Global Frameworks for Chemistry Education for the 11-14 and 14-16 age ranges

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ABOUT THIS PUBLICATION

This report represents the output of the first stage of a wide-ranging project to establish guidelines for curriculum development. It is accompanied by globally relevant knowledge and skills frameworks for the 11-14 and 14-16 age ranges, which explore the fundamental science that underlies the priority areas outlined in the Royal Society of Chemistry’s (RSC) roadmap for the chemical sciences, Chemistry for Tomorrow’s World.

Chemistry for Tomorrow’s World lists the challenges that need to be addressed by the chemical sciences in the 21st century, from enhancing our lifestyle and recreation, to improving human health. The chemical sciences have a crucial role to play in tackling these challenges. However, our ability to do so is critically dependent on both a steady supply of talented scientists and a supportive, informed population. It is vital that the core chemistry education in schools and colleges equips students with the knowledge and skills needed to develop scientific literacy, as well as providing the foundations for further study.

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ABOUT THE RSC

Since 1841, the RSC has been the leading society and professional body for chemical scientists and we are committed to ensuring that an enthusiastic, innovative and thriving scientific community is in place to face the future. The RSC has a global membership of over 47,000 and is actively involved in the spheres of education, qualifications and professional conduct. It runs conferences and meetings for chemical scientists, industrialists and policy makers at both national and local level. It is a major publisher of scientific books and journals, the majority of which are held in the RSC Library and Information Centre. In all its work, the RSC is objective and impartial, and it is recognised throughout the world as an authoritative voice for chemistry and chemists.
FOREWORD

The students of today are the scientists and decision-makers of the future. They will be responsible for tackling some formidable global challenges – improving agricultural productivity and drinking water quality, conservation of scarce natural resources, developing new and sustainable energy systems and ensuring a healthy population, to name but a few. The chemical sciences are central to understanding how potential solutions to these challenges can be formulated. It is therefore vitally important that all students are equipped with a fundamental ‘toolkit’ of skills as well as a grasp of core chemical knowledge that will enable them to understand and help solve the scientific challenges of the future. Chemistry education has never been more important than in these times of rapid global change and, in recognition of this, the RSC is carrying out a comprehensive review of the knowledge and skills required at each stage of chemical sciences education.

These documents represent the initial outputs of the wider-reaching RSC Global Framework for Chemistry Education project and we offer them to the community for use in curriculum development and the teaching of chemistry around the world. The RSC is extremely grateful to all of the people who have supported and contributed to this project so far, and hopes that the completion of this first phase of work takes the chemistry community one step closer to safeguarding the future of the chemical sciences and helping to solve the global challenges we face.

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EXECUTIVE SUMMARY

The first phase of the Royal Society of Chemistry’s (RSC) Global Framework for Chemistry Education project has developed frameworks for the 11-14 and 14-16 age ranges, and this report provides the rationale behind these documents. Chemistry for Tomorrow’s World: A roadmap for the chemical sciences outlines the key global challenges that society faces and addresses the fundamental role the chemical sciences have in tackling these challenges in the future. The Global Framework for Chemistry Education project represents the application of these findings to chemistry education.

Today’s students are tomorrow’s scientists and decision-makers. It is therefore vitally important that through their chemistry education they are equipped with the knowledge and skills needed to understand and interact with the global challenges that the world faces. The future of the chemical sciences depends on both talented scientists and a supportive, informed population. Consequently, the core component of chemistry education in schools and colleges must both prepare students to become scientifically literate citizens and provide the knowledge and skills required for progression to further study in the chemical sciences. Given that the identified global challenges represent the main contexts in which students will need to apply their science knowledge and understanding, these contexts should be fundamental to the curriculum rather than simply illustrative of it – this is the central concept of the Global Framework for Chemistry Education project. The Chemistry for Tomorrow’s World report therefore plays two fundamental roles in the development of the framework:

• an examination of the fundamental underlying chemistry needed to understand and interact with these contexts forms the basis for identifying appropriate core chemistry content that is globally applicable;
• by including examples of how the core content could be delivered within these global contexts, the framework document can serve as a tool to aid schools and teachers in the contextualisation of core chemistry content for delivery in the classroom.

The report itself outlines the philosophical approach behind the development of these initial frameworks and is intended to provide some guiding principles for curriculum development. The frameworks are not meant to represent a syllabus. Rather, they are intended to represent an illustrative approach as to how syllabi might be drawn up and to provide contextual examples of how the knowledge and skills identified could be delivered in the classroom. It should be noted, however, that it is not the intention of this document to prescribe how content should be delivered. The important point is that, irrespective of how the chemical concepts will be delivered in the classroom, context remains integral to the framework through its fundamental role in defining and identifying the core chemistry content.

