate the chemical structures and properties of a range of materials, including covalent compounds, metals, ionic compounds and polymers. They are introduced to ways that chemical quantities are measured. They consider how manufacturing innovations lead to more sustainable products being produced for society through the use of renewable raw materials and a transition from a linear economy towards a circular economy.

Students conduct practical investigations involving the reactivity series of metals, separation of mixtures by chromatography, use of precipitation reactions to identify ionic compounds, determination of empirical formulas, and synthesis of polymers.

Throughout this unit students use chemistry terminology including symbols, formulas, chemical nomenclature and equations to represent and explain observations and data from their own investigations and to evaluate the chemistry-based claims of others.

A student-directed research investigation into the sustainable production or use of a selected material is to be undertaken in Area of Study 3. The investigation explores how sustainability factors such as green chemistry principles and the transition to a circular economy are considered in the production of materials to ensure minimum toxicity and impacts on human health and the environment. The investigation draws on key knowledge and key science skills from Area of Study 1 and/or Area of Study 2.

Area of Study 1

How do the chemical structures of materials explain their properties and reactions?

In this area of study students focus on elements as the building blocks of useful materials. They investigate the structures, properties and reactions of carbon compounds, metals and ionic compounds, and use chromatography to separate the components of mixtures. They use metal recycling as a context to explore the transition in manufacturing processes from a linear economy to a circular economy.

The selection of learning contexts should allow students to develop practical techniques to investigate the properties and reactions of various materials. Students develop their skills in the use of scientific equipment and apparatus. Students may conduct flame tests to identify elements in the periodic table. They may model covalent, metallic and ionic structures using simple ball-and-stick models and may use computer simulations of the three-dimensional representations of molecules and lattices to better understand structures. They use solubility tables to experimentally identify unknown ions in solution. They respond to challenges such as developing their own reactivity series by reacting samples of metals with acids, oxygen and water.

Outcome 1

On completion of this unit the student should be able to explain how elements form carbon compounds, metallic lattices and ionic compounds, experimentally investigate and model the properties of different materials, and use chromatography to separate the components of mixtures.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Elements and the periodic table

* the definitions of elements, isotopes and ions, including appropriate notation: atomic number; mass number; and number of protons, neutrons and electrons
* the periodic table as an organisational tool to identify patterns and trends in, and relationships between, the structures (including shell and subshell electronic configurations and atomic radii) and properties (including electronegativity, first ionisation energy, metallic and non-metallic character and reactivity) of elements
* critical elements (for example, helium, phosphorus, rare-earth elements and post-transition metals and metalloids) and the importance of recycling processes for element recovery

Covalent substances

* the use of Lewis (electron dot) structures, structural formulas and molecular formulas to model the following molecules: hydrogen, oxygen, chlorine, nitrogen, hydrogen chloride, carbon dioxide, water, ammonia, methane, ethane and ethene
* shapes of molecules (linear, bent, pyramidal, and tetrahedral, excluding bond angles) as determined by the repulsion of electron pairs according to valence shell electron pair repulsion (VSEPR) theory
* polar and non-polar character with reference to the shape of the molecule
* the relative strengths of intramolecular bonding (covalent bonding) and intermolecular forces (dispersion forces, dipole-dipole attraction and hydrogen bonding)
* physical properties of molecular substances (including melting points and boiling points and non-conduction of electricity) with reference to their structure and bonding
* the structure and bonding of diamond and graphite that explain their properties (including heat conductivity and electrical conductivity and hardness) and their suitability for diverse applications

Reactions of metals

* the common properties of metals (lustre, malleability, ductility, melting point, heat conductivity and electrical conductivity) with reference to the nature of metallic bonding and the existence of metallic crystals
* experimental determination of a reactivity series of metals based on their relative ability to undergo oxidation with water, acids and oxygen
* metal recycling as an example of a circular economy where metal is mined, refined, made into a product, used, disposed of via recycling and then reprocessed as the same original product or repurposed as a new product

Reactions of ionic compounds

* the common properties of ionic compounds (brittleness, hardness, melting point, difference in electrical conductivity in solid and molten liquid states), with reference to the nature of ionic bonding and crystal structure
* deduction of the formula and name of an ionic compound from its component ions, including polyatomic ions (NH4+, OH‾, NO3‾, HCO3‾, CO32‾, SO42‾ and PO43‾)
* the formation of ionic compounds through the transfer of electrons from metals to non-metals, and the writing of ionic compound formulas, including those containing polyatomic ions and transition metal ions
* the use of solubility tables to predict and identify precipitation reactions between ions in solution, represented by balanced full and ionic equations including the state symbols: (s), (l), (aq) and (g)

Separation and identification of the components of mixtures

* polar and non-polar character with reference to the solubility of polar solutes dissolving in polar solvents, and non-polar solutes dissolving in non-polar solvents
* experimental application of chromatography as a technique to determine the composition and purity of different types of substances, including calculation of Rf values

Area of Study 2

How are materials quantified and classified?

In this area of study students focus on the measurement of quantities in chemistry and the structures and properties of organic compounds, including polymers.

The selection of learning contexts should allow students to develop practical techniques to quantify amounts of substances and to investigate the chemistry of organic compounds. Students develop their skills in the use of scientific equipment and apparatus. They perform calculations based on the generation of primary data, such as determining the empirical formula of an ionic compound or hydrated salt, and consider how the quality of data generated in experiments can be improved. They may construct models to visualise the similarities and differences between families of organic compounds. Students may use common substances in their experiments such as making glue from milk. They may investigate the environmental impact of the production of polymers: for example, the recycling of biodegradable polymers derived from natural resources such as biopolyethene (Bio-PE). Students respond to challenges such as investigating how changing formulations for polymers affects their structure and properties: for example, by creating slime.

Outcome 2

On completion of this unit the student should be able to calculate mole quantities, use systematic nomenclature to name organic compounds, explain how polymers can be designed for a purpose, and evaluate the consequences for human health and the environment of the production of organic materials and polymers.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Quantifying atoms and compounds

* the relative isotopic masses of isotopes of elements and their values on the scale in which the relative isotopic mass of the carbon-12 isotope is assigned a value of 12 exactly
* determination of the relative atomic mass of an element using mass spectrometry (details of instrument not required)
* Avogadro’s constant as the number 6.02 × 1023 indicating the number of atoms or molecules in a mole of any substance; determination of the amount, in moles, of atoms (or molecules) in a pure sample of known mass
* determination of the molar mass of compounds, the percentage composition by mass of covalent compounds, and the empirical and molecular formula of a compound from its percentage composition by mass

Families of organic compounds

* the grouping of hydrocarbon compounds into families (alkanes, haloalkanes, alkenes, alcohols, carboxylic acids) based upon similarities in their physical and chemical properties, including general formulas and general uses based on their properties
* representations of organic compounds (structural formulas, semi-structural formulas) and naming according to the International Union of Pure and Applied Chemistry (IUPAC) systematic nomenclature (limited to non-cyclic compounds up to C8, and structural isomers up to C5)
* plant-based biomass as an alternative renewable source of organic chemicals (for example, solvents, pharmaceuticals, adhesives, dyes and paints) traditionally derived from fossil fuels
* materials and products used in everyday life that are made from organic compounds (for example, synthetic fabrics, foods, natural medicines, pesticides, cosmetics, organic solvents, car parts, artificial hearts), the benefits of those products for society, and the health and/or environmental hazards they pose

Polymers and society

* the differences between addition and condensation reactions as processes for producing natural and manufactured polymers from monomers
* the formation of addition polymers by the polymerisation of alkene monomers
* the distinction between linear (thermoplastic) and cross-linked (thermosetting) addition polymers with reference to structure and properties
* the features of linear addition polymers designed for a particular purpose, including the selection of a suitable monomer (structure and properties), chain length and degree of branching
* the categorisation of different plastics as fossil fuel based (HDPE, PVC, LDPE, PP, PS) and as bioplastics (PLA, Bio-PE, Bio-PP); plastic recycling (mechanical, chemical, organic), compostability, circularity and renewability of raw ingredients
* innovations in polymer manufacture using condensation reactions, and the breakdown of polymers using hydrolysis reactions, contributing to the transition from a linear economy towards a circular economy

Area of Study 3

How can chemical principles be applied to create a more sustainable future?

