ROYAL SOCIETY OF CHEMISTRY

TALENT

Answering the Big Questions: our chemistry curriculum in detail

The Royal Society of Chemistry's vision for 11–19 chemistry education

The elements of a successful chemistry curriculum

Answering the Big Questions: our chemistry curriculum in detail

Last reviewed: January 2026

Summary

The Royal Society of Chemistry aims to inform the development of chemistry curricula and qualifications by governments and other authorities throughout the UK and Ireland. This document presents a proposed framework to inform curriculum design at ages 11–19. While this proposal is intended to be a valuable resource to policymakers and curriculum designers, we hope it will also be of interest and use to teachers.

The ideas in this document rest on a much greater body of work, which provide further details and suggestions for implementation. Building on the curriculum framework that was originally published in 2020, this updated and expanded framework represents what we see as the core of an ideal chemistry curriculum, but by no means its totality. While our ideas about good curricula should always be reviewed in the light of evidence and experience, we aim here to present something that is enduring and can be used flexibly in different education systems and types of qualification.

Foreword

We are currently in a period of unprecedented global challenge on both environmental and societal issues such as climate change, food supply, healthcare and the economy. The chemical sciences have a vital role to play in tackling these issues and underpin several key growth sectors prioritised by government, including clean energy, life sciences, and advanced manufacturing.

Chemistry offers a world of opportunity for young people. Everyone deserves an engaging, relevant, and inspiring chemistry education. Now more than ever, the curriculum must be fit for purpose – highlighting these opportunities, equipping learners with the skills and knowledge to be scientifically informed citizens, and showing that chemistry is for people like them. Learners are eager to explore contemporary issues and want to understand the many ways chemistry can improve lives and address global challenges.

In 2014, the Royal Society of Chemistry established the Curriculum and Assessment Working Group (CAWG) to develop an evidence-based, expert-led curriculum framework that progresses coherently through secondary education. Since then, through direct engagement and our Science Teaching Survey, teachers have told us that chemistry curriculums have become overloaded and disconnected from real-world issues that fail to inspire learners to think ‘chemistry is for people like me’.

To address these concerns and shape our thinking on curriculum reform, we’ve developed detailed positions on key areas such as sustainability, digital skills, and representation: grounded in evidence and informed by the community. The vision for chemistry education presented here is designed to prepare young people for the future, whatever path they choose.

This 11–19 curriculum framework enables learners to encounter a broad range of modern chemistry, demonstrating both its everyday impact and its potential to solve some of the most pressing challenges of the 21st century. It also ensures students develop the skills and knowledge that employers value. With flexibility built in, curriculum developers can design courses that work for all learners, regardless of qualification pathway.

We have updated this this document in October 2025 to serve as a starting point for current and future curriculum reform across the UK and Ireland.

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Introduction

The chemical sciences have a critical role to play in the global challenges we face and in the technological advances being developed to help meet these challenges. We must ensure science and chemistry curriculums are equipping young people with the skills and knowledge needed for the future.

The Royal Society of Chemistry aims to inform the development of chemistry curricula and qualifications by governments and other authorities throughout the UK and Ireland. This document presents a proposed framework to inform curriculum design at ages 11–19. While this proposal is intended to be a valuable resource to policymakers and curriculum designers, we hope it will also be of interest and use to teachers.

The ideas in this document rest on a much greater body of work, which provide further details and suggestions for implementation. Building on the curriculum framework that was originally published in 2020, this updated and expanded framework represents what we see as the core of an ideal chemistry curriculum, but by no means its totality. While our ideas about good curricula should always be reviewed in the light of evidence and experience, we aim here to present something that is enduring and can be used flexibly in different education systems and types of qualification.

We have engaged with the chemical sciences and education communities to update and expand on this framework, so that we continue to be aligned with their needs and have broad support for our proposals. This is part of a continuing conversation; our rationale and overall vision for chemistry education is detailed in the associated report, and our policy positions expand on those ideas. Further details on content and implementation can be found in this document.

A community and evidence-informed framework

The curriculum framework presented here has been developed by a succession of curriculum and assessment working groups, composed of experts in curriculum design and experienced teachers and educators.

The working groups referred to evidence on good curriculum design in general and on effective learning in chemistry in particular, as well as looking at current practice. They thought about the most important knowledge and skills to teach to learners aged 11–16 years and 16–19 years, as well as the guiding principles that should underpin good curriculum design. From these discussions, our curriculum framework emerged.

We have tested our ideas with teachers and other educators through reviews of draft documents, focus groups and other discussions. Practice was also shared with our sister professional bodies, the Institute of Physics and the Royal Society of Biology, which have conducted parallel exercises. We are grateful to everyone who has shared their insights with us.

This framework is not intended to be a scheme of work or an exam specification, or to imply any particular teaching sequence. It is designed to guide the development of more detailed courses of study and qualifications that will suit learners and serve progression paths throughout the UK and Ireland.

Guiding principles

The Curriculum and Assessment Working Group considered the existing curriculum documents for the nations of the UK and Ireland, as well as views from experts in curriculum design to arrive at a set of guiding principles that underpinned the development of the curriculum framework. These guiding principles are as follows:

• **A clear framework or narrative** that gives a coherent 'big picture' of chemistry as a subject, explains why it matters, and shows how different areas of content are connected.

• **Clear progression**, in which deepening understanding is built on a secure foundation in each aspect of the framework.

• **Encourage understanding of fundamental principles** (as opposed to surface learning of facts). This promotes deeper conceptual understanding and the ability to apply learning to novel situations.

• **Incorporate the procedural knowledge**; and **skills**, (including practical skills), that are core to the discipline of chemistry.

• Be informed by the **available evidence**[2], including findings from research, best practice, and views from informed stakeholders.

[2] A list of the references used can be found here: https://rsc.li/chemistry-curriculum-framework

In using this framework, it is also important to ensure that fully developed curricula offer:

• **Appropriate alignment** with the wider curriculum in related subjects.

• **A defined learning entitlement** that sets out clearly the level of understanding and skill that learners are expected to achieve at each stage.

• **A level of demand** that is aspirational but also allows an educational experience that is inclusive of all learners.

• **A considered amount of prescribed content**, to allow time within the curriculum to develop understanding and the flexibility for teachers to introduce meaningful contexts and applications that demonstrate the breadth of chemistry and its contribution to society.

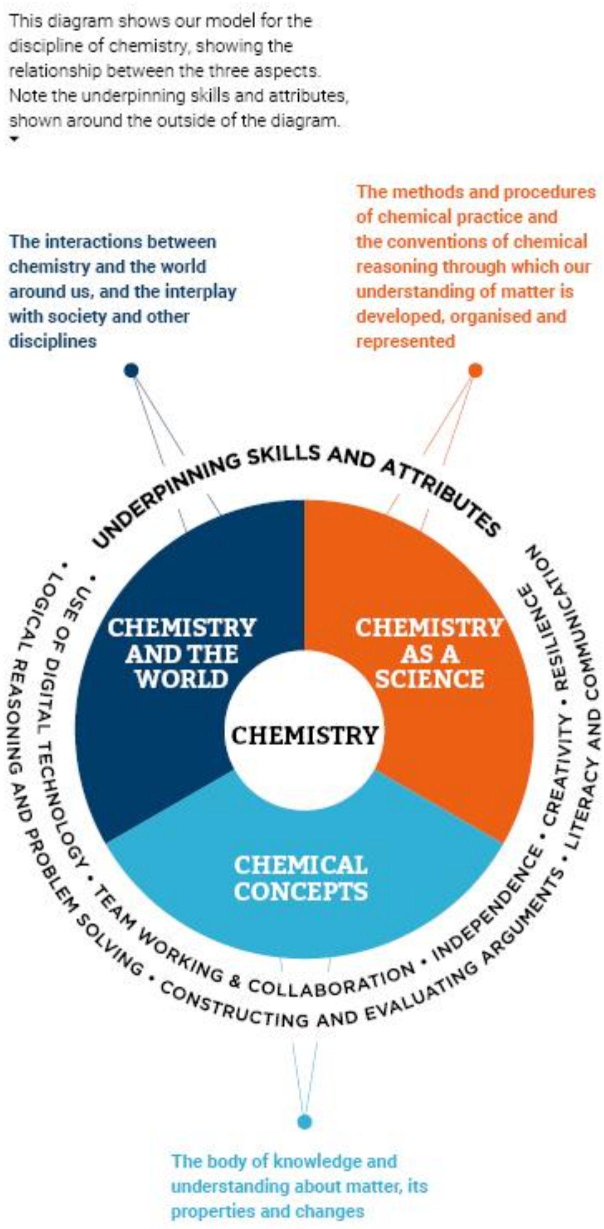
A framework for a successful chemistry curriculum

A complete view of chemistry

Developing an understanding of what chemistry is, and how we can use it, is central to a successful chemistry curriculum. So we have thought deeply about what matters in, and about, chemistry and how our discipline[3] is evolving.

[3] By discipline we mean an area of learning that has a particular object of research, but also specific range of practices used to further understanding in that field.

At the heart of the framework sits our model for the discipline, shown in the diagram below. The approaches to reasoning and enquiry that are important in chemistry are covered in Chemistry as a science, whilst the fundamental understandings of the material world that we have developed so far are covered in Chemical concepts. Chemistry and the world focuses on how we use these practices and concepts and how they impact society and the world. Whilst each of these aspects of chemistry is important in its own right, and should be made explicit as so, chemistry as a discipline can only be understood through the relationship between them.



An overview of structure

The following pages lay out more detail on the hierarchy of the framework. Stepping down from the three aspects that make up chemistry as a discipline, the next level of structure is a set of “Big Questions”. This approach ensures there is a narrative that learning can be connected to, whilst also reflecting the enquiring nature of chemistry.

Within each Big Question we have identified the key ideas that we envisage that all learners should encounter by age 16, and in more depth in post-16 qualifications. These key ideas should not be viewed as teaching topics or suggestions. Rather they are an indication of the core ideas that need to be understood to answer each Big Question.

We have also undertaken more detailed thinking on exactly what content could, and should, be included at each educational stage, for each Big Question. The Big Questions and key ideas are considered further in the following pages.

The structure of this framework is intended to be flexible enough that it can be applied to technical and academic pathways and be appropriate for any educational system in the UK and Ireland.

The Big Questions and key ideas

Our approach to developing a clear narrative has been informed by expert thinking on curriculum design, in particular the Big Ideas of Science Education[4], which explains how the links between ideas and experience is better preserved in a narrative form than in a list of disconnected points.