The publication of this report and the frameworks for the 11-14 and 14-16 age ranges represents the completion of the first stage of the Global Framework for Chemistry Education project.
DEVELOPING A GLOBAL FRAMEWORK FOR CHEMISTRY EDUCATION

The RSC’s vision is to be foremost in the world at promoting and developing the chemical sciences for the benefit of society. In order to develop this role the RSC has identified six strategic aims1 for the next five years:

• enhancing international influence and impact with industry, academia and policy makers;
• pursuing opportunities for growth through collaboration, partnership and acquisition;
• achieving high impact publishing through sustainability and growth;
• ensuring an appropriate supply of people equipped to practise chemistry competently at all levels;
• raising awareness and understanding of the role and value of the chemical sciences;
• setting the chemical science agenda and directions for businesses, academia and policy makers.

Safeguarding chemistry education and playing an active role in driving education policy forward are key to most of these strategic aims. The future of the chemical sciences relies on a diverse supply of people at all levels who are equipped to practise and communicate chemistry competently, and a general population who can understand and engage with the key issues and advancements in the field.

The RSC has a longstanding reputation as an innovator in the field of chemistry education, and supports schools and colleges by providing teaching resources, enrichment and enhancement activities, and professional development opportunities for educators. The RSC is also active in education policy and recognises that there is a need for a comprehensive review of the knowledge and skills required at each stage of chemical sciences education, in order to drive positive change in the current systems. Two of the targets identified by the RSC to support the achievement of the strategic aims look to address this need directly:

• the development of a globally relevant knowledge, skills and assessment framework for chemistry education;
• the use of the RSC framework for chemistry education and competitions as drivers for new education and qualification structures adopted by governments.

Fundamentally, there should be global agreement on what students should know and what they should be able to do in science at the end of each stage within schools and colleges. The first stage in the development of a globally relevant framework for chemical education is identifying the key issues in the chemical sciences that students will need to engage with in the current and future stages of their lives. In order to understand the science behind these issues, students will require a fundamental ‘toolkit’ of skills as well as a grasp of core chemical knowledge. This information will form the basis of the framework but, as assessment directs teaching and learning in schools and colleges to varying degrees, the way that this knowledge and skills toolkit is assessed will have a strong impact on how chemical education is delivered in the classroom.

It is commonly accepted that there should be a coherent programme of science which builds on previous knowledge and skills throughout the age ranges. In cases where changes to curriculum and qualification frameworks have occurred rapidly in isolated key stages, there has been a risk of this resulting in a dysfunctional system that lacks coherence.2 It is therefore crucial that the proposed framework shows clear progression through the age ranges. A minimum skills and knowledge requirement for 16-year-olds has been taken as the starting point for the development of the framework as this is the age at which compulsory science education ceases in many countries, for example England. This, therefore, represents the highest level of chemical education that the majority of students in these countries will receive. Once the nature of the skills toolkit, key knowledge and the associated assessment has been established for this age group, the process will be expanded to consider progression to higher levels of study.
THE ROLE OF CHEMISTRY EDUCATION

Chemistry education in schools and colleges has two distinct roles. For those who stop compulsory education at 16, or who do not continue with science post-16, chemistry education should serve as a preparation for becoming a scientifically literate citizen. The future of the chemical sciences depends on both talented scientists and a supportive, informed population. Science is playing an increasing role in the media and on political agendas, and chemistry education needs to equip students with the skills and understanding required to meaningfully access this science within their everyday lives. Sixteen-year-olds are the scientists and decision-makers of the future and it is vitally important for them to be scientifically literate and able to make informed decisions in order to have an influence on how society moves forward.

In addition to fulfilling this role, chemistry education must provide the knowledge and skills required to enable students to progress to further study in the chemical sciences. It is vital that the content is relevant and inspires students to become the scientists of the future, and that careers information, advice and guidance is embedded throughout. There needs to be clear progression in the requirements of each level, and curriculum and qualification systems should be designed with this in mind. The skills and knowledge achieved by each potential exit point from the system must clearly match the requirements of employers as well as of the next education stage.

While there is a need to focus on the required outputs of chemical education, a key aspect of the framework must also be a clear and challenging delivery of the subject at each level. The teaching at each stage needs to be intellectually coherent so that the concept of chemistry is clearly identifiable and that the building of knowledge and skills can occur in logical progression. Chemistry is often taught within ‘Science’ in the lower age ranges. It is vital that, within this subject group, chemistry is identifiable as a distinct subject so that students begin to acquire the fundamental concepts that form the basis of the chemical sciences.