Knowledge of the structure and properties of matter has developed over time through scientific and technological research, leading to the production of a range of useful chemicals, materials and products for society. Chemists today, through sustainable practices, seek to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Chemists also learn from Aboriginal and Torres Strait Islander peoples about the ways that they sustainably modify and process raw materials using techniques developed over millennia. Sustainability requires innovation in designing and discovering new chemicals, production processes and product management systems that will provide increased yield or performance at a lower cost while meeting the goals of protecting and enhancing human health and the environment.

In this area of study students undertake an investigation involving the selection and evaluation of a recent discovery, innovation, advance, case study, issue or challenge linked to the knowledge and skills developed in Unit 1 Area of Study 1 and/or Area of Study 2, including consideration of sustainability concepts (green chemistry principles, sustainable development and the transition towards a circular economy). Examples of investigation topics and possible research questions are provided below.

Students may select a research question related to the investigation topics included below or, in conjunction with their teacher, develop their own research question related to Unit 1 Area of Study 1 and/or Area of Study 2. Possible starting points when developing a research question may include visiting a chemical laboratory, local chemical manufacturer or industrial plant; announcements of recent materials science research findings; an interview with an expert involved in materials science or sustainability; an expert’s published point of view; a public concern about an issue related to the production of a chemical or material; ‘green field’ research leading to new technologies; changes in government funding or policy or new government initiatives, such as incentives promoting the transition from a linear economy to a circular economy; case studies related to how Aboriginal and Torres Strait Islander peoples process natural materials for particular purposes; a TED talk; a YouTube presentation; or an article from a scientific publication.

Students apply critical and creative thinking and science inquiry skills to prepare a communication to explain the relevant chemical concepts associated with their investigation, critically examine the information and data available to answer the research question, and identify the sociocultural, economic, political, legal and ethical implications of the selected investigation in terms of sustainability.

Investigation topic 1: Endangered elements in the periodic table

Today’s chemists are involved in many branches of chemistry, covering all 118 elements in the periodic table. Some of these elements are now considered to be critical and endangered, particularly due to the prevalence of modern technologies that rely on many different scarce minerals. It has been estimated that   
44 elements will soon be, or are already, facing supply limitations, making a future of continuing technological advancement uncertain.

Questions that may be explored in this investigation include:

* Which chemicals are used in the manufacture of fireworks, what is the environmental impact of the combustion of these chemicals to produce the colourful effects seen in fireworks displays, and what alternatives are available?
* Based on their usefulness for society, how would you compare the value of lanthanoids and actinoids with the value of other metal groups in the periodic table?
* Why is helium classified as a critical and endangered element, and how can it be saved given that its atmospheric recovery is almost impossible?
* How is indium mined and used in the manufacture of products such as LCD screen televisions and computer monitors, mobile phones or photovoltaic panels, and what alternatives are available if indium becomes scarce?
* How do the properties of the metalloids (such as germanium, antimony, tellurium) differ so much to their neighbours on the periodic table, and how have these properties made them highly important for society and consequentially scarce in supply?
* How are precious metals from electronic waste (e-waste) recycled and what are the environmental and economic benefits of these recovery processes?

Investigation topic 2: Producing and using ‘greener’ polymers

Both natural and synthetic polymers play an important role in everyday life. The cells in animals and plants are built of, and metabolise, natural polymers. Proteins and carbohydrates in our food are both polymers. Synthetic polymers are used for a myriad of purposes in everyday life but may present challenges in terms   
of the by-products resulting from their manufacture or breakdown, and their persistence in the environment. The sustainability of polymers can be considered in terms of whether these plastics can be avoided by using different products or activities, reduced through design, or replaced by different materials.

Questions that may be explored in this investigation include:

* What are plant-based biopolymers and what are the impacts of their production on the environment?
* How do biodegradable and degradable polymers, compostable polymers and recyclable polymers differ in structure, production and environmental impacts?
* What is the difference between micropolymers and nanopolymers, and how are used plastic materials and litter managed and repurposed?
* Is the recycling of packaging products containing aluminium more sustainable than LDPE polymer-based packaging products?
* Why is the sale of plastic water bottles and single-use plastics banned in many countries?
* How do animal proteins compare with non-animal proteins for different applications, such as meat substitutes and non-animal leather?
* How do the chemical structures of elastomers differ from the structures of thermosetting and thermoplastic polymers, and what are the implications of the production of elastomers for society?
* What impact does the vulcanisation of rubber have on the environment and the communities where rubber is sourced and produced?
* What are the risks and benefits to the environment of the manufacturing, production and application of synthetic fibres for the textile industry (for example, synthetic grass, active wear, shoes and single-use plastics such as takeaway cups, containers, and electrical and electronic products such as mobile phone cords and USB flash drives)?

Investigation topic 3: The chemistry of Aboriginal and Torres Strait Islander peoples’ practices

Throughout history, people all over the world have hypothesised, experimented, made empirical observations, gathered evidence, recognised patterns, verified through repetition, and made inferences and predictions to help them to make sense of the world around them and their place within it. Recent research and discussion have confirmed many Aboriginal and Torres Strait Islander groups use the environment and its resources to solve the challenges they face in the different Australian climates in ways that are more sustainable than similar materials produced in Western society. Their solutions can be explained by a variety of organic and non-organic chemical processes.

Questions that may be explored in this investigation include:

* Which plants are important to Aboriginal and Torres Strait Islander peoples for their medicinal properties, how are the plants processed before they are used, and what are the active ingredients (for example, the terpineols, cineoles and pinenes as the active constituents of tea trees and eucalyptus resin)?
* What are the chemical processes that occur when Aboriginal and Torres Strait Islander peoples detoxify poisonous food items: for example, the preparation of nardoo as a food source by heating, and the detoxification of cycad seeds through the removal of cycasins?
* How do Aboriginal and Torres Islander peoples utilise animal fats, calcination and plant pigments to vary the properties of the paints they make, and how does this compare to Western paint production processes and materials?
* How do binders and fixatives work to allow Aboriginal and Torres Islander peoples’ paintings to be preserved for thousands of years?
* How do Aboriginal and Torres Islander peoples’ glue formulations parallel the use of modern epoxy resins, and how sustainable are the chemical processes involved in producing these materials?
* How are plant-based toxins such as saponins used in Aboriginal and Torres Strait Islander peoples’ fishing practices, and how is this similar to other First Nation Peoples’ fishing practices around the world?
* Kakadu plums have long been a component of Aboriginal and Torres Islander Peoples diets. What active ingredients do they contain that may make them a ‘super food’?

Investigation topic 4: The sustainability of a commercial product or material

In Australia, new materials that are useful for society tend to be produced through a linear economy in which products are purchased, used and then thrown away. Increasingly, manufacturing companies are moving towards a circular economy, which seeks to reduce the environmental impacts of production and consumption while enabling economic growth through more productive use of natural resources and creation of less waste.