[4] Principles and big ideas of science education, edited by Wynne Harlen, 2010 (Association for Science Education)

A narrative is important in ensuring a curriculum is coherent and aids planning for progression in learning. We have adopted a “Big Questions” approach, which reflects the enquiring nature of the discipline. The Big Questions help to define the central areas of interest in studying chemistry.

Using Big Questions as a narrative framework supports development of a coherent curriculum, as content – both knowledge and skills – can be selected to answer each question. All content earns its place, which means both teachers and learners can see the relevance of what is being taught.

The Big Questions can be answered at different levels of sophistication, and therefore can be applied to development of a continuous progression of learning.

The working groups have considered in detail the knowledge and skills that are relevant to include in answer to the Big Questions at ages 11–16 years and 16–19 years. In the framework diagram, this content is summarised as the key ideas that provide answers to the Big Questions. All learners should have the entitlement to study these ideas during their study of chemistry at secondary level, and in more depth if they choose to take the subject further. Curriculum developers would need to adapt the key ideas to the appropriate level for different educational stages and qualifications.

CHEMISTRY

CHEMISTRY AS A SCIENCE

CHEMICAL CONCEPTS

CHEMISTRY AND THE WORLD

How do we think about chemistry?

- Chemists group and classify things such as substances, particles, structures and reactions, in order to build understanding of what exists, identify patterns and trends, and develop scientific explanations.
- How we use mathematics, statistics and data is integral to chemistry to produce and analyse quantitative results, and to help us predict chemical behaviour.
- Standardised representations in chemistry, such as symbols, equations and diagrams, allow clear communication between chemists and within the global society.
- Chemists develop and use models to help explain phenomena, represent things that cannot be easily visualised, highlight specific features and simulate or predict behaviour.

How do we do chemistry?

- Empirical enquiry into the material world requires the use of a range of practical and computational techniques, to produce valid, accurate and reproducible evidence.
- Chemists use current understanding in chemistry to help them choose appropriate processes and methods to answer new questions, where appropriate analysis of observations and evidence can lead to the development of new understandings and make chemistry greener.

How can substances be made and changed?

- Chemical reactions result in the formation of new substances, through rearrangement of the bonding between atoms or ions, resulting in observable changes in physical properties.
- Formation of a product is dependent on the reaction rate and equilibrium position, both of which can be influenced by a number of factors.
- Whether or not a reaction occurs spontaneously can be explained in terms of energy transfer and entropy (dispersion).
- Reactions can be designed to synthesise specific products with new properties.
- Synthesis routes can be optimised to maximise yield and to minimise waste and pollution.

How do we find out what things are made of?

- Differences in chemical and physical properties can be used to identify, quantify and separate substances.

What are things made of?

- All matter is made of one or more chemical substances, which have unique properties and chemical composition.
- Bulk properties of substances in different phases can be explained in terms of the nature and interactions of their constituent particles.
- Atoms or ions of elements (of which there are only a relatively small number) combine in different ratios and structures to produce the huge variety of compounds that exist.

How do we explain how substances behave?

- Models for different types of chemical bonding and structure have been developed to explain physical and chemical properties of substances.
- Atomic models have been developed to explain physical and chemical phenomena.

What is the impact of chemistry?

- Using understanding of chemistry, we can produce new substances and materials, and develop useful chemical processes, to enrich our lives and address local and global challenges.
- Decisions about the use of chemistry are subject to social, economic, environmental and political influences. The importance of drawing on evidence to identify misinformation and tackle controversy, as well as having an awareness of the potential implications of chemistry at individual, local, national and global levels must be recognised.
- Using analytical processes, chemistry can help us to explain natural phenomena and the impact of systems at different scales, enabling us to understand ourselves, our world and the wider universe.

This diagram shows our narrative framework for a chemistry curriculum. The three aspects that make up chemistry as a discipline (Chemistry as a science, Chemical concepts, and Chemistry and the world) are framed through a set of 'Big Questions'. These Big Questions help define the central areas of interest in studying chemistry.

The knowledge and skills content required to answer each of the Big Questions is summarised in this diagram as a set of 'key ideas'. All learners should encounter these key ideas by age 16, and in more depth in post-16 qualifications.

Although not shown explicitly in this diagram, the curriculum should also enable learners to develop a broad range of skills within a chemistry context.

Dimension: Chemistry as a science

The methods and procedures of chemical practice and the conventions of chemical reasoning through which our understanding of matter is developed, organised and represented.

Big Question: How do we think about chemistry?

Key idea: Chemists develop and use models to help explain phenomena, represent things that cannot be easily visualised, highlight specific features and simulate or predict behaviour.

	11–16	**16–19**
Rationale	Models are a central part of scientific reasoning and are important for explaining observations, but they also enable predictions that can test the quality and robustness of the model. Models can become more sophisticated as learners progress and it is important that, as they go through their education, they appreciate the degree of sophistication of a model is increasing rather than thinking the previously studied models are 'wrong'. This contributes to a sound understanding of how science is constructed and reduces the emphasis on thinking of science as a collection of isolated facts.	Models are central to scientific thought; an appreciation of the development and use of models is essential to understanding how knowledge in chemistry is produced. They are constructed to make sense of empirical findings and are continually used to make predictions and devise hypotheses for testing.
Introduction	Scientific models are based on observations and data from experiments. Models are continually evaluated and, as a result, improved or rejected as new evidence becomes available. A good model is generalizable and should be the simplest that can still explain the observations. In chemistry, we need models of the sub-microscopic scale to explain macroscopic observations. Models help to describe, explain and predict chemical processes, but have strengths and weaknesses in how well they explain phenomena and how successful their predictions are.	Learners study examples of models, including computational models, to understand their bases in experimental observation, and their function in explaining phenomena and predicting behaviour. They should appreciate that models are not necessarily 'true' descriptions. All models have strengths and weaknesses in terms of what they are able to explain and predict, and may be developed as new information comes to light.

Content	Models are used in chemistry to predict experimental outcomes and, at times, discrepancies between prediction and outcome means that the model needs to be improved or refined. New evidence leads to changes in the models. Models such as the particle model, atomic model, models for bonding and collision theory can be used to explain experimental data and observations. The particle model can be used to explain the physical properties of the different states of matter, differences in melting/boiling points between substances, diffusion in liquids and gases and the shape of cooling curves. Collision theory can be used to explain the effect of increasing temperature or pressure on the rate of reaction. Models for bonding can explain the properties of simple molecules, covalent lattices, metallic substances and ionic compounds. Energy changes within reactions can be represented using diagrams.	Models: • give a convenient way of considering chemical concepts • are based on and tested through experimental observation • can explain phenomena and predict behaviour, but have limitations • underpin thinking in chemistry. There are numerous models mentioned in Chemical concepts Strands that can be used to bring out these understandings. Appropriate models for discussion could include, but are not limited to: • the ideal gas model • models for atomic structure (including developments over time) • models to describe types of chemical bonding • reaction mechanisms as models to explain experimental observations • applications of computer modelling.

Key idea: Standardised representations in chemistry, such as symbols, equations and diagrams, allow clear communication between chemists and within the global society

	11–16	16–19
Rationale	Representations are deeply engrained in the language of chemistry. They exist in order to help articulate our understanding of the sub-microscopic world: they aid in communicating and thinking about abstract concepts of atoms and molecules that we cannot directly see.	Representations – symbols, formulae and so on – make up the language of chemistry. However, representations can often mean different things depending on the context, and it is often important to choose the most appropriate one. Therefore, it is valuable to explicitly discuss the representations used and understand their subtleties.
Introduction	Representations of the sub-microscopic scale (atoms, molecules etc.), such as symbols, diagrams or 3D objects are used to communicate models and other chemical ideas. It is important when thinking about chemistry to be able to both create and interpret a variety of representations and to translate between representations. Chemistry also uses standardised nomenclature which avoids ambiguity and helps to make sense of patterns.	Learners should appreciate the necessity of using representations for objects of study, which are too small to be seen. They should become fluent in the use of chemical symbols, formulae, nomenclature, equations, and different ways of depicting structures. Representations differ from models in the sense that they are descriptive, where models are explanatory and predictive.
Content	• Elements can be represented using symbols and compounds can be represented using chemical formulae. • The physical states of products and reactants can be described using state symbols (s, l, g and aq). • The formula of a simple molecular substance shows the number of each type of atom in each molecule; the formula of substances with an ionic lattice or giant covalent structure represents the ratio of the different elements. • Standardised nomenclature is used in chemistry to specify a given chemical entity in an unambiguous manner. • There are different ways of representing bonding and electronic structures as drawings or by using 3D objects.	• Chemical formulae as representations of the ratio of atoms in a molecule or in the substance as a whole, and how this relates to the nature of bonding in the substance. • Balanced formula equations to represent reactions, including half-equations, redox equations, ionic equations, and appropriate use of state symbols. • Balanced formula equations as representations of the overall stoichiometry of a reaction, rather than the actual rearrangement of atoms that takes place. • Different representations for molecules and giant structures, and their suitability for different purposes. To include space-filling models, and their advantage as a more accurate depiction of the 3D shape and size of a molecule.

- A chemical reaction can be summarised using a balanced chemical equation. Similarly, equilibrium reactions and reactions of ions can also be represented using symbols. Energy changes within reactions can be represented using diagrams.
- Because chemical structures are three-dimensional, it is important to be able to interpret and translate between 2D illustrations and 3D representations of a giant ionic lattice or giant covalent structures, and between 2D formulae and 3D representations of molecules.

- Systematic nomenclature as a system of unambiguously identifying a substance, and providing information about its composition, structure and properties.
- Representation of reaction mechanisms, including the use of lines to represent pairs of electrons and curly arrows to represent movement of electrons.

Key idea: How we use mathematics, statistics and data is integral to chemistry to produce and analyse quantitative results, and to help us predict chemical behaviour.