FOCUSING ON THE CHEMICAL CHALLENGES OF THE FUTURE

Identifying the chemical challenges of the future is a fundamental step in providing chemistry education that inspires tomorrow’s scientists and creates an informed and interested general population. The RSC has identified the future priorities for the chemical sciences in *Chemistry for Tomorrow’s World: A roadmap for the chemical sciences*. This document will form the content basis of the chemistry education framework. It outlines key future challenges for chemical sciences which the RSC considers will have a major influence on society, and the underpinning scientific areas that need to develop in order to solve these challenges.

These challenges provide the context within which chemistry should be delivered, as students need to be given the skills and knowledge to understand and interact with these topics. The development of a global framework for chemistry education must build on these globally important contexts and identify the fundamental chemistry knowledge required to understand them, and the skills required to apply and interpret this knowledge.

The roadmap for the chemical sciences can play another vital role in shaping chemistry education. In schools and colleges, chemistry education aims to provide the skills and knowledge needed by students at each potential exit point from the system. But an equally important requirement of the material taught is that it enthuses and excites students about the chemical sciences. Another strategic aim of the RSC is to increase the uptake of chemistry at post-16 and degree level, as well as fostering interest and excitement about the chemical sciences among the general population. Allowing students to engage with and understand globally relevant issues brings science to life in the classroom, and context-based learning is key to building enthusiasm and allowing students to identify with the knowledge required of them.

Relevant and exciting content for the classroom can also enthuse teachers and this, in turn, contributes to student engagement with the subject. Students will only be able to achieve their full potential in chemistry under the guidance of talented, knowledgeable and enthusiastic teachers. It is vital that more appropriately qualified people are encouraged to enter the teaching profession so that students can be taught by subject specialists, and one aspect of this is ensuring that the material taught is challenging and exciting for teachers as well as students.
THE CONTEXT-LED APPROACH TO CONTENT SELECTION

It is important to distinguish clearly between the two roles that the global chemical challenges play as contexts within this global framework project. Firstly, examining the fundamental underpinning chemistry needed to understand and interact with these contexts forms the basis for identifying appropriate core chemistry content that is globally applicable. Secondly, the inclusion of examples of how the core content could be delivered within these global contexts will allow the framework document to serve a second purpose as a tool to aid schools and teachers in the contextualisation of core chemistry content for delivery in the classroom. It should be noted, however, that it is not the intention of this document to prescribe how content should be delivered. There is a natural continuum in classroom delivery between fully context-based approaches and more traditional academic approaches which centre on core chemical concepts. Different approaches suit different students and it should remain the responsibility of the individual countries, schools and teachers to determine the appropriate teaching style and delivery for their students within this continuum.

The important point is that, independently of how the chemical concepts will be delivered in the classroom, context remains integral to the framework through its fundamental role in defining and identifying the core chemistry content. Although delivery of chemistry in the classroom can be highly successful at any point within the context-content continuum, a purely content-based approach to the selection of core chemistry content can be extremely limiting. When this model of content selection is applied, context tends to be built in at a later stage to ‘dress’ or ‘theme’ the content (see Figure 1).

This can be demonstrated by the delivery of knowledge related to the extraction and use of natural resources in the GCSE specifications prepared for first teaching in England in 2011.

The extraction and uses of metals are covered by all of the Awarding Organisations to deliver one aspect of the knowledge content outlined in the GCSE criteria relating to natural resources. Figure 2 outlines the knowledge statements covered in part by this topic, and the general skills that the criteria suggest should be integrated into teaching throughout the specifications. This diagram also outlines the contexts used to present this material within the specifications of different Awarding Organisations. These contexts are simply used to illustrate and theme the knowledge delivery.

If, in contrast, context is fundamental to the curriculum rather than illustrative of it (see Figure 3), content can be identified according to the type and nature of science that will be important in the lives of students in the future, so that the core component that all students receive can give them the ability to interact with this science. The structure of chemical education in schools and colleges must be more than an intellectual framework and, in order to achieve this, the contexts used as the basis for the framework should be more than make-up or uses of metals – they must inform future citizens and inspire future scientists.
Figure 2: An example of how knowledge related to natural resources will be delivered within the new Chemistry GCSEs for first teaching in 2011

Knowledge
- Chemical reactions including reduction and oxidation, neutralisation, electrolysis and polymerisation reactions
- The Earth’s crust, sea and atmosphere, and living organisms, as the ultimate sources from which all useful materials are obtained or synthesised
- The production, use and disposal of materials and how an understanding of chemistry helps to reduce the resulting impacts on the environment