Research questions that may be explored in this investigation include:

* What is ‘green steel’ and what are the implications of its production for human health and the environment?
* Research a metal mined in Australia: for example, gold, copper or lithium. How is the metal processed and what are its useful properties? To what extent has the metal production and use moved towards a circular economy over the last decade? What innovations have led to the production of the metal being more sustainable over time?
* Select a commercial product that is available in different formulations: for example, vinegar (fermented, synthetic); salt (river salt, sea salt, iodised salt, Himalayan salt); cleaning products (soaps and detergents); oil (fish oil, coconut oil, olive oil); or milk (whole milk, skim milk, low-fat milk, A2 milk, plant milks such as almond, soy and coconut). What ingredients are in the product? How do the ingredients compare in the different product formulations? How is the product made? To what extent does the production of the product involve a linear economy or a circular economy? How does the production and use of the product impact human health and the environment?
* Select a product whose composition has changed over time: for example, hair comb (tortoiseshell to polymer); dental fillings (from silver amalgam and gold to porcelain and composite resin fillings); contact lenses (glass to polymers); paints (lead-based to oil-based and water-based); and tennis racquet strings (from cat gut to nylon and polyester). How have the properties and efficacies of the products changed over time? To what extent have the manufacturing processes become ‘greener’?
* Examine the life cycle of a new product or material: for example, unbreakable glass inspired by seashells; new nanomaterials for the treatment of skin infections; and ultra-thin self-healing polymers to make water-resistant coatings. What is the relationship between the properties, structure and the nature and strength of the chemical bonding in the product or material? What are the raw materials used to make the product or material? How is the product or material manufactured? How are the by-products of production treated and managed? Is the product recyclable? Can any wastes during production or at the end of the product’s use be repurposed into a useful product or material?

Outcome 3

On completion of this unit the student should be able to investigate and explain how chemical knowledge is used to create a more sustainable future in relation to the production or use of a selected material.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Scientific evidence

* the distinction between primary and secondary data
* the nature of evidence and information: distinction between opinion, anecdote and evidence; and scientific and non-scientific ideas
* the quality of evidence, including validity and authority of data and sources of possible errors or bias
* methods of organising, analysing and evaluating secondary data
* the use of a logbook to authenticate collated data

Sustainability

* sustainability concepts and principles: green chemistry principles, sustainable development, and the transition from a linear economy towards a circular economy
* identification of sustainability concepts and principles relevant to the selected research question

Scientific communication

* chemical concepts specific to the investigation: definitions of key terms; and use of appropriate chemical terminology, conventions and representations
* characteristics of effective science communication: accuracy of chemical information; clarity of explanation of chemical concepts, ideas and models; contextual clarity with reference to importance and implications of findings; conciseness and coherence; and appropriateness for purpose and audience
* the use of data representations, models and theories in organising and explaining observed phenomena and chemical concepts, and their limitations
* the influence of social, economic, legal and/or political factors relevant to the selected research question
* conventions for referencing and acknowledging sources of information

Assessment

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks that provide a range of opportunities for students to demonstrate the key science skills and key knowledge in the outcomes.

The areas of study, including the key science skills and key knowledge listed for the outcomes, should be used for course design and the development of learning activities and assessment tasks. Assessment must be a part of the regular teaching and learning program and should be completed mainly in class and within a limited timeframe.

All assessments at Units 1 and 2 are school-based. Assessment instruments should be aligned with the VCE assessment principles. Procedures for assessment of levels of achievement in Units 1 and 2 are a matter for school decision.

For this unit students are required to demonstrate three outcomes. As a set these outcomes encompass the areas of study in the unit.

Suitable tasks for assessment in this unit may be selected from the following:

**Outcome 1 and Outcome 2**

For each outcome, at least one task selected from:

* a report of a laboratory or fieldwork activity, including the generation of primary data
* comparison and evaluation of chemical concepts, methodologies and methods, and findings from at least two student practical activities
* reflective annotations of one or more practical activities from a logbook
* a summary report of selected practical investigations
* critique of an experimental design, chemical process or apparatus
* analysis and evaluation of generated primary and/or collated secondary data
* a modelling or simulation activity
* a media analysis/response
* problem-solving involving chemical concepts, skills and/or issues
* a report of an application of chemical concepts to a real-world context
* analysis and evaluation of a chemical innovation, research study, case study, socio-scientific issue, secondary data or a media communication, with reference to sustainability (green chemistry principles, sustainable development and/or the transition to a circular economy)
* an infographic
* a scientific poster.

If multiple tasks are selected for Outcome 1 and/or Outcome 2, they must be different. The same task cannot be selected more than once across Outcomes 1 and 2.

Where teachers allow students to choose between tasks, teachers must ensure that the tasks they set are of comparable scope and demand.

**Outcome 3**

* a response to a question involving the production or use of a selected material, including reference to sustainability

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on [page 13](#methodologies). A minimum of 10 hours of class time should be devoted to student practical activities and investigations across Areas of Study 1 and 2. For Area of Study 3, a minimum of seven hours of class time should be devoted to undertaking the investigation and communicating findings.

Unit 2: How do chemical reactions shape the natural world?

Society is dependent on the work of chemists to analyse the materials and products in everyday use. In this unit students analyse and compare different substances dissolved in water and the gases that may be produced in chemical reactions. They explore applications of acid-base and redox reactions in society.

Students conduct practical investigations involving the specific heat capacity of water, acid-base and redox reactions, solubility, molar volume of a gas, volumetric analysis, and the use of a calibration curve.

Throughout the unit students use chemistry terminology, including symbols, formulas, chemical nomenclature and equations, to represent and explain observations and data from their own investigations and to evaluate the chemistry-based claims of others.

A student-adapted or student-designed scientific investigation is undertaken in Area of Study 3. The investigation involves the generation of primary data and is related to the production of gases, acid-base or redox reactions, or the analysis of substances in water. It draws on the key science skills and key knowledge from Unit 2 Area of Study 1 and/or Area of Study 2.

Area of Study 1

How do chemicals interact with water?

In this area of study students focus on understanding the properties of water and investigating acid-base and redox reactions. They explore water’s properties, including its density, specific heat capacity and latent heat of vaporisation. They write equations for acid-base and redox reactions, and apply concepts including pH as a measure of acidity. They explore applications of acid-base reactions and redox reactions in society.

The selection of learning contexts should allow students to develop practical techniques to investigate the properties of water and acid-base and redox reactions. Students develop their skills in the use of scientific equipment and apparatus. They may demonstrate their understanding of concentration using coloured solutions such as ammonium molybdate. Students explore pH: for example, by making their own indicators from natural materials, developing their own pH scale and comparing the accuracy of their indicators with commercial indicators. They may investigate redox reactions by comparing corrosion rates of iron in tap water and sea water or building simple cells to power a diode. They respond to challenges such as investigating the action of soda water on seashells and linking their findings to socio-scientific issues such   
as ocean acidification.