	11–16	16–19
Rationale	Mathematics is a key tool in chemistry as it helps us to interpret representations in a quantitative manner. For example, a quantitative relationship between atoms in a molecule or substances in a reaction allows us to predict the amount of product from a reaction or the amounts of reactants required. Mathematical formulae show how physical quantities relate to each other and can be used to predict, for example, how the concentration of a solution changes upon dilution or how quickly a reaction occurs. Transferring mathematical ideas to problems outside of the mathematics classroom is important to develop a more generalizable view of mathematics. Furthermore, handling, processing and presenting data is a key transferable skill, increasingly so in the modern world.	Mathematics is an indispensable tool in chemistry. The mathematical representation of the physical world allows us to identify proportional relationships between physical quantities, giving us the power to make deductive predictions.
Introduction	Thinking mathematically provides an essential tool for the collection, analysis and interpretation of data from investigative processes. The identification of quantifiable trends also relies on mathematical understanding. Many representations of models used in chemistry are created by thinking mathematically using ideas such as ratio and proportion.	Learners should come to appreciate the importance of thinking quantitatively in chemistry, and become confident in the application of mathematical operations to contexts in chemistry.
Content	Use calculators to efficiently perform calculations • Carry out a wide range of chemical calculations including addition, subtraction, multiplication, division with numbers as integers, decimals, fractions and standard form. • Use standard form where numbers are very large or very small, e.g. numbers of molecules, concentrations.	Use of numeracy (arithmetic, algebra, graphical) skills. • Calculations in quantitative analysis. • The rationale for the use of logarithms to express acidity (pH).

- Round the result of a calculations and express with the appropriate number of significant figures.

Estimation

- Estimate the result of a calculation, including using order of magnitude.
- Evaluate and predict the effect of changing experimental parameters.

Ordering numbers

- Order and compare numbers (including negative numbers), e.g.:
  - melting point and boiling point data to predict the state of a substance;
  - distances moved by substances on a chromatogram;
  - the effect of loss or gain of electrons on the overall charge of an atom or ion.

Recognise and make use of appropriate units in a calculation

- Know that a measurement should always be associated with a unit and use appropriate units when substituting experimental measurements into a formula.
- Know the seven SI base units and the prefixes for numbers from 10^{-9} to 10^{9}.
- Convert between unit prefixes, e.g. $cm^3 \leftrightarrow dm^3$.
- Understand that derived units arise from compound measures, e.g. g/dm^3 is used for concentration when mass is measured in grams and volume in dm^3.

Data handling

- Process data, for example, using statistical techniques such as calculating the mean and displaying the data to consider the degree of variation.
- Represent the variation in data using graphical approaches, e.g. show the results of chemical analysis including the experimental error.
- Calculate or estimate the rate of a reaction from a graph.

Data presentation

- Present data in tables following scientific conventions.

- The use of mathematical models to represent observed correlations between physical quantities (details included in the Chemical Concepts strands where relevant).
- How mathematical models (e.g. rate laws) are derived from experimental observations, relying on quantitative measurements, and can be used to show the interdependence of variables and make predictions about behaviour.

NB full list of mathematical skills required to underpin chemistry at this level is included in an appendix – see end of this document.

- Choose the most appropriate graph for discrete and continuous data and draw the graph with an appropriate scale and precision following scientific conventions.
- Interpret the cooling curve of a pure sample of substance and a mixture.
- Recognise when two variables are linearly or proportionally related.

Using ratio, proportion and percentages in solving numerical problems

- Work out the ratio of different types of atom in a substance from a 2D or 3D representation.
- Calculate the percentage composition e.g. of a substance in a mixture.
- Interpret a balanced symbolic equation in terms of stoichiometry (the ratio with which substances react and are formed).
- Use a balanced chemical equation to calculate theoretical yield along with experimental data to calculate percentage actual yield.

Using mathematical formulae

- Explain the link between physical measurements using a formula.
- Substitute physical measurements into a mathematical formula to make a calculation.
- Change the subject of a formula if required.
- Use bond energies to calculate the overall energy change of a reaction.

Key idea: Chemists group and classify things such as substances, particles, structures and reactions, in order to build understanding of what exists, identify patterns and trends, and develop scientific explanations.

	11–16	16–19
Rationale	Classification is how scientists impose order on the physical world. By grouping and ordering substances according to their properties and behaviour, we can identify similarities and differences, patterns and trends. These observations can lead to new ideas about the nature of matter.	Classification is how scientists impose order on the physical world. By grouping and ordering substances according to their properties and behaviour, we can identify similarities and differences, patterns and trends. These observations can lead to new ideas about the nature of matter.
Introduction	Classification is a formal method of grouping that uses a commonly agreed set of criteria. The periodic table is one of the most important classification systems used in chemistry. It was originally organised by similarities in properties of the elements and refined through incorporating ideas relating to atomic structure. Classification and grouping are also used more generally in chemistry. Grouping substances or reactions based on similar observations, properties or characteristics can lead to ideas about the principles underlying chemical behaviour. Trends are generalisable patterns within a group that can be observed or obtained from data. Looking for trends involves considering how substances may differ in a systematic manner. Thinking about chemistry using groups and trends rationalises the vast number of substances and processes.	Learners study how the periodic table resulted from organisation of the elements by similarities in properties of the elements, and was later refined according to ideas about atomic structure. This, along with methods of classifying compounds and reactions, shows how identifying patterns and trends can support the development of models, leading to ideas about the principles underlying chemical behaviour.
Content	o Common elements and compounds can be grouped according to their observable properties, for example, properties can be used to classify elements as metals and non-metals. o Trends in the groups of the periodic table can be used to predict physical and chemical properties. o The reactivity series can be used to predict trends in the reactivity of metals. o A substance can be classified according to its structure (simple molecular, giant covalent, giant ionic or metallic) and reactions according to their type.	Classification systems in chemistry can be used to o group and order elements and substances based on similarities or trends in physical characteristics or chemical properties o group chemical reactions according to the mechanism, type of reactants or products, or other features o identify patterns and trends in behaviour, in turn helping us to think about underlying chemical principles. Appropriate classification systems for discussion could include: o the periodic table o functional group type and level o types of reaction (e.g. redox, acid–base, organic reaction mechanisms).

Big Question: How do we do chemistry?

Key idea: Chemists use current understanding in chemistry to help them choose appropriate processes and methods to answer new questions, where appropriate analysis of observations and evidence can lead to the development of new understandings and make chemistry greener

	11–16	**16–19**
Rationale	Understanding the process of investigation serves two broad purposes. First, it illustrates where the concepts of chemistry have come from. Second, the skills involved in carrying out investigations are transferable to many other fields where it is necessary to collect data, analyse and present it and make conclusions in order to answer a given question. Equally, assessing the quality of data collected by others and the conclusions drawn is an important transferable skill.	Understanding investigative processes helps learners understand how concepts in chemistry are developed. Being able to plan how to test a question, collect and analyse data, and draw conclusions is essential in scientific careers, as well as being more widely applicable.
Introduction	Each stage in an investigative process helps to supply evidence. How the evidence is put together helps to answer the question under investigation and to appraise evidence and conclusions from others. There are a number of different types of investigative process: **Comparative or fair testing**: A single variable is changed whilst keeping other variables constant and the effect of changing the single variable is measured. This approach works well when there is a readily measurable outcome. Examples include the effect of the concentration of reactant on the temperature rise in the reaction, and the effect of an acid on different metals. **Identifying and classifying**: sorting objects, chemicals, events into categories based on criteria which may be given in advance or developed in the course of the investigation. An example might be sorting materials into those that conduct electricity and those that don't. **Pattern seeking**: observing and recording observations when variables are not able to be controlled. This approach can be used in conjunction with identifying and classifying or may be used to create a model. An example might be to investigate how violently different metals react with acid solution.	Learners should develop their understanding of practical investigation, in terms of the full cycle from developing a research question situated in existing knowledge, through gathering of observations and/or measurements, to interpreting results and reporting outcomes. Learners should be supported in taking a creative, problem-solving approach to investigation.

	Observation over time: measuring a variable that changes with time or observing changes over time. An example might be measuring the amount of product of a reaction over time and then calculating the rate of reaction or changes in greenhouse gas emissions over time. Each investigative process can include some or all of the stages listed under Content.	
Content	To include experience and understanding of the following aspects of investigative processes (though not necessarily all in one investigation): *Planning* o Proposing a question to investigate that can be tested practically. o Designing the investigation. This could include: researching, selecting and/or adapting a protocol (method); following a given protocol; deciding what variables can be changed (or not), what can be measured or observed and what can be controlled (or not). It would also include choosing appropriate measuring apparatus or sampling technique and identifying how to assess and minimise uncertainty. o Making predictions using scientific knowledge and understanding, including the use of computational modelling. o Using the web to search for data and using it for sources. *Identifying risks and hazards* o Working safely and considering ethical and environmental issues. *Observing and recording* o Making careful observations or measurements. o Understanding the limitations of measurements in terms of uncertainty and error o Keeping records of the procedure. o Recording results using scientific conventions, including units and using tables where appropriate. *Analysing and processing data* o Grouping, classifying or looking for patterns. o Carrying out any further processing as appropriate, for example determining percentage change, ratios between variables, calculating mean.	Aspects of investigative processes. Developing and demonstrating these skills should include planning and performing investigative practical work, and presenting outcomes. *Planning* o Developing questions that can be tested practically, using chemical knowledge and understanding and informed by research in online and/or offline sources. o Designing experiments or investigations to answer a question or test a hypothesis. This could include the use of computational modelling. o Identifying hazards, and taking steps to minimise risk. *Observing and recording* o Making careful observations or measurements, and recording them using scientific conventions so that they can be interpreted and analysed. o Keeping records of the exact procedure followed, so that the investigation can be repeated. o Assessing the quality of results using understanding of error and uncertainty. *Analysis and presentation* o Data processing (e.g. through presentation in graphs, tables or other formats, coding, mathematically or using software, including propagation of uncertainty) to allow interpretation and to draw conclusions.

- Using information technology to assist with data processing, including the use of basic spreadsheet workbooks, coding and data analysis.

Presenting data in graphs, tables or other formats

- Demonstrating an understanding of how to handle both qualitative and quantitative data and continuous or discrete forms of measurement.
- Using scientific conventions.
- Using information technology to assist with the presentation of results.

Evaluating

- Evaluating the experimental protocol as well as the analysis; to include identifying potential sources of error, including confounding variables, procedural error, shortcomings in design and measurement uncertainty, considering whether the same results would be obtained if the experiment were to be repeated.
- Assessing the quality of evidence and the validity of conclusions, suggesting improvements to practical design to improve the quality of results.
- Using outcomes to identify further questions.

Making conclusions

- Relating conclusions back to the original question and an understanding of the underlying chemistry.
- Reflecting upon the conclusions in the light of other knowledge. Carrying out research to relate results to a wider perspective.