Outcome 1

On completion of this unit the student should be able to explain the properties of water in terms of structure and bonding, and experimentally investigate and analyse applications of acid-base and redox reactions in society.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Water as a unique chemical

* the existence of water in all three states at Earth’s surface, including the distribution and proportion of available drinking water
* explanation of the anomalous properties of H2O (ice and water), with reference to hydrogen bonding:
* trends in the boiling points of Group 16 hydrides
* the density of solid ice compared with liquid water at low temperatures
* specific heat capacity of water including units and symbols
* the relatively high latent heat of vaporisation of water and its impact on the regulation of the temperature of the oceans and aquatic life

Acid-base (proton transfer) reactions

* the Brønsted-Lowry theory of acids and bases, including polyprotic acids and amphiprotic species, and the writing of balanced ionic and full equations, with states, for their reactions in water
* the distinction between strong and weak acids and strong and weak bases, and between concentrated and dilute acids and bases, including common examples
* neutralisation reactions to produce salts:
* reactions of acids with metals, carbonates and hydroxides, including balanced full and ionic equations, with states
* types of antacids and their use in the neutralisation of stomach acid
* use of the logarithmic pH scale to rank solutions from most acidic to most basic; calculation of pH for strong acid and strong base solutions of known concentration using the ionic product of water (Kw at a given temperature)
* accuracy and precision in measurement as illustrated by the comparison of natural indicators, commercial indicators, and pH meters to determine the relative strengths of acidic and basic solutions
* applications of acid-base reactions in society: for example, natural acidity of rain due to dissolved CO2 and the distinction between the natural acidity of rain and acid rain, or the action of CO2 forming a weak acid in oceans and the consequences for shell growth in marine invertebrates

Redox (electron transfer) reactions

* oxidising and reducing agents, and redox reactions, including writing of balanced half and overall redox equations (including in acidic conditions), with states
* the reactivity series of metals and metal displacement reactions, including balanced redox equations, with states
* applications of redox reactions in society: for example, corrosion or the use of simple primary cells in the production of electrical energy from chemical energy

Area of Study 2

How are chemicals measured and analysed?

In this area of study students focus on the analysis and quantification of chemical reactions involving acids, bases, salts and gases. They measure the solubility of substances in water, explore the relationship between solubility and temperature using solubility curves, and learn to predict when a solute will dissolve or crystallise out of solution. They quantify amounts in chemistry using volumetric analysis, application of the ideal gas equation, stoichiometry and calibration curves.

The selection of learning contexts should allow students to develop practical techniques to investigate substances that may be dissolved in water or found in soils, particularly salts, acids and bases, as well as gases. Students develop their skills in the use of scientific equipment and apparatus. They use precipitation reactions to purify water: for example, by using iron or aluminium compounds to precipitate and remove phosphorus from wastewater. They perform acid-base titrations, such as comparing the ethanoic acid concentrations of vinegar, mayonnaise and tomato sauce. They construct calibration curves to analyse unknown concentrations of substances, such as the amount of nitrates or phosphates in water or soil samples. Students respond to challenges such as determining the set of standards required in setting up   
a calibration curve in colorimetry.

Outcome 2

On completion of this unit the student should be able to calculate solution concentrations and predict solubilities, use volumetric analysis and instrumental techniques to analyse for acids, bases and salts, and apply stoichiometry to calculate chemical quantities.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Measuring solubility and concentration

* solution concentration as a measure of the quantity of solute dissolved in a given mass or volume of solution (mol L-1, g L-1, %(m/v), %(v/v), ppm), including unit conversions
* the use of solubility tables and solubility graphs to predict experimental determination of ionic compound solubility; the effect of temperature on the solubility of a given solid, liquid or gas in water
* the use of precipitation reactions to remove impurities from water

Analysis for acids and bases

* volume-volume stoichiometry (solutions only) and application of volumetric analysis, including the use of indicators, calculations related to the preparation of standard solutions, dilution of solutions, and use of acid-base titrations (excluding back titrations) to determine the concentration of an acid or a base in a water sample

Measuring gases

* CO2, CH4 and H2O as three of the major gases that contribute to the natural and enhanced greenhouse effects due to their ability to absorb infrared radiation
* the definitions of gas pressure and standard laboratory conditions (SLC) at 25 °C and 100 kPa
* calculations using the ideal gas equation (*pV* = *nRT*), limited to the units kPa, Pa, atm, mL, L ,°C, and K (including unit conversions)
* the use of stoichiometry to solve calculations related to chemical reactions involving gases (including moles, mass and volume of gases)
* calculations of the molar volume or molar mass of a gas produced by a chemical reaction

Analysis for salts

* sources of salts found in water or soil (which may include minerals, heavy metals, organo-metallic substances) and the use of electrical conductivity to assess the salinity and quality of water or soil samples
* quantitative analysis of salts:
* molar ratio of water of hydration for an ionic compound
* the application of mass-mass stoichiometry to determine the mass present of an ionic compound
* the application of colorimetry and/or UV-visible spectroscopy, including the use of a calibration curve to determine the concentration of ions or complexes in a water or soil sample

Area of Study 3

How do quantitative scientific investigations develop our understanding of chemical reactions?

Many of the 17 goals in the United Nations’ 2030 Agenda for Sustainable Development relate to ensuring that people have access to potable water, clean air and good quality soil to meet their basic needs. The quality of water, air and soil must be monitored closely to ensure that human health and the environment are not compromised.

In this area of study students adapt or design and then conduct a scientific investigation related to chemical equations and/or analysis, which must include the generation of primary data. They develop a research question related to the production of gases, acid-base or redox reactions or the analysis of substances in water, and adapt or design and then conduct a scientific investigation to generate appropriate quantitative data. Students organise and interpret the data and reach a conclusion in response to their research question.

Research questions may relate to different scientific methodologies. Pattern seeking may be utilised in investigating questions such as ‘Is there a relationship between salinity concentration and the rate of rusting of iron?’. Controlled experiments may be designed to investigate questions such as ‘Why is isopropyl alcohol measured as %(v/v) while chlorine bleach is measured in ppm, and what concentrations of isopropyl alcohol and chlorine bleach are required to disinfect surfaces?’. Students may also investigate product, process or system development, such as formulating a UV-stable natural indicator.

The student-adapted or student-designed scientific investigation relates to knowledge and skills developed in Unit 2 Area of Study 1 and/or Area of Study 2.

Outcome 3

On completion of this unit the student should be able to draw an evidence-based conclusion from primary data generated from a student-adapted or student-designed scientific investigation related to the production of gases, acid-base or redox reactions or the analysis of substances in water.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Investigation design

* chemical science concepts specific to the selected scientific investigation and their significance, including the definition of key terms
* scientific methodology relevant to the selected scientific investigation, selected from the following: classification and identification; controlled experiment; fieldwork; modelling; product, process or system development; or simulation
* techniques of primary qualitative and quantitative data generation relevant to the investigation
* accuracy, precision, repeatability, reproducibility, resolution, and validity of measurements in relation to the investigation
* health, safety and ethical guidelines relevant to the selected scientific investigation

Scientific evidence

* the distinction between an aim, a hypothesis, a model, a theory and a law
* observations and investigations that are consistent with, or challenge, current scientific models or theories
* the characteristics of primary data
* ways of organising, analysing and evaluating generated primary data to identify patterns and relationships, and to identify sources of error
* the use of a logbook to authenticate generated primary data
* the limitations of investigation methodologies and methods, and of data generation and/or analysis

Science communication

* the conventions of scientific report writing, including scientific terminology and representations, standard abbreviations and units of measurement
* ways of presenting key findings and implications of the selected scientific investigation

Assessment

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks that provide a range of opportunities for students to demonstrate the key science skills and the key knowledge in the outcomes.

The areas of study, including the key science skills and the key knowledge listed for the outcomes, should be used for course design and the development of learning activities and assessment tasks. Assessment must be a part of the regular teaching and learning program and should be completed mainly in class and within a limited timeframe.

All assessments at Units 1 and 2 are school-based. Assessment instruments should be aligned with the VCE assessment principles. Procedures for assessment of levels of achievement in Units 1 and 2 are a matter for school decision.

For this unit students are required to demonstrate three outcomes. As a set these outcomes encompass the areas of study in the unit.

Suitable tasks for assessment in this unit may be selected from the following:

**Outcome 1 and Outcome 2**

For each outcome, at least one task selected from:

* a report of a laboratory or fieldwork activity, including the generation of primary data
* comparison and evaluation of chemical concepts, methodologies and methods, and findings from at least two student practical activities
* reflective annotations of one or more practical activities from a logbook
* a summary report of selected practical investigations
* critique of an experimental design, chemical process or apparatus
* analysis and evaluation of generated primary and/or collated secondary data
* a modelling or simulation activity
* a media analysis/response
* problem-solving involving chemical concepts, skills and/or issues
* a report of an application of chemical concepts to a real-world context
* analysis and evaluation of a chemical innovation, research study, case study, socio-scientific issue, secondary data or a media communication, with reference to sustainability (green chemistry principles, sustainable development and/or the transition to a circular economy)
* an infographic
* a scientific poster.

If multiple tasks are selected for Outcome 1 and/or Outcome 2, they must be different. The same task cannot be selected more than once across Outcomes 1 and 2.

Where teachers allow students to choose between tasks, teachers must ensure that the tasks they set are of comparable scope and demand.

**Outcome 3**

* a report of a student-adapted or student-designed scientific investigation using a selected format, such as a scientific poster, an article for a scientific publication, a practical report, an oral presentation, a multimedia presentation or a visual representation

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations, modelling and other direct experiences as described in the scientific investigation methodologies on [page 13.](#methodologies) A minimum of 10 hours of class time should be devoted to student practical activities and scientific investigations across Areas of Study 1 and 2. For Area of Study 3, a minimum of seven hours of class time should be devoted to undertaking, and communicating findings of, the student-adapted or student-designed scientific investigation.

Unit 3: How can design and innovation help to optimise chemical processes?

The global demand for energy and materials is increasing with world population growth. In this unit students investigate the chemical production of energy and materials. They explore how innovation, design and sustainability principles and concepts can be applied to produce energy and materials while minimising possible harmful effects of production on human health and the environment.

Students analyse and compare different fuels as energy sources for society, with reference to the energy transformations and chemical reactions involved, energy efficiencies, environmental impacts and potential applications. They explore food in the context of supplying energy in living systems. The purpose, design and operating principles of galvanic cells, fuel cells, rechargeable cells and electrolytic cells are considered when evaluating their suitability for supplying society’s needs for energy and materials. They evaluate chemical processes with reference to factors that influence their reaction rates and extent. They investigate how the rate of a reaction can be controlled so that it occurs at the optimum rate while avoiding unwanted side reactions and by-products. Students conduct practical investigations involving thermochemistry, redox reactions, electrochemical cells, reaction rates and equilibrium systems.

Throughout the unit students use chemistry terminology, including symbols, formulas, chemical nomenclature and equations, to represent and explain observations and data from their own investigations and to evaluate the chemistry-based claims of others.

A student-designed scientific investigation involving the generation of primary data related to the production of energy and/or chemicals and/or the analysis or synthesis of organic compounds is undertaken in either Unit 3 or Unit 4, or across both Units 3 and 4, and is assessed in Unit 4 Outcome 3. The design, analysis and findings of the investigation are presented in a scientific poster format as outlined on [pages 14 and 15](#poster).

Area of Study 1

What are the current and future options for supplying energy?

In this area of study students focus on analysing and comparing a range of fossil fuels and biofuels as energy sources for society, and carbohydrates, proteins and lipids as fuel sources for the body. They write balanced thermochemical equations for the combustion of various fuels. The amounts of energy and gases produced in combustion reactions are quantified using stoichiometry. They explore how energy can be sustainably produced from chemicals to meet the needs of society while minimising negative impacts on the environment.

The selection of learning contexts should allow students to develop practical techniques to investigate how energy from fuels can be obtained and measured, and to determine the efficiency of different fuels and electrochemical cells as sources of energy. Students develop their skills in the use of scientific equipment and apparatus. They may measure energy released in combustion reactions through quantitative calorimetry experiments and may compare amounts of energy released in different fuels, such as methane, alcohols, waxes and foods. They design, construct and test galvanic and fuel cells, and account for differences between experimental findings and predictions made by using the electrochemical series. Students may work collaboratively to construct electrochemical half-cells and experiment with different combinations of half-cells to develop their own electrochemical series. Students respond to challenges such as designing an electrochemical cell that generates the most energy under laboratory conditions using a limited range of supplied chemicals and materials.

Outcome 1

On completion of this unit the student should be able to compare fuels quantitatively with reference to combustion products and energy outputs, apply knowledge of the electrochemical series to design, construct and test primary cells and fuel cells, and evaluate the sustainability of electrochemical cells in producing energy for society.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Carbon-based fuels

* the definition of a fuel, including the distinction between fossil fuels (coal, natural gas, petrol) and biofuels (biogas, bioethanol, biodiesel) with reference to their renewability (ability of a resource to   
  be replaced by natural processes within a relatively short period of time)
* fuel sources for the body measured in kJ g-1: carbohydrates, proteins and lipids (fats and oils)
* photosynthesis as the process that converts light energy into chemical energy and as a source of glucose and oxygen for respiration in living things: 6CO2(g) + 6H2O(l) → C6H12O6(aq)+ 6O2(g)
* oxidation of glucose as the primary carbohydrate energy source, including the balanced equation for cellular respiration: C6H12O6(aq) + 6O2(g) ⭢ 6CO2(g) + 6H2O(l)
* production of bioethanol by the fermentation of glucose and subsequent distillation to produce a more sustainable transport fuel: C6H12O6(aq) → 2C2H5OH(aq) + 2CO2(g)
* comparison of exothermic and endothermic reactions, with reference to bond making and bond breaking, including enthalpy changes (∆*H*) measured in kJ, molar enthalpy changes measured in   
  kJ mol-1 and enthalpy changes for mixtures measured in kJ g-1, and their representations in energy profile diagrams
* determination of limiting reactants or reagents in chemical reactions
* combustion (complete and incomplete) reactions of fuels as exothermic reactions: the writing of balanced thermochemical equations, including states, for the complete and incomplete combustion   
  of organic molecules using experimental data and data tables

Measuring changes in chemical reactions

* calculations related to the application of stoichiometry to reactions involving the combustion of fuels, including mass-mass, mass-volume and volume-volume stoichiometry, to determine heat energy released, reactant and product amounts and net volume or mass of major greenhouse gases   
  (CO2, CH4 and H2O), limited to standard laboratory conditions (SLC) at 25 °C and 100 kPa
* the use of specific heat capacity of water to approximate the quantity of heat energy released during   
  the combustion of a known mass of fuel and food
* the principles of solution calorimetry, including determination of calibration factor and consideration of the effects of heat loss; analysis of temperature-time graphs obtained from solution calorimetry
* energy from fuels and food:
* calculation of energy transformation efficiency during combustion as a percentage of chemical energy converted to useful energy
* comparison and calculations of energy values of foods containing carbohydrates, proteins and fats and oils

Primary galvanic cells and fuel cells as sources of energy

* redox reactions as simultaneous oxidation and reduction processes, and the use of oxidation numbers to identify the reducing agent, oxidising agent and conjugate redox pairs
* the writing of balanced half-equations (including states) for oxidation and reduction reactions, and the overall redox cell reaction in both acidic and basic conditions
* the common design features and general operating principles of non-rechargeable (primary) galvanic cells converting chemical energy into electrical energy, including electrode polarities and the role of the electrodes (inert and reactive) and electrolyte solutions (details of specific cells not required)
* the use and limitations of the electrochemical series in designing galvanic cells and as a tool for predicting the products of redox reactions, for deducing overall equations from redox half-equations and for determining maximum cell voltage under standard conditions
* the common design features and general operating principles of fuel cells, including the use of porous electrodes for gaseous reactants to increase cell efficiency (details of specific cells not required)
* the application of Faraday’s Laws and stoichiometry to determine the quantity of galvanic or fuel cell reactant and product, and the current or time required to either use a particular quantity of reactant or produce a particular quantity of product
* contemporary responses to challenges and the role of innovation in the design of fuel cells to meet society’s energy needs, with reference to green chemistry principles: design for energy efficiency, and use of renewable feedstocks

Area of Study 2

How can the rate and yield of chemical reactions be optimised?