Reporting

- Communicating outcomes from practical work as a record of investigations done and in such a way that others could use the information to inform their research.
- Using scientific style and conventions to aid common understanding.
- Presenting data and conclusions in other ways and for other audiences – e.g. oral presentations, in videos, news articles etc.

Evaluation

- Evaluation of procedures and results to determine how confidently conclusions can be drawn. Consideration of potential sources of error, including confounding variables, procedural error, shortcomings in design and measurement uncertainty.
- Using evaluation to suggest improvements to the experiment or investigation.

Concluding

- Drawing conclusions by relating observations and processed data to understanding of related chemical concepts.
- Relating outcomes back to the original aim of the investigation, and suggesting further questions for investigation.

Reporting

- Communicating procedures, results and conclusions in such a way that others could use the information to inform their research.
- Use of scientific style and conventions in written reports to aid common understanding.
- Other methods of presentation as appropriate to other audiences or purposes – e.g. oral presentations, in videos, news articles etc.

Key idea: Empirical enquiry into the material world requires the use of a range of practical and computational techniques, to produce valid, accurate and reproducible evidence.

	11–16	16–19
Rationale	An ability to make accurate measurements and assess the quality of data are transferable skills that are useful in everyday life as well as in a number of careers. Gaining an appreciation of what practical work involves can help learners with deciding on their own career path. Experiencing phenomena is also important for understanding and sense-making, to illustrate and affirm theory. For example, processes such as chromatography or distillation can be learned from books, pictures and videos but actually carrying out the process and seeing, feeling, hearing and smelling it is much more powerful.	Learning specific practical techniques offers a basis for learners to understand the value of a well-developed practical procedure. Individual techniques have been honed to achieve a particular outcome, such as the synthesis or isolation of a product or the investigation of the nature of a reaction. Becoming familiar with techniques also allows learners to develop their manipulative skills, safely handling equipment and chemicals. Certain techniques allow learners to demonstrate that they can make accurate measurements and observations, which is central to scientific investigation.
Introduction	To carry out experimental techniques requires skill in the handling and use of specific apparatus and chemicals as well as the appropriate use of technology. This could include the use of computational modelling, coding and data analysis. There are a number of common (essential) laboratory skills and it is important that learners are able to carry these out, choosing the most appropriate equipment for the particular task, selecting appropriate measurement units, the degree of precision and accuracy and to work safely and carefully. Learners should be able to use these laboratory skills in a number of processes.	Practical techniques are used to achieve particular outcomes in investigations or procedures. These techniques have evolved to maximise efficiency and accuracy. Practical techniques can broadly be applied for the following purposes: o carrying out a reaction, e.g. to produce a specific product o investigating the characteristics of a reaction, such as the rate or energetics o separating and purifying substances o characterising and quantifying substances (chemical analysis). Digital tools can also be used to achieve these outcomes, including further integration of computational modelling, coding and more advanced data handling and manipulation.

Content	*Laboratory skills* o Controlling temperature (e.g. using a Bunsen burner or water bath). o Measuring volume of solids, liquids and gases (e.g. measuring cylinder, burette, syringe, ruler). o Measuring length, time, mass, temperature, pH. *Use of the above laboratory skills in specific processes* o Measuring quantitative changes during a reaction. o Separating components of a mixture. o Determining pH changes in a reaction. o Identifying unknown substances (by observing colour changes and/or precipitates, melting point). o Observations of relative reactivity. o Comparing physical and chemical properties of substances.	The broad purposes of practical techniques, and an understanding of why certain procedures are performed in a specific way. Confident and competent use of standard experimental procedures and basic equipment. To include hands-on experience of the following techniques: o use of heating apparatus for controllably and safely heating flasks and beakers (sand bath, water bath and/or electrical heater) o choosing appropriate glassware for carrying out a reaction o use of retort stand and clamps to set up apparatus o heating under reflux o measuring rate of reaction o filtration to separate a solid product or remove an impurity o recrystallization to purify a solid product o use of a separating funnel to purify a product o distillation to separate or purify a liquid product o paper or thin-layer chromatography to separate and identify products o use of melting point apparatus o volumetric analysis, including titration, making up a standard solution, selecting indicators, measuring pH o setting up electrochemical cells and measuring voltages. An understanding of the procedures involved in the following techniques: o colorimetry o calorimetry o use of vacuum in separation techniques (e.g. filtration, distillation) o column chromatography o spectroscopic techniques.

Dimension: Chemical concepts

The body of knowledge and understanding about matter, its properties and changes.

Big Question: What are things made of?

Key idea: All matter is made of one or more chemical substances, which have unique properties and chemical composition

	11–16	16–19
Rationale	Understanding that the natural world is made of mixtures of substances leads to the idea that the substances can be separated or combined and this can make them more useful.	
Introduction	A substance, in a scientific sense, is a specific kind of "stuff" with an identity conferred by its properties. Every substance has distinctive physical and chemical properties. These can be used to identify a substance. A mixture is made up of two or more substances that are not chemically bonded. Solutions are a common type of mixture and acids and alkalis are both solutions that are commonly used reagents. If a sample contains only one type of substance it is said to be pure. The different properties of the constituent substances allow mixtures to be separated. A substance can change state whilst remaining the same substance or it can become a new substance.	

Content	o The term pure is used to mean a single substance whilst an impure sample contains other substances as part of a mixture. Most substances in the natural and made world are present in mixtures.
	    o An alloy is a mixture of a metal with at least one other element.
	    o A solution is a mixture of a solute and a solvent.
	o Concentration of a solution is determined by the mass of solute and volume of solvent. The terms dilute and concentrated are used in relation to aqueous solutions.
	o Gases, liquids and solids can dissolve in water.
	o The formulation of a mixture can be expressed as a fixed ratio.	

- There are different separation techniques used to separate the components of a mixture and these methods are based on using the different physical properties of substances.
- The shapes of the cooling curve of a pure sample and an impure sample are different.

Key idea: Bulk properties of substances in different phases can be explained in terms of the nature and interactions of their constituent particles

	11–16	16–19
Rationale	Understanding of the particle model underpins all of chemistry: it explains why substances have distinct melting or boiling points and behave differently in the solid, liquid and gas states. It also explains many everyday observations, for example why perfume sprayed at one end of the room can soon be detected a distance away and why washing dries faster on a windy day.	This strand incorporates some of the basic ideas about the nature of substances, which serve to make the link between the sub-microscopic world and the macroscopic world. Recognising the relationship between the arrangement of particles in solids and the bulk material properties is essential in material design. Understanding of the behaviour of gases has relevance for industrial reactions and atmospheric chemistry.
Introduction	Physical properties and change can be explained using the particle model. Any sample of a substance is made up of a very large number of particles: for this reason, calculations of amount of substance use the quantity of a mole.	Learners build on their understanding of the particle model by exploring the behaviour of matter in more detail, including deeper insight into the behaviour of gases through the ideal gas model. They study new types of materials, which demonstrate different ways in which particles can be arranged, and how this affects bulk properties.
Content	o Substances are made of atoms, molecules or ions. The physical properties of the different states of matter and the transitions between them can be explained using the particle model. o Differences in melting/boiling point and the shape of cooling curves can be explained in terms of energy transfers and the relative strength of chemical bonds or intermolecular forces. o The mass of a given substance is related to the amount of that substance in moles and vice versa. o Diffusion in liquids and gases can be understood in terms of the particle model.	o The solid, liquid and gas phases of matter, and their transitions. The behaviour and arrangement of the particles explains the bulk properties in each phase. o Physical properties of materials depend on the arrangement of and interactions between the constituent particles. (This should include study of some contemporary types of materials.) o The ideal gas model and equation, including their basis on experimental observations, and the usefulness and limitations of the model.

Key idea: Atoms or ions of elements (of which there are only a relatively small number) combine in different ratios and structures to produce the huge variety of compounds that exist

	11–16	**16–19**
Rationale	Knowledge of the elements and their compounds is important for understanding that materials have different properties as a result of the elements or compounds of which they are made. Understanding the development of the periodic table helps to make sense of the large number of elements: it demonstrates that chemical scientists use trends, and similarities, in the properties of the elements to discover overarching ideas about the behaviour of the elements.	Chemical scientists use systematic nomenclature to unambiguously identify substances. The names also provide information about the nature of the substance, and therefore the properties it is likely to have. Studying the development of the periodic table shows how observations of similarities in properties led to the organisation of elements into groups. This is one aspect of the periodic table, which links to other aspects connected to atomic structure.
Introduction	Every substance is either an element or compound. Each element is made up of one type of atom only and has distinctive physical and chemical properties. Elements are grouped and classified in the periodic table. There are similarities between elements in groups. This allows trends in properties to be used to make predictions. Every element has a name and symbol. A compound is made up of more than one type of atom that are chemically bonded. The properties of a compound are different to those of the elements of which it is made. The properties of a compound are dependent upon its bonding and structure. Individual atoms or molecules do not have these properties. A compound can be represented by a name, formula, 2-D diagram or 3-D model.	Applying nomenclature to a wider range of substances will help learners appreciate the need for systematic nomenclature.
Content	o An element is a substance consisting of atoms which all have the same number of protons and may be made up of separate atoms, molecules or exist as a giant structure. o The periodic table contains over 100 elements, most of which are naturally occurring though some are synthetic. The elements are organised by atomic number, and into groups and periods. o Trends in the groups of the periodic table can be used to predict physical and chemical properties. o A compound is formed of more than one type of atom chemically bonded. o Compounds are named using the internationally recognised system based on their constituent elements.	o Systematic approaches to naming compounds. o The organisation of the periodic table in terms of similarities and trends in properties of elements.

Big Question: How do we find out what things are made of?