In this area of study, students explore the factors that affect the rate and yield of equilibrium and electrolytic reactions involved in producing important materials for society. Reactants and products in chemical reactions are treated qualitatively through the application of Le Chatelier’s principle and quantified using equilibrium expressions, reaction quotients and Faraday’s Laws. Students explore the sustainability of different options for producing useful materials for society.

The selection of learning contexts should allow students to develop practical techniques to investigate equilibrium and electrolysis. Students develop their skills in the use of scientific equipment and apparatus. They investigate reaction rates including the measurement of mass, gas volumes and time. They use an equilibrium system, such as iron(III) thiocyanate, to predict and test the effect of different changes to the system. They investigate the effect of catalysts on reaction rates, such as comparing the rate of decomposition of hydrogen peroxide using organic and inorganic catalysts. Students explore the application of electrolysis in the manufacture of useful products through experiments such as electroplating and anodising. They model and explain the operation of secondary cells: for example, those in portable devices such as laptops or cell phones. Students respond to challenges such as predicting and testing the optimum conditions under which a selected reaction can produce the highest product yield.

Outcome 2

On completion of this unit the student should be able to experimentally analyse chemical systems to predict how the rate and extent of chemical reactions can be optimised, explain how electrolysis is involved in the production of chemicals, and evaluate the sustainability of electrolytic processes in producing useful materials for society.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Rates of chemical reactions

* factors affecting the frequency and success of reactant particle collisions and the rate of a chemical reaction in open and closed systems, including temperature, surface area, concentration, gas pressures, presence of a catalyst, activation energy and orientation
* the role of catalysts in increasing the rate of specific reactions, with reference to alternative reaction pathways of lower activation energies and represented using energy profile diagrams

Extent of chemical reactions

* the distinction between reversible and irreversible reactions, and between rate and extent of a reaction
* the dynamic nature of homogenous equilibria involving aqueous solutions or gases, and their representation by balanced chemical or thermochemical equations (including states) and by concentration-time graphs
* the change in position of equilibrium that can occur when changes in temperature or species or volume (concentration or pressure) are applied to a system at equilibrium, and the representation of these changes using concentration-time graphs
* the application of Le Chatelier’s principle to identify factors that favour the yield of a chemical reaction
* calculations involving equilibrium expressions (including units) for a closed homogeneous equilibrium system and the dependence of the equilibrium constant (*K*) value on the system temperature and the equation used to represent the reaction
* the reaction quotient (*Q*) as a quantitative measure of the extent of a chemical reaction: that is, the relative amounts of products and reactants present during a reaction at a given point in time
* responses to the conflict between optimal rate and temperature considerations in producing equilibrium reaction products, with reference to the green chemistry principles of catalysis and designing for energy efficiency

Production of chemicals using electrolysis

* the use and limitations of the electrochemical series to explain or predict the products of the electrolysis of particular chemicals, given their state (molten liquid or in aqueous solution) and the electrode materials used, including the writing of balanced equations (with states) for the reactions occurring at the anode and cathode and the overall redox reaction for the cell
* the common design features and general operating principles of commercial electrolytic cells (including, where practicable, the removal of products as they form), and the selection of suitable electrode materials, the electrolyte (including its state) and any chemical additives that result in a desired electrolysis product (details of specific cells not required)
* the common design features and general operating principles of rechargeable (secondary) cells, with reference to discharging as a galvanic cell and recharging as an electrolytic cell, including the conditions required for the cell reactions to be reversed and the electrode polarities in each mode (details of specific cells not required)
* the role of innovation in designing cells to meet society’s energy needs in terms of producing ‘green’ hydrogen (including equations in acidic conditions) using the following methods:
* polymer electrolyte membrane electrolysis powered by either photovoltaic (solar) or wind energy
* artificial photosynthesis using a water oxidation and proton reduction catalyst system
* the application of Faraday’s Laws and stoichiometry to determine the quantity of electrolytic reactant and product, and the current or time required to either use a particular quantity of reactant or produce   
  a particular quantity of product

School-based assessment

Satisfactory completion

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks to provide a range of opportunities for students to demonstrate the key science skills and the key knowledge in the outcomes.

The areas of study, key science skills and key knowledge listed for the outcomes should be used for course design and the development of learning activities and assessment tasks.

Assessment of levels of achievement

School-assessed Coursework

The student’s level of achievement in Unit 3 will be determined by School-assessed Coursework. School-assessed Coursework tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe.

Where teachers provide a range of options for the same School-assessed Coursework task, they should ensure that the options are of comparable scope and demand.

The types and range of forms of School-assessed Coursework for the outcomes are prescribed within the study design. The VCAA publishes [Support materials](https://www.vcaa.vic.edu.au/curriculum/vce/vce-study-designs/chemistry/Pages/Index.aspx) for this study, which includes advice on the design of assessment tasks and the assessment of student work for a level of achievement.

Teachers will provide to the VCAA a numerical score representing an assessment of the student’s level of achievement. The score must be based on the teacher’s assessment of the performance of each student on the tasks set out in the following table.

Contribution to final assessment

School-assessed Coursework for Unit 3 will contribute 20 per cent to the study score.

|  |  |  |
| --- | --- | --- |
| **Outcomes** | **Marks allocated** | **Assessment tasks** |
| **Outcome 1**  Compare fuels quantitatively with reference to combustion products and energy outputs, apply knowledge of the electrochemical series to design, construct and test primary cells and fuel cells, and evaluate the sustainability of electrochemical cells in producing energy for society. | **40** | *For Outcomes 1 and 2*  For each outcome, one task selected from:   * comparison and evaluation of chemical concepts, methodologies and methods, and findings from at least two practical activities * analysis and evaluation of primary and/or secondary data, including identified assumptions or data limitations, and conclusions * problem-solving, including calculations, using chemistry concepts and skills applied to real-world contexts * analysis and evaluation of a chemical innovation, research study, case study, socio-scientific issue, or media communication.   Each task type can be selected only once across Units 3 and 4.  At least one of the four tasks should include reference to sustainability.  For each task the time allocated should be approximately 50–70 minutes for a written response and 10 minutes for a multimodal or oral presentation. |
| **Outcome 2**  Experimentally analyse chemical systems to predict how the rate and extent of chemical reactions can be optimised, explain how electrolysis is involved in the production of chemicals, and evaluate the sustainability of electrolytic processes in producing useful materials for society. | **40** |
| **Total marks** | **80** |  |

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations and other direct experiences as described in the scientific investigation methodologies on [page 13](#methodologies). A minimum of 10 hours of class time should be devoted to student practical activities and investigations across Areas of Study 1 and 2.

External assessment

The level of achievement for Units 3 and 4 is also assessed by an end-of-year examination, which will contribute 50 per cent to the study score.

Unit 4: How are carbon-based compounds designed for purpose?

Carbon is the basis not only of the structure of living tissues but is also found in fuels, foods, medicines, polymers and many other materials that we use in everyday life. In this unit students investigate the structures and reactions of carbon-based organic compounds, including considering how green chemistry principles are applied in the production of synthetic organic compounds. They study the metabolism of food and the action of medicines in the body. They explore how laboratory analysis and various instrumentation techniques can be applied to analyse organic compounds in order to identify them and to ensure product purity.

Students conduct practical investigations related to the synthesis and analysis of organic compounds, involving reaction pathways, organic synthesis, identification of functional groups, direct redox titrations, solvent extraction and distillations.

Throughout the unit students use chemistry terminology including symbols, formulas, chemical nomenclature and equations to represent and explain observations and data from their own investigations and to evaluate the chemistry-based claims of others.

A student-designed scientific investigation involving the generation of primary data related to the production of energy and/or chemicals and/or the analysis or synthesis of organic compounds is undertaken in either Unit 3 or Unit 4, or across both Units 3 and 4, and is assessed in Unit 4 Outcome 3. The design, analysis and findings of the investigation are presented in a scientific poster format as outlined on [pages 14 and 15](#poster).

Area of Study 1

How are organic compounds categorised and synthesised?

In this area of study students focus on the structure, naming, properties and reactions of organic compounds, including the chemical reactions associated with the metabolism of food. They explore how synthetic organic compounds can be produced more sustainably for use in society.

The selection of learning contexts should allow students to develop practical techniques to investigate organic structures and reactions. Students develop their skills in the use of scientific equipment and apparatus. They may construct models to explore organic structures, including isomers. Students may compare the properties of biodiesels produced using different oils, or may investigate organic reaction pathways such as the synthesis of esters used in food flavourings. They may investigate food metabolism by hydrolysing different types of plant starches. Students respond to challenges such as how to improve the atom economy of a selected chemical reaction or reaction pathway.

Outcome 1

On completion of this unit the student should be able to analyse the general structures and reactions of the major organic families of compounds, design reaction pathways for organic synthesis, and evaluate the sustainability of the manufacture of organic compounds used in society.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 1 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Structure, nomenclature and properties of organic compounds

* characteristics of the carbon atom that contribute to the diversity of organic compounds formed, with reference to valence electron number, relative bond strength, relative stability of carbon bonds with other elements, degree of unsaturation (carbon-carbon double bonds), and the formation of structural isomers
* molecular, structural and semi-structural (condensed) formulas and skeletal structures of alkanes (including cyclohexane), alkenes, benzene, haloalkanes, primary amines, primary amides, alcohols (primary, secondary and tertiary), aldehydes, ketones, carboxylic acids and non-branched esters
* the International Union of Pure and Applied Chemistry (IUPAC) systematic naming of organic compounds up to C8, with no more than two functional groups for a molecule, limited to non-cyclic hydrocarbons, haloalkanes, primary amines, alcohols (primary, secondary and tertiary), aldehydes, ketones, carboxylic acids and non-branched esters
* trends in physical properties within and between homologous series (boiling point and melting point, viscosity), with reference to structure and bonding

Reactions of organic compounds

* organic reactions and pathways, including equations, reactants, products, reaction conditions and catalysts (specific enzymes not required):
* synthesis of primary haloalkanes and primary alcohols by substitution
* addition reactions of alkenes
* the esterification between an alcohol and a carboxylic acid
* hydrolysis of esters
* pathways for the synthesis of primary amines and carboxylic acids
* transesterification of plant triglycerides using alcohols to produce biodiesel
* hydrolytic reactions of proteins, carbohydrates and fats and oils to break down large biomolecules in food to produce smaller molecules
* condensation reactions to synthesise large biologically important molecules for storage as proteins, starch, glycogen and lipids (fats and oils)
* calculations of percentage yield and atom economy of single-step or overall reaction pathways, and the advantages for society and for industry of developing chemical processes with a high atom economy
* the sustainability of the production of chemicals, with reference to the green chemistry principles of use of renewable feedstocks, catalysis and designing safer chemicals

Area of Study 2

How are organic compounds analysed and used?

In this area of study students focus on laboratory and instrumental analyses of organic compounds, and the function of some organic compounds as medicines. They use distillation to separate mixtures, use volumetric analysis to calculate redox quantities, and explore how instrumental analysis is used to ensure the quality of consumer products. Students explain how some medicines that bind to the active sites of enzymes function by inhibiting the enzymes’ mode of action.

The selection of learning contexts should allow students to develop practical techniques to analyse organic compounds. Students develop their skills in the use of scientific equipment and apparatus. They may perform qualitative tests to identify features of organic compounds, such as the identification of functional groups in an unknown compound. Students may perform quantitative analyses including redox titrations to determine concentrations and quantities of substances, such as the amount of Vitamin C in fruits. They design and improve on experiments such as the testing of the viscosity of alcohols. They respond to challenges such as the identification of a molecule using primary data from analytical techniques used in the laboratory or secondary data obtained from spectroscopy. Students may use distillation to extract and purify the natural organic compounds in plants, such as extracting limonene from orange peel.

Outcome 2

On completion of this unit the student should be able to apply qualitative and quantitative tests to analyse organic compounds and their structural characteristics, deduce structures of organic compounds using instrumental analysis data, explain how some medicines function, and experimentally analyse how some natural medicines can be extracted and purified.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 2 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Laboratory analysis of organic compounds

* qualitative tests for the presence of carbon-carbon double bonds, hydroxyl and carboxyl functional groups
* applications and principles of laboratory analysis techniques in verifying components and purity of consumer products, including melting point determination and distillation (simple and fractional)
* measurement of the degree of unsaturation of compounds using iodine
* volumetric analysis, including calculations of excess and limiting reactants using redox titrations (excluding back titrations)

Instrumental analysis of organic compounds

* applications of mass spectrometry (excluding features of instrumentation and operation) and interpretation of qualitative and quantitative data, including identification of molecular ion peak, determination of molecular mass and identification of simple fragments
* identification of bond types by qualitative infrared spectroscopy (IR) data analysis using characteristic absorption bands
* structural determination of organic compounds by low resolution carbon-13 nuclear magnetic resonance (13C-NMR) spectral analysis, using chemical shift values to deduce the number and nature of different carbon environments
* structural determination of organic compounds by low and high resolution proton nuclear magnetic resonance (1H-NMR) spectral analysis, using chemical shift values, integration curves (where the height is proportional to the area underneath a peak) and peak splitting patterns (excluding coupling constants), and application of the n+1 rule (where n is the number of neighbouring protons) to deduce the number and nature of different proton environments
* the principles of chromatography, including high performance liquid chromatography (HPLC) and the use of retention times and the construction of a calibration curve to determine the concentration of an organic compound in a solution (excluding features of instrumentation and operation)
* deduction of the structures of simple organic compounds using a combination of mass spectrometry (MS), infrared spectroscopy (IR), proton nuclear magnetic resonance (1H-NMR) and carbon-13 nuclear magnetic resonance (13C-NMR) (limited to data analysis)
* the roles and applications of laboratory and instrumental analysis, with reference to product purity and the identification of organic compounds or functional groups in isolation or within a mixture

Medicinal chemistry

* extraction and purification of natural plant compounds as possible active ingredients for medicines, using solvent extraction and distillation
* identification of the structure and functional groups of organic molecules that are medicines
* significance of isomers and the identification of chiral centres (carbon atom surrounded by four different groups) in the effectiveness of medicines
* enzymes as protein-based catalysts in living systems: primary, secondary, tertiary and quaternary structures and changes in enzyme function in terms of structure and bonding as a result of increased temperature (denaturation), decreased temperature (lowered activity), or changes in pH (formation of zwitterions and denaturation)
* medicines that function as competitive enzyme inhibitors: organic molecules that bind through lock-and-key mechanism to an active site preventing binding of the actual substrate

Area of Study 3

How is scientific inquiry used to investigate the sustainable production of energy and/or materials?