Key idea: Differences in chemical and physical properties can be used to identify, quantify and separate substances

	11–16	16–19
Rationale	Chemical analysis is central to our understanding of the world around us. Analysis is how we have come to know about the nature of substances, how they are constructed, and what substances exist in a world that mostly consists of mixtures. Being able to analyse samples has a whole range of applications. We use analysis to keep us safe, for example in quality control or detecting hazardous compounds. We can monitor changes in the environment, such as the composition of the atmosphere or soils. Being able to separate, combine and purify substances is fundamental in the production of many consumer goods.	Chemical analysis is central to our understanding of the world around us, and in keeping us safe. Analysis can demonstrate the presence of particular substances, such as contaminants in food or markers for disease. It can determine the quantity of substances of interest, such as CO_2 in the atmosphere. It can determine whether a product, such as a pharmaceutical, is pure.
Introduction	The distinctive physical properties of a substance, such as melting point, may be used in chemical analysis to help identify a substance or assess its purity. A series of chemical reactions may be used as evidence to deduce the identity of a substance.	Learners build upon the understanding of analysis methods that they have developed at previous stages, through deeper understanding of the principles behind separation methods, and the interpretation of results from a variety of techniques widely used in research including chromatography and spectroscopy. Learners should appreciate that analytical techniques may be used to confirm the identity or assess the purity of a substance. They engage with analytical techniques on a more quantitative basis, using relevant calculations to determine amounts of substance present. Throughout, the emphasis should be on understanding the principles behind the methods involved and how they are applied, rather than providing learners with a 'checklist' of techniques.
Content	*Analysis based on physical properties* o Physical properties such as melting point data can be used to distinguish pure from impure substances and support identification. Separation techniques that exploit changes of state, e.g. distillation, evaporation, crystallisation are commonly used.	o The principles behind the separation of mixtures, including through filtration, distillation and chromatography. o The use of melting or boiling points to assess the purity and confirm the identity of a pure substance. o Preparative and analytical (qualitative and quantitative) uses of chromatography (e.g. TLC, column, LC, GC).

- Chromatography can be used to distinguish pure from impure substances.

Analysis based on chemical reactions

- Observations of chemical tests to identify gases or ions in solution.
- An indicator dye can be used to estimate the pH of an acid or alkali.
- An indicator dye can be used to show a chemical change has occurred.

Analysis using electromagnetic radiation

- Atoms and molecules absorb and emit electromagnetic radiation in a way that is characteristic for a given molecule and this can be used to aid identification.
- The use of spectroscopic techniques (e.g. NMR, IR, UV-Vis) to investigate molecular structure, including their origin in the interactions of substances with electromagnetic radiation.
- Modern mass spectrometry methods and their applications, including identification of species and determining isotopic ratio and relative molecular mass.
- The purpose of elemental analysis, and its use in finding empirical and molecular formulae.
- The principles behind titrations and their use to measure the concentration of substances in solution.

Big Question: How do we explain how substances behave?

Key idea: Atomic models have been developed to explain physical and chemical phenomena

	11–16	**16–19**
Rationale	Understanding the electronic structure of atoms is fundamental to understanding how they form compounds and how they react, i.e. their chemical properties. It explains, for example, why sodium metal reacts violently with chlorine gas to form the substance we know as table salt and why a salt solution can conduct electricity. Many natural processes involve ionic substances, for example formation of stalactites in caves and limescale in a kettle.	Atoms are the fundamental building blocks of chemistry. Understanding their structure is underpinning knowledge for understanding bonding and structure – why atoms combine in the way that they do. Atomic structure also helps to explain certain properties of elements, including their reactivity and the way atoms interact with electromagnetic radiation. Again, this underpins the content in other strands.
Introduction	The smallest particle that forms the structure of a substance is an atom or an ion. The atoms of each element differ. Some substances have a structure made up of groups of atoms, called molecules. In other substances the atoms or ions are all joined into one giant structure. Some atoms consist of more than one atom. According to the atomic model, which was gradually developed over time, an atom is made up of three subatomic particles (protons, neutrons and electrons) that are held together by electrostatic interactions. This model describes an atom as consisting of a central positive nucleus surrounded by shells of electrons. The periodic table can be used to deduce the number of each subatomic particle and hence the electronic structure of the atom based on occupation of different energy levels. Ions are formed when atoms gain or lose one or more electrons through ionisation and, since ions are charged particles, they can interact electrostatically.	Learners develop the simple model of the atom into a more complex one, incorporating the concept of orbitals to expand on the concept of shells. They apply this model to understanding the layout of the periodic table in terms of organisation into s, p, d and f blocks, and explaining some of the trends in behaviour of elements and their compounds seen in the periodic table. The interactions of atoms and ions with electromagnetic radiation is an example of how an observable phenomenon led to the development of a more sophisticated explanatory model.

Content	*The atomic model* o The atomic model can be described in terms of protons, neutrons and electrons which have charge and relative mass. The atomic number of an element is linked with the number of protons (and hence electrons) in each atom. o An atom is held together by the balance of electrostatic attraction and repulsion. o Isotopes of an element have the same number of protons but different numbers of neutrons, and hence a different mass. The relative atomic mass is the weighted mean mass of isotopes of an element. *Modelling electronic structure* o The electronic structure of an element can be worked out from its atomic number (for the first 20 elements) and linked to the position of an element in the periodic table. o The process of ionisation is the loss or gain of electrons from an atom to produce a charged ion. The net charge on an ion is determined by the number of protons and electrons.	o The development of models of atomic structure through successively better approximations to real behaviour in response to experimental findings. o The s,p,d,f orbital model of atomic structure, including electron configurations of atoms and ions up to $Z = 36$. o The relationship between atomic structure and the organisation of the periodic table. o How the model of atomic structure accounts for the general trends in behaviour across periods and down groups (e.g. ionisation energy, melting points, reactivity, thermal decomposition of compounds). o How absorption and emission of energy by atoms and ions relates to electronic structure, giving rise to spectra, and colour in transition metal ions.

Key idea: Models for different types of chemical bonding and structure have been developed to explain physical and chemical properties of substances

	11–16	16–19
Rationale	The arrangement of bonds can explain the bulk properties of a substance. For example, graphite, diamond and graphene are all made of carbon atoms but differences in the arrangement of the bonds leads to substantial differences in properties and therefore uses.	The way that atoms and ions bond together in molecules or extended structures determines how the resulting substances behave. Patterns in the bonding of elements can also be used to predict what compounds can form, and what reactions may occur between substances. Intermolecular forces are similarly fundamental to understanding bulk properties, and are of critical importance in explaining interactions in biomolecules. Studying isomers promotes deeper thinking about molecular structure, and informs understanding of the limitations of synthesis. The existence of stereoisomers has particular relevance in biomedical chemistry.
Introduction	All substances are held together by the electrostatic attraction of chemical bonds and the electronic structure of an atom influences which type(s) of chemical bonds it forms. These bonds can be represented by three different models of bonding (ionic, covalent and metallic) based on the attraction between different entities (oppositely charged ions, electrons and a positive nucleus or positive ions and delocalised electrons). The underlying structure of a substance formed through these chemical bonds can be one single giant structure or it may be composed of separate simple molecules. In this case there are also forces of attraction/intermolecular bonds between the molecules. The properties of a substance may be explained by its structure and bonding.	Learners develop a detailed understanding of chemical bonds and intermolecular forces. Fundamental principles that underpin all aspects of this topic include energy, electrostatic interactions, and electronegativity. A detailed understanding of structure and bonding (submicroscopic level) helps to explain the physical and chemical properties of bulk substances (macroscopic level).

Content

Representations of bonding

- A substance is held together by chemical bonds resulting from the electrostatic attraction between opposite charges.
- There are different types of bond found in an element or compound:
  - ionic (metal and non-metal compound)
  - covalent (non-metal element or compound)
  - metallic (metal element)

Types of structure

- There are four main types of structure, simple molecular, giant covalent or giant ionic lattice.
- A molecule is formed from two or more atoms that are chemically bonded and the formula of a simple molecular substance can be written based on the number of each type of atom. Molecules have a characteristic three dimensional shape.
- The formula of a giant covalent or ionic substance can be written based on the ratio of each type of atom and the formula of an ionic substance can be worked out from the charges of its constituent ions (including polyatomic ions).
- Some elements exist as different allotropes where the atoms and the bonds between them are arranged differently.

Linking structure and properties

- The different structures, ionic, covalent (simple and giant) and metallic substances have typical properties.
- The higher melting or boiling point of substances with giant structures compared with simple molecular substances can be explained in terms of the relative strength of bonds within and between molecules.
- The differences in melting and boiling point of simple molecular substances can be explained in terms of differences in the force of attraction between molecules.
- Some substances can conduct electricity if they contain charged particles (electrons or ions) that are able to move freely.
- The structure of a molecule or compound can be linked with its three dimensional shape which affects the properties of a substance.

- Covalent and ionic bonding as two extremes of bonding, with polar covalent bonds as the intermediate type; dative bonds as a type of covalent bond.
- The nature of metallic bonding.
- Electronegativity, its relationship to bonding character, and its relevance in intermolecular interactions.
- The origin and relative strengths of intermolecular forces (e.g. London and dipolar forces, hydrogen bonds) and how they affect properties of substances, such as melting and boiling point, and dissolution.
- Properties of nanoparticles may depend on their size, and may differ from those of the same substance in bulk quantities.
- The dependence of lattice enthalpies on ion size and charge, and their correlation to properties such as melting point and dissolution.
- The use of orbital models to describe shape and bonding in organic and inorganic species including aromatic compounds and complex ions.
- The VSEPR model and its use to predict and account for shapes of molecules and ions.
- The different structural arrangements in solid materials, including simple molecular lattices, giant covalent and ionic lattices, metallic lattices, and polymer chain structures.
- How knowledge of chemical bonding and structure can be used to make predictions about bulk properties of compounds and materials, and is used in the design of novel materials.
- The principles of isomerism in terms of differences in bonding and structure, and how isomers, in particular stereoisomers, may show both similarities and differences in properties.

Big Question: How can substances be made and changed?

Key idea: Chemical reactions results in the formation of new substances, through rearrangement of the bonding between atoms or ions, resulting in observable changes in physical properties

	11–16	**16–19**
Rationale	The concept of a chemical reaction, whereby substances recombine to form new substances, is fundamental in chemistry. Investigating how reactions occur and the effects they have, helps us understand why we see the reactions that we do. An appreciation of chemical reactions is also central to understanding biological and environmental processes.	Chemical reactions are how new substances are made. By investigating how reactions occur, and how they are dependent on conditions, we can understand why we see the reactions that we do. The models built on this understanding provide a predictive power, allowing a rational approach to the search for new compounds and materials. Harnessing electrochemistry and thermodynamic principles has many industrial applications, as well as being crucial in developing renewable energy sources and replacements for fossil fuels.
Introduction	During a chemical reaction bonding changes and a new substance or substances are made. No atoms are created or destroyed so mass is conserved. These changes can be summarised using a balanced chemical equation. Many chemical reactions occur naturally, for example in biological systems.	Rearrangement of electrons between atoms is a characteristic of many chemical reactions. Studying this idea through the lenses of redox and organic mechanisms helps learners to understand why species react in the way they do. In the case of redox, we use differences in reactivity to generate electricity. Organic mechanisms can be understood as models that explain experimentally observed characteristics of the reaction.
Content	*Understanding reactions* o Whether or not a chemical reaction has taken place can be determined on the basis of observable changes in physical properties when a new substance (or substances) is formed. This can be confirmed using chemical analysis. o During a chemical reaction, changes in bonding take place but the nuclei of the atoms themselves are not changed. This explains why mass is conserved during a chemical reaction.	o Balanced chemical equations express stoichiometric relationships and demonstrate conservation of mass; calculation of reacting masses including conversion of masses, concentrations or volumes to amount of substance in moles, or *vice versa*. o Redox reactions in terms of change in oxidation state, including the implications for reactivity. o Electrochemical cells (half equations, electrode potentials and electron flow) including calculation of cell potentials. o Reaction mechanisms as models for reactivity that explain experimental observations, such as the identity and stereochemistry of products and the order of reaction.

- A chemical reaction can be represented by a balanced symbol equation which gives information about the ratio with which substances react and are formed. These chemical equations can also be used to calculate masses, and therefore moles, of reactants or products. This can also be used to calculate the limiting quantity of a reactant since the relative formula mass of any compound can be calculated using relative atomic masses from the periodic table.
- Reactions that occur in aqueous solution can be explained in terms of the ions and molecules that are reacting.
- Neutralisation, the reaction between H^+ ions in an acidic and OH^- ions in an alkaline solution to form a neutral solution.
- The formation of a precipitate can be explained in terms of the formation of an insoluble product from soluble reactants.

Key idea: Whether or not a reaction occurs spontaneously can be explained in terms of energy transfer and entropy (dispersion)

	11–16	16–19
Rationale		Chemical reactions are how new substances are made. By investigating how reactions occur, and how they are dependent on conditions, we can understand why we see the reactions that we do. The models built on this understanding provide a predictive power, allowing a rational approach to the search for new compounds and materials. Harnessing electrochemistry and thermodynamic principles has many industrial applications, as well as being crucial in developing renewable energy sources and replacements for fossil fuels.
Introduction	The reactivity of a substance relates to the ease with which an atom gains or loses electrons. Overall there is a transfer of energy between reactants, products and their surroundings. There may also be a change in the overall order/disorder when a reaction takes place.	Learners develop their understanding of the energetics of reactions and add the concept of entropy to explain why a reaction is feasible, or not, at a given temperature. Enthalpy cycles can explain, and to an extent predict, the enthalpy change of a reaction.
Content	*Reactivity* o Reactivity is related to the ease with which atoms lose or gain electrons. o Information from the periodic table, proton numbers and electron arrangements, can be used to explain trends in reactivity. *Energy* o Most reactions require an initial input of energy to make the reaction happen, which is known as the activation energy. o This input of energy is required to break chemical bonds and energy is transferred to the surroundings when new chemical bonds are formed. o During a chemical reaction, overall energy is conserved. o There is an energy transfer because the chemical energy store of the reactants is different to that of the products. The difference in total bond energy of the reactants and products is equal to the overall energy transfer of the reaction.	o Hess's law, and the link between enthalpy changes of reaction and bond enthalpies; including bond enthalpy and enthalpy change calculations. o How differences arise between using a model to theoretically calculate an enthalpy change and determining it experimentally, e.g. in terms of assumptions about bonding character, averaging of bond enthalpy values, etc. o Entropy and how it influences chemical reactions. o Gibbs energy change; calculation from changes of enthalpy and entropy and its use to predict spontaneity of reactions. o The basic principles of reaction mechanisms; the conservation of electrons and charge, electron flow and electron pushing.

- Not all reactions happen spontaneously at all temperatures. Whether a reaction happens depends upon both the change in energy due to bonds being made/broken, and the change in the order/disorder when reactants rearrange to become products.

Key idea: Formation of a product is dependent on the reaction rate and equilibrium position, both of which can be influenced by a number of factors

	11–16	**16–19**
Rationale	Even when chemical reactions are possible, they do not always proceed quickly or fully. This can be understood and characterised using ideas such as collision theory; in turn these ideas can be applied to increase the yield of useful reactions and reduce harmful reactions. These concepts can also be applied to understanding reactions in the environment and in biological systems. For example, life as we know it would not exist without biological catalysts.	Knowing when a reaction comes to equilibrium means we can find the maximum yield. Knowledge of rates of reactions and how they change with temperature is essential for optimising chemical reactions. Both concepts can also be applied to understanding the natural world, and the extent to which substances persist in it. Acid–base buffer solutions provide stability in natural systems, with biological and ecological relevance.
Introduction	Reactions occur when particles collide with sufficient energy. The rate of reaction can be altered by changing a range of variables. These changes can be explained by modelling the number of successful collisions per unit of time. Rate of reaction can be calculated from graphs of experimental data. Some reactions are reversible, that is, they can go forwards and backwards. If these processes happen at the same time, and at the same rate, and the quantity of reactants and products remain constant, then the system is said to be in dynamic equilibrium. A change imposed on a system under dynamic equilibrium can alter the proportion of reactants and products as the system counteracts the change.	Learners progress their understanding of dynamic equilibrium to the use of equilibrium constants, including their application to the dissociation of weak acids and connection to pH. In the process, the nature of acid–base reactions is developed. The equilibria formed by weak acids and bases can be used to establish buffer systems, which can maintain a stable pH value. Learners can link particle theory to reaction rate using the collision model, providing an explanation for changes in reaction rate depending on conditions. Activation energy offers a link between rate and reaction mechanisms. Learners should understand that rate laws, which must be established experimentally, are mathematical models that can be used to propose reaction mechanisms.
Content	o Chemical reactions occur when particles collide, but not all collisions result in reactions. The more successful collisions per unit time occur, the faster the rate of reaction. A number of different factors can affect the rate of a reaction. o A catalyst can increase the rate of a reaction in terms of lowering activation energy and thereby increasing the number of collisions that are successful. o The rate of reaction is the amount of product formed (or reactant lost) over time and can be measured using experimental techniques.	o Chemical equilibrium as a dynamic process, and how equilibrium is affected when conditions are changed. o The significance of equilibrium constants, including calculations. o The Brønsted–Lowry theory of acid–base behaviour; strong and weak acids, buffer solutions. o pH, K_a and pK_a, including their use in interpreting experimental pH curves and explaining the behaviour of indicators.

- Many reactions are reversible i.e. they can go forwards as well as backwards.
- Dynamic equilibrium occurs when the forwards and backwards reactions happen at the same rate such that the proportion of reactants and products in the system remains constant.
- A number of changes can alter the proportion of reactants and products and these changes can be predicted.

- Rates of reaction, including rate laws and orders of reaction, and the relationship between rate laws and reaction mechanisms.
- Calculations involving rate laws, orders of reaction and rate constants, including the use of experimental data to construct rate laws.
- The theoretical basis of homo- and heterogeneous catalysis.
- The collision model of chemical kinetics and its use to explain how reaction rate depends on changes in conditions, including an understanding of how rate relates to both activation energy and temperature.

Key idea: Synthesis routes can be optimised to maximise yield and to minimise waste and pollution

	11–16	16–19
Rationale	Using ideas about the nature of reactions, and the way certain types of substance react, chemical scientists can plan to produce new substances. These may be completely new substances – just to see if it's possible – or substances designed with desired properties in mind. We can also plan how to minimise harmful effects of reactions, such as pollution.	Chemical scientists can plan to produce specific compounds of interest. An understanding of how to transform one substance into another is fundamental to applications of chemistry, ranging from pharmaceuticals and pesticides to materials used in electronics and displays. Minimising waste and use of energy in synthesis is important in developing sustainable procedures.
Introduction	The synthesis of a substance requires the design of a sequence of steps including a method of separation and purification of the product. Working out a suitable reaction pathway requires an understanding of patterns in types of reaction as well as the structure of any molecules and the mechanism by which they react. Industrial manufacture requires the scaling up of laboratory processes. The feedstock for industrial processes are produced from raw materials. The reaction and its conditions must be designed to ensure a balance between ensuring an acceptable rate of reaction whilst maximising the yield of product. Chemical analysis can be used to ensure quality control.	Learners study characteristic reactions of organic functional groups and reactions at transition metals, using these tools to demonstrate how to plan the synthesis of specific compounds. It should come across that planning synthesis applies in all areas of chemistry, not merely organic chemistry. Learners study how synthesis routes should be evaluated and optimised, bearing in mind considerations such as yield and the principles of green chemistry. Ideas about energetics, rate and equilibrium – included in other strands – also have a bearing on synthesis.
Content	o Reaction conditions can be chosen to balance the need for a fast rate, low cost and high yield. o Many chemicals are produced on an industrial scale from raw materials and the scale of the synthesis will have an impact on the design of the synthetic process. o Suitable methods can be used to separate and purify the product of a planned synthesis. Chemical analysis has an important role to play in quality control in terms of identification and assessment of purity of a product o Some reactions may result in production of isomers of a product which need to be identified.	o Organic functional groups and their reactivity. o Functional group level and how to carry out simple functional group interconversions. o Reactions at transition metals, including ligand substitution reactions, and the preparation of transition metal complexes. o The principles underlying the reactions required for the production of some industrially important inorganic compounds. o Development of synthetic strategies, including the limitations of synthesis (e.g. in relation to yield, formation of multiple isomeric products, low reactivity of reagents, purification of product required) and consideration of the twelve principles of green chemistry. o Calculations involving theoretical yield, percentage yield and atom economy.

Dimension: Chemistry and the world

The interactions between chemistry and the world around us, and the interplay with society and other disciplines.

Big Question: What is the role and impact of chemistry?