Students undertake a student-designed scientific investigation in either Unit 3 or Unit 4, or across both   
Units 3 and 4. The investigation involves the generation of primary data related to the production of energy and/or chemicals and/or the analysis or synthesis of organic compounds, and should be inspired by a contemporary chemical challenge or issue. The investigation draws on knowledge and related key science skills developed across Units 3 and 4 and is undertaken by students in the laboratory and/or in the field.

When undertaking the investigation students are required to apply the key science skills to develop a question, state an aim, formulate a hypothesis and plan a course of action to answer the question, while complying with safety and ethical guidelines. Students then undertake an experiment to generate primary quantitative data, analyse and evaluate the data, identify limitations of data and methods, link experimental results to scientific ideas, discuss implications of the results, and draw a conclusion in response to the question. The presentation format for the investigation is a scientific poster constructed according to the structure outlined [on page 14](#Poster). A logbook is maintained by students for recording, assessment and authentication purposes.

Outcome 3

On completion of this unit the student should be able to design and conduct a scientific investigation related to the production of energy and/or chemicals and/or the analysis or synthesis of organic compounds, and present an aim, methodology and method, results, discussion and conclusion in a scientific poster.

To achieve this outcome the student will draw on key knowledge outlined in Area of Study 3 and the related key science skills on [pages 11 and 12](#skills) of the study design.

Key knowledge

Investigation design

* chemical concepts specific to the selected scientific investigation and their significance, including definitions of key terms
* characteristics of the selected scientific methodology and method, and appropriateness of the use of independent, dependent and controlled variables in the selected scientific investigation
* techniques of primary quantitative data generation relevant to the selected scientific investigation
* the accuracy, precision, repeatability, reproducibility, resolution and validity of measurements
* the health, safety and ethical guidelines relevant to the selected scientific investigation

Scientific evidence

* the nature of evidence that supports or refutes a hypothesis, model or theory
* ways of organising, analysing and evaluating primary data to identify patterns and relationships, including sources of error and uncertainty
* authentication of generated primary data through the use of a logbook
* assumptions and limitations of investigation methodology and/or data generation and/or analysis methods

Science communication

* conventions of science communication: scientific terminology and representations, symbols, formulas, standard abbreviations and units of measurement
* conventions of scientific poster presentation, including succinct communication of the selected scientific investigation, and acknowledgements and references
* the key findings and implications of the selected scientific investigation

School-based assessment

Satisfactory completion

The award of satisfactory completion for a unit is based on whether the student has demonstrated the set of outcomes specified for the unit. Teachers should use a variety of learning activities and assessment tasks to provide a range of opportunities for students to demonstrate the key science skills and the key knowledge in the outcomes.

The areas of study, key science skills and key knowledge listed for the outcomes should be used for course design and the development of learning activities and assessment tasks.

Assessment of levels of achievement

School-assessed Coursework

The student’s level of achievement in Unit 4 will be determined by School-assessed Coursework.

School-assessed Coursework tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe.

Where teachers provide a range of options for the same School-assessed Coursework task, they should ensure that the options are of comparable scope and demand.

The types and range of forms of School-assessed Coursework for the outcomes are prescribed within the study design. The VCAA publishes [Support materials](https://www.vcaa.vic.edu.au/curriculum/vce/vce-study-designs/chemistry/Pages/Index.aspx) for this study, which include advice on the design of assessment tasks and the assessment of student work for a level of achievement.

Teachers will provide to the VCAA a numerical score representing an assessment of the student’s level of achievement. The score must be based on the teacher’s assessment of the performance of each student on the tasks set out in the following table.

Contribution to final assessment

School-assessed Coursework for Unit 4 will contribute 30 per cent to the study score.

|  |  |  |
| --- | --- | --- |
| **Outcomes** | **Marks allocated** | **Assessment tasks** |
| **Outcome 1**  Analyse the general structures and reactions of the major organic families of compounds, design reaction pathways for organic synthesis, and evaluate the sustainability of the manufacture of organic compounds used in society. | **40** | *For Outcomes 1 and 2*  For each outcome, one task selected from:   * comparison and evaluation of chemical concepts, methodologies and methods, and findings from at least two practical activities * analysis and evaluation of primary and/or secondary data, including identified assumptions or data limitations, and conclusions * problem-solving, including calculations, using chemistry concepts and skills applied to real-world contexts * analysis and evaluation of a chemical innovation, research study, case study, socio-scientific issue, or media communication.   Each task type can be selected only once across Units 3 and 4.  At least one of the four tasks should include reference to sustainability.  For each task the time allocated should be approximately 50–70 minutes for a written response and 10 minutes for a multimodal or oral presentation. |
| **Outcome 2**  Apply qualitative and quantitative tests to analyse organic compounds and their structural characteristics, deduce structures of organic compounds using instrumental analysis data, explain how some medicines function, and experimentally analyse how some natural medicines can be extracted and purified. | **40** |
| **Outcome 3**  Design and conduct a scientific investigation related to the production of energy and/or chemicals and/or the analysis or synthesis of organic compounds, and present an aim, methodology and method, results, discussion and conclusion in a scientific poster. | **40** | *For Outcome 3*  Communication of the design, analysis and findings of a student-designed and student-conducted scientific investigation through a structured scientific poster and logbook entries.  The poster should not exceed 600 words. |
| **Total marks** | **120** |  |

Practical work

Practical work is a central component of learning and assessment and may include activities such as laboratory experiments, fieldwork, simulations and other direct experiences as described in the scientific investigation methodologies on [page 13](#methodologies). A minimum of 10 hours of class time should be devoted to student practical activities and investigations across Areas of Study 1 and 2. For Area of Study 3, a minimum of 10 hours of class time should be devoted to designing and undertaking the student-designed scientific investigation and communicating findings.

External assessment

The level of achievement for Units 3 and 4 is also assessed by an end-of-year examination.

Contribution to final assessment

The examination will contribute 50 per cent to the study score.

End-of-year examination

Description

The examination will be set by a panel appointed by the VCAA. All the key knowledge and key skills that underpin the outcomes in Units 3 and 4 are examinable.

Conditions

The examination will be completed under the following conditions:

* Duration: 2.5 hours
* Date: end-of-year, on a date to be published annually by the VCAA
* VCAA examination rules will apply. Details of these rules are published annually in the   
  [*VCE Administrative Handbook*](https://www.vcaa.vic.edu.au/administration/vce-vcal-handbook/Pages/index.aspx)
* The examination will be marked by assessors appointed by the VCAA.

Further advice

The VCAA publishes specifications for all VCE examinations on the VCAA website. Examination specifications include details about the sections of the examination, their weighting, the question format(s) and any other essential information. The specifications are published in the first year of implementation of the revised Unit 3 and 4 sequence together with any sample material.