Key idea: Using analytical processes, chemistry can help us to explain natural phenomena and the impact of systems at different scales, enabling us to understand ourselves, our world and the wider universe

	11–16	**16–19**
Rationale	Understanding the chemistry of our world, our universe and ourselves is a prerequisite of understanding and monitoring the impacts of chemistry.	Understanding the chemistry of our world, our universe and ourselves is a prerequisite of understanding and monitoring the impacts of chemistry.
Introduction	Chemistry helps us to explain natural phenomena and to understand human impacts on natural systems ranging from large macro systems such as the oceans and atmosphere to the biochemistry of living organisms. An understanding of the world around us can require an understanding of the interaction of many systems, for example in developing deeper understanding of climate change.	Learners should appreciate how analytical techniques and modelling are applied to investigate and monitor environmental and biological systems. This may include investigating the 'natural' state, or monitoring the effect of imposed changes. Some spectroscopic techniques have the advantage that they can be applied at a distance, allowing us to explore the chemistry beyond our planet.
Content	o Analytical chemistry is used to study the environment, including monitoring the environmental impacts of man-made chemicals. However, there are limitations and difficulties to using real-world samples. o Real-life scenarios can be explained using chemistry concepts; for example the link between particle theory and wet clothes drying over time, or the link between chemical reactions and metabolism in animals. o Chemistry has contributed to understanding the causes, effects and solutions in relation to climate change. o Several underlying chemical concepts are required to explain many phenomena, for example in climate change: o the effects of gases in the atmosphere on warming of the Earth's surface;	o The application of analytical chemistry in monitoring the environment (e.g. groundwater, soils, atmosphere) and the chemistry of living things. o The limitations of analytical methods and the difficulties involved in preparing real-world samples for analysis. o The use of spectroscopic techniques to explore the chemistry of the universe. o The application of computer modelling to understanding aspects of our world (e.g. distribution of gases in the atmosphere, biochemical structures or systems, drug design).

- the production of gases from human activity such as burning fuels and agriculture;
- the effect of increased temperature on sea level via melting of ice and by water expanding;
- the idea that levels of CO_2 in the atmosphere depend on CO_2 production and absorption processes.

Key idea: Using understanding of chemistry, we can produce new substances and materials, and develop useful chemical processes, to enrich our lives and address local and global challenges

	11–16	16–19
Rationale	Production of particular materials such as plastics, dyes, fabrics and medicines demonstrates relevance and is of itself important. Developing this to considering issues of cost and benefit analysis and sustainable development emphasises the role that chemistry plays in society. Identifying and bringing together a number of factors develops analytical skills and debating the issues demonstrates the interrelationship between science and society.	Studying a varied range of industrial and societal uses of chemistry not only illustrates how the chemical sciences help to ensure our health and comfort, but also serves to illustrate how core ideas in chemistry are applied.
Introduction	Chemistry is used to address the global challenges facing society including water and food supply, health, environment and energy. The materials needed can be produced through the processing of natural resources by physical or chemical means. Alternatively, novel materials can be designed with the specific properties needed. These can then be manufactured on an industrial scale. Industrial manufacture requires the scaling up of laboratory processes. The feedstock for industrial processes are produced from raw materials. The reaction pathway and reaction conditions must be designed to ensure a balance between ensuring an acceptable rate of reaction whilst maximising the yield of product. Chemical analysis can be used to ensure quality control.	Learners study how the chemical industries produce a wide range of substances and materials that find use in society, and bring direct or indirect benefits to our everyday lives. They should appreciate key principles from across the subject are applied in optimising processes and designing materials. Learners study examples of the role chemistry plays in resolving global challenges that face our society, and the importance of sustainability in all chemical processes. They should realise that chemical processes and products may also have negative effects, which must be balanced with the benefits and mitigated as far as possible.

Content	o Industrial processes are used to convert raw materials into useful products.
	o In many cases, industrial processes involve scaling up reactions.
	o Chemistry can be used to make novel materials, for example medicines and materials for clothing and building shelters. These novel materials have properties that would not otherwise be available.
	o Cost-benefit analysis and considerations of sustainability are important in understanding the impacts of producing novel materials on an industrial scale.
		o Industrial chemical reagents are obtained through processing natural resources or recycling materials; a series of processes may be required for some reagents.
		o Optimisation of industrial chemical processes involves considering
		    o yield (e.g. energetics, kinetics, equilibrium, availability of catalyst)
		    o principles of green chemistry (e.g. atom economy, nature of waste products, use of energy)
		    o economy (e.g. cost and availability of reagents, cost of maintaining reaction conditions).

	o Examples chosen should reflect a wide range of contexts and applications and, ideally, be situated within local, national and global contexts such as energy, environment, food, health and water.	o Evaluation of product life cycle to assess environmental impact, including consideration of e.g. the reagents, waste management, product recycling.
		o Application of ideas about structure, bonding and reactivity to understand the macroscopic properties of some modern materials, including ‘smart’.
		o The role of chemistry in solving global challenges in the following areas, incorporating detailed examples relating to at least some of these areas:
		  o *Environment*: monitoring and tackling pollution; climate change.
		  o *Energy*: environmentally sustainable, affordable energy production, with a focus on renewable sources.
		  o *Food*: products for crop protection and nutrition; soil environment.
		  o *Health*: drug discovery and development; diagnosis; the mechanisms of disease.
		  o *Water*: water treatment; improvements in water quality testing.
		o Potential negative effects of chemistry, both inadvertent (e.g. pollution) and by design (e.g. use of chemicals in warfare), and the role of chemistry in resolving such negative effects.

Key idea: Decisions about uses of chemistry are subject to social, economic, environmental and political influences. The importance of drawing on evidence to identify misinformation and tackle controversy, as well as having an awareness of the potential implications of chemistry at individual, local, national and global levels must be recognised.

	11–16	**16–19**
Rationale	Marshalling evidence for and against an argument (including identifying misinformation) gives scope for learners to develop a greater awareness of how politics, ethics and chemistry interrelate, particularly when considering controversies in science. Debating and decision-making based on key chemistry concepts and evidence develops skills in analysis and presentation. Learners should begin to understand that chemists need to be aware of the wider world and have a sense of their own role as a world citizen.	It is important to understand that chemical scientists usually do not make decisions about their work in isolation. Chemistry is a human endeavour, which involves and affects all of society. Chemical scientists need to be aware of the wider context in which they operate, be aware of the wider world and have a sense of their own role as a world citizen.
Introduction	Chemistry can have ethical and moral implications, economic and political consequences and significant effects on the environment. These impacts can have both positive and negative impacts on individuals, society and the environmental locally, nationally and on a global scale.	Learners should study a range of examples which illustrate how chemical research and industry affect and are affected by factors other than chemical principles. For example, they might consider issues relating to applications of chemistry in society and consider arguments for and against the introduction of new processes or products.
Content	o There are always ethical and moral implications to the development of new technologies, and economic and political impacts on which new technologies are developed and how they are managed. Identifying these impacts is important and should be discussed and debated, showing which aspects are backed up by evidence and which are opinion. o In many cases the ethical, moral, economic and political issues surrounding chemistry may have conflicting influences. The arguments for and against production of new technologies involves marshalling evidence and ideas and weighing up conflicting views.	Chemical research and applications affect and are affected by the following types of decisions, all of which require the weighing of evidence and construction of arguments: o economic decisions, e.g. whether savings or profits outweigh costs to the environment o policy and political decisions, e.g. international agreements about CFCs, fossil fuels, plastics o social decisions, including awareness of issues among citizens, and moral and ethical considerations, e.g. chemistry as reported in the news or used in advertising claims.

Mathematical skills at 16-19

Arithmetic and numerical computation

Mathematical skill	*Example of use in a chemistry context*
Use calculators to efficiently perform calculations	o wide range of chemical calculations involving addition, subtraction, multiplication, division, logarithms and standard form (e.g. amount of substance, enthalpy, rate, equilibrium and pH calculations)
Recognise and make use of numbers in standard and ordinary form	o convert between numbers in standard and ordinary form o carry out calculations (using a calculator) using numbers in standard and ordinary form, e.g. calculate amounts and numbers of molecules o deal with numbers across a large range of magnitudes from very large (e.g. numbers of molecules) to very small (e.g. bond lengths)
Use ratios, fractions and percentages	o calculate percentage composition and percentage yields o calculate the atom economy of a reaction o construct and/or balance equations using ratios of reactants/products
Use logarithms in relation to quantities that range over several orders of magnitude	o carry out pH and pK_a calculations (e.g. relate pH to ionic concentrations)
Accurately use and interconvert between SI units and prefixes and multipliers	o convert between units (e.g. cm^3 to dm^3 as part of volumetric calculations) o conversions between enthalpy changes in J mol^{-1} and kJ mol^{-1}
Recognise and make use of appropriate units in a calculation	o evaluate units for an equilibrium constant or a rate constant o use correct units when substituting values into equations, e.g. the ideal gas equation
Estimate results	o estimate the results (e.g. order of magnitude) of calculations without using a calculator o evaluate/predict the effect of changing experimental parameters

Algebra

Mathematical skill	*Example of use in a chemistry context*
Understand and use the symbols =, <, >, <<, >>, », ±, ∝, D, /, °, Ö	
Recognise that the same letter may stand for different variables	o e.g. *E* = energy, cell potential
Change the subject of an equation	o manipulate equations to express in terms of a subject (e.g. interconvert mass and amount of substance; find a rate constant from a rate equation); ideal gas equation
Substitute numerical values into algebraic equations using appropriate units for physical properties	o carry out structured and unstructured calculations (e.g. interconvert mass and numbers of moles; use Hess's Law; calculations involving the ideal gas equation)
Solve algebraic equations	o carry out Hess's law calculations o calculate a rate constant from a rate equation

Geometry and trigonometry

Mathematical skill	*Example of use in a chemistry context*
Use shapes and angles in regular 2D and 3D structures	o predict bond angles in molecules from their shapes (e.g. NH_3, CH_4, H_2O)
Visualise and represent 2D and 3D forms including 2D representations of 3D objects	o draw different forms of isomers (including an indication of stereochemistry) o identify chiral centres from a 2D or 3D representation
Understand the symmetry of 2D and 3D shapes	o describe the types of stereoisomerism shown by molecules/complexes o identify chiral centres from a 2D or 3D representation

Handling data

Mathematical skill	*Example of use in a chemistry context*
Use an appropriate number of significant figures	o perform and report calculations to an appropriate number of significant figures given raw data quoted to varying numbers of significant figures o understand that calculated results can only be reported to the limits of the least accurate measurement
Find arithmetic means	o calculate weighted means, e.g. calculation of an atomic mass based on supplied isotopic abundances o select appropriate data (e.g. identification of outliers in repeated titrations, rate measurements) to calculate mean values
Identify uncertainties and use simple techniques to determine uncertainty when data are combined	o Determine uncertainty for a variety of different apparatus, including where quantities are measured by difference (e.g. the uncertainty in using a burette or volumetric flask)

Plot graphs of two variables from experimental or other data	o plot concentration–time graphs from collected or supplied data and draw an appropriate best-fit curve
Determine the slope and intercept of a linear graph and/or the slope of a tangent to a curve as a measure of rate of change (manual and spreadsheet methods should be covered)	o calculate the rate constant from a graph of appropriate kinetic data o determine the order of a reaction using the initial rates method
Translate information between graphical, numerical and algebraic forms	o interpret and analyse spectra o determine the order of a reaction from a graph o derive rate expression from a graph
Test tabulated data for proportionality	o compare reaction rates with concentration to determine orders of reaction

Underpinning skills and attributes

Beyond the subject-specific content, the curriculum should enable learners to develop a broader range of skills and attributes. Without being directly subject-specific, these skills are fundamental to success in chemistry-related careers, as well as being more broadly applicable. To elevate students' long-term performance and employability, chemistry curriculums across the UK should ensure students have multiple opportunities to develop key skills. Giving young people access to practical, hands-on learning that is rooted in the real world is still seen as a key driver in generating positive perceptions of chemistry and a heightened level of interest; therefore these opportunities are regarded as crucial.

Learners should be given the opportunity to develop in the areas detailed below in the context of the chemistry curriculum.

Use of digital technology

Digital skills are essential in the chemistry-using workforce, yet current education pathways are not keeping pace with industry demands. The rapid evolution of digital tools, combined with outdated curriculums, has contributed to a growing digital skills deficit, estimated to cost the UK economy £63 billion annually. Modern scientists rely on digital technologies to improve accuracy, collaboration, and sustainability. Yet, school chemistry curriculums remain largely manual and disconnected from these professional practices.

To help close this gap, digital competencies must be introduced early and developed progressively - from primary education through to university. Students should build both core digital literacy and subject-specific competencies - introduced in a purposeful way that complements foundational analogue techniques. This approach will better prepare learners for the evolving demands of the future workforce.

Example approaches to implementation

11-16
Application of block-based languages, e.g. Scratch, into a science context. Students at 11-14 will be familiar with Scratch due to its inclusion in the primary curriculum, and it can be used to simulate experiments, experimental design and data analysis. If infrastructure allows, virtual simulations of techniques could support the understanding of investigative processes and give learners a greater awareness of the current technology used in research.
Wider skills such as basic spreadsheet workbooks (using them for calculations, basic data manipulation, basic graph drawing), using the web to search for data and using it for sources (including misinformation and trusting sources), and introducing the effective use (and potential misuse) of AI in a scientific context.

16-19
Building on the use of block-based languages, introducing programming languages such as Python to manipulate and present data, predict properties and conduct simple modelling. More advanced use of spreadsheet software for data handling and manipulation. Further use of simulation to support understanding and explore techniques.
Develop an awareness of how digital tools are used by scientists (e.g. spectroscopy, automation, AI/machine learning, simulation and modelling).
Suggested approaches include having a potential list of competencies to provide some consistency and ensure all chemistry learners at level 3 are achieving the same base level of digital skills (in a chemistry context).
Digital skills could be folded into the existing A-level/Higher/Advanced Higher practical assessment scheme and into vocational course tasks.

Logical reasoning and problem-solving

Whether answering their own questions, or questions that others have posed, learners should be taught to reason through evidence and arguments to find the logically consistent answer.

Reasoning skills should be applied in a range of situations, including:

- constructing explanations for new phenomena based on prior knowledge
- proposing questions for investigation based on prior knowledge
- designing investigative approaches to answer a research question
- drawing conclusions from information and data.

Constructing and evaluating arguments

Chemical scientists seek to construct explanations for phenomena and suggest solutions for problems. This involves constructing convincing arguments, often combining empirical evidence with existing knowledge, theories or models. Learners should be supported in developing the skill of constructing arguments.

Likewise, learners should practise evaluating arguments put forward by others. This might include evaluating whether the reasoning is logical and sound, or whether data or other evidence put forward is reliable. Evaluating arguments is a core skill in science, but also an essential part of being an informed, scientifically literate citizen.

Literacy and communication

In the study of any subject, it is important that learners are able to access information and data and make best use of it. Accessing technical information can be difficult, and it should not be underestimated how much support learners may need. In particular, learners should be supported in understanding and being able to use

- technical vocabulary, including terms that may have different meanings in science than in everyday life
- non-technical vocabulary used in a particular way (e.g. effect, impact, composition)
- structures of technical language, such as connectives and comparatives
- chemical and mathematical symbols, formulae and equations.

Learners should have opportunities to practise accessing information and data and assessing its relevance in a chemical context. Relevant skills include:

- reading texts and extracting useful information, e.g. to learn more about a topic
- scanning texts to find relevant sections
- searching for information online (using relevant search terms)
- selecting relevant sources of information for a particular purpose.

To be successful within their field, scientists must be able to clearly communicate their findings. Learners should be supported in constructing concise and clear explanations of scientific ideas, using appropriate vocabulary, both verbally and in writing. Activities might include:

- participating in debates and discussions
- presenting information to an audience, including the use of prompts and visual aids
- writing scientific reports and other texts
- sharing information and engaging others through social media.

To be able to communicate clearly within scientific fields, learners should be introduced to scientific conventions in communication, including

- appropriate ways of presenting data, including graphs and tables
- the language and usual content of scientific reports
- referencing.

Team working / collaboration

Learners should be given the opportunity to work collaboratively towards a common goal. Productive team work involves each individual taking responsibility for a particular aspect of a task, with the group collaboratively allocating those roles and monitoring progress.

Team work opportunities in the curriculum should extend beyond group work within practical lessons, to give learners the opportunity to identify their strengths and weaknesses when working in teams. Group project work – such as preparing for a discussion or presentation, or compiling a report – would provide such opportunities.

Independence

Learners should be supported in taking responsibility for their own learning. Independent research projects can provide opportunities for learners to make their own decisions, safely plan a course of action and reflect upon their results, taking charge of the endeavour from start to finish. Good literacy skills and resilience will help learners become independent.

Creativity

Chemistry is a creative subject. Chemical scientists need to be inventive in the interpretation of evidence, development of theories, approaches to investigation and the development of chemical technologies. Learners should be given the opportunity to be inventive and think 'outside the box'. Modelling creative thought and giving examples of creativity in the development of chemical ideas and processes should be part of the curriculum.

Resilience

The study of chemistry is able to build resilience in learners. They should be supported in building the confidence to try new things, for example in investigations, and to accept that sometimes things do not work as planned. Learners should be encouraged to take a proactive approach to resolving issues. They should be reassured that solving a problem often requires trying different approaches, and that an unsuccessful attempt does not always equate to failure.

Assessment

We acknowledge the importance of both formative and summative assessment in promoting learning and development of chemical competencies. Assessment is an indispensable tool in ensuring that learners are making progress against the learning expectations, and in planning next steps for teaching and learning. It is also a powerful force in shaping how chemistry is taught and experienced in schools.

Formative assessment is part of the pedagogy applied in the delivery of the course. It is frequently informal and embedded in teaching. The main purpose is to help both teachers and learners understand where and how progress can be made; teachers use outcomes to direct subsequent teaching and learning activities.

Summative assessment is used to evaluate learning at the end of a course or part thereof (e.g. at the end of a term or year). These assessments may be set within schools, or take the form of standardised tests set by governments or their agencies, or awarding organisations.

We do not make detailed recommendations on the form that any assessment should take. However, we here set out a number of principles and suggestions for consideration in the design of assessments that will support the intentions of our curriculum proposals. These principles have primarily summative assessment in mind, in view of the main intended audiences for this document, and the high value commonly placed on standardised tests and school-leaving qualifications. However, many of these principles can also be usefully applied to formative assessment.

Assessments should be tailored to the setting in which the curriculum is delivered and likely progression routes, whether academic or technical. Every effort should also be made to avoid bias, including on the basis of gender, socio-economic background, ethnicity or disability.

Principles for assessment

- Chemistry assessment needs to include a broader range of methods to better reflect real-world chemistry practice and provide students with more varied opportunities to demonstrate their skills.
- Assessment structure should consider both student wellbeing and measuring attainment. There is a need to strike a balance between maintaining standards and enabling all students to show their potential.
- Practical work needs to be valued and assessed directly.
- Tiering in assessment should support progression and equity. When designed inclusively, tiering should offer flexibility and appropriate challenge.
- Assessments should be designed to enable every pupil to demonstrate their ability. Fair and rigorous assessment should be inclusive by design, enabling all students - regardless of background, ability, or disability - to demonstrate their skills.
- Generative AI (GenAI) presents opportunities for alternative assessment models and reducing teacher burden, but it should be used with caution. Any use must be trialled and developed iteratively and carefully to maintain standards and fairness.
- Digital assessment offers new opportunities to assess skills like experimental design, data analysis, and conceptual reasoning through simulations and interactive tasks. However, it should complement – not replace – traditional methods.

Suggestions for forms of assessment

- Assessment structure should consider both student wellbeing and measuring attainment. The quantity and length of examinations and the high-stakes nature of them should be reviewed through the lens of student wellbeing, to try and strike a balance between maintaining standards and enabling all students to show their potential. Although evidence suggests examination structure makes little difference to grading outcomes, there may be positive student wellbeing impacts from a more modular approach. Similarly, linear examinations also offer positive aspects such as encouraging deeper understanding and offering teachers more flexibility in delivery of content.
- Providing sources of information during assessments (whether written, practical or project-based) can help to maintain focus on application of understanding as opposed to knowledge recall. This might include textbooks, data books, basic practical methods etc. There is some research to suggest that allowing learners to bring in their own prepared notes, as opposed to e.g. a textbook, leads to better preparation and performance on assessments that require deeper thinking skills.[1]
- Project-based assessments such as in-depth research projects or case studies might be used to assess learners' appreciation of the ideas covered in Chemistry and the world, the ideas relating to how we think about chemistry, and their ability to make links across the Components. However, the impact on teacher workload and manageability must be considered, alongside equity issues surrounding non-examined assessment (NEA) tasks.
- Practical chemistry skills should be directly assessed using authentic tasks rather than written proxies wherever possible; in England this should be part of curriculum and assessment reform at GCSE, while regulators in Wales, Scotland and Northern Ireland should explore increasing the weighting, validity and consistency of practical assessment.
  Options to explore include:
- A GCSE/National level practical endorsement (similar to A-level)
- Practical exams where students carry out a simple task
- Oral or video-based demonstration of understanding of a practical task they have completed.
  The balance between practical vs written assessment should align with the purpose and intentions of each qualification (e.g. vocational vs academic), while ensuring assessments remain manageable for teachers.