Skills
- Develop their knowledge and understanding of chemistry
- Develop their understanding of the effects of chemistry on society
- Develop an understanding of the importance of scale in chemistry
- Develop and apply their knowledge and understanding of the nature of science and of the scientific process
- Develop their understanding of the relationships between hypotheses, evidence, theories and explanations
- Develop their awareness of risk and the ability to assess potential risk in the context of potential benefits
- Develop and apply their observational, practical, modelling, enquiry and problem-solving skills and understanding in laboratory, field and other learning environments
- Develop their ability to evaluate claims based on science through critical analysis of the methodology, evidence and conclusions both qualitatively and quantitatively
- Develop their skills in communication, mathematics and the use of technology in scientific contexts

Context
- **AQA**: Metals and their uses. Metals are very useful in our everyday lives. Ores are naturally occurring rocks that provide an economic starting point for the manufacture of metals. Iron ore is used to make iron and steel. Copper can be easily extracted but copper-rich ores are becoming scarce so new methods of extracting copper are being developed. Aluminium and titanium are useful metals but are expensive to produce. Metals can be mixed together to make alloys.
- **Edexcel**: Obtaining and using metals. Students will find out how metals are extracted from their ores and consider how metals are used. They will also learn the importance of humans moving to a more sustainable use of the Earth’s resources, and how recycling metals contributes by preserving ores. Students will also consider how chemists develop new alloys to fit new applications and how alloys have different properties from their component metals.
- **OCR B Gateway**: Metals and Alloys. Metallic elements and alloys have many uses in our society. This item examines how metals are extracted from their ores. It also describes some of the uses of some important alloys including smart alloys.
- **OCR A Twenty First Century Science**: Chemicals of the natural environment. How can we extract useful metals from minerals?
- **WJEC**: METALS

Learning Outcomes

Figure 3: Model of a context-based delivery
Figure 4 gives an example of how one of the key challenges identified in *Chemistry for Tomorrow’s World*¹ can form the context to identify the knowledge and skills required by pupils to meaningfully access that science. In this model, the issue of the scarcity of natural resources becomes central to the teaching structure. The diagram focuses on metals in order to allow comparison to Figure 2. Similar knowledge would be delivered using this model in terms of extraction methods, reactivity of metals and their uses. However, the use of this context drives the inclusion of content that supports the understanding of ideas of sustainability, developing new materials to replace the functionality of those that are at risk of running out, and the possibilities of extracting metals from waste materials. Using a context that incorporates the economic, social and environmental impacts of continued metal extraction and use means that the knowledge taught is structured in a way that is relevant to students and will ultimately allow them to engage with issues that will become more pressing in their future lives.

**Figure 4: Example of context-based selection of knowledge and skills**

**Context**
Conservation of scarce natural resources

**Learning Outcomes**

**Knowledge**
- Types of reaction – reduction, oxidation electrolysis
- Reactivity
- Purity, chemical analysis and separation techniques
- Uses of materials related to their properties
- Assessment of materials related to sustainability
- Development of new materials including nanomaterials

**Skills**
- Identification of trends and patterns
- Formation of hypotheses based on scientific theories or previous findings
- Critical interpretation and comparison of data, conclusions taken from data and methods used
- Planning to test hypotheses and solve problems
- Interpretation of information against criteria
- Synthesis of conclusions from available data
- Evaluation of ethical, environmental and economic implications of science
- Communication and discussion of data or findings
BUILDING THE FRAMEWORK

The first step in establishing this global framework for chemistry education is to determine the knowledge and skills needed by students who undertake the minimum requirement in chemistry education. In England for example, students are required to cover a core chemistry component within science up to the age of 16. This minimum content must give a rounded balance of skills and knowledge that allows students to understand the processes behind the major scientific issues and assess the validity of scientific concepts in their daily lives.

This core requirement will also form the basis of science education for pupils who will continue to study chemical sciences at a higher level. Although the framework is not intended to outline the full chemistry content required for progression, it is vital that the core chemistry included provides a solid base which allows individual countries, schools and teachers to develop appropriate additional content that will enable progression within their individual systems (see Figure 5).

The RSC’s roadmap for the chemical sciences\(^3\) identified seven priority areas:

- **Future cities**
  Developing and adapting cities to meet the emerging needs of citizens.

- **Lifestyle and recreation**
  Providing a sustainable route for people to live richer and more varied lives.

- **Water and air**
  Ensuring the sustainable management of water and air quality, and addressing societal impacts on the quality and availability of water resources.

- **Food**
  Improving agricultural productivity and creating and securing a safe, environmentally friendly, diverse and affordable food supply.

- **Human health**
  Improving and maintaining accessible health, for example through better diagnosis and new drugs and therapies as well as disease prevention.

- **Energy**
  Creating and securing environmentally sustainable energy supplies (such as solar energy, nuclear energy and biofuels), and improving the efficiency of power generation, transmission, storage and use.

- **Raw materials and feedstocks**
  Creating and maintaining a supply of sustainable feedstocks by designing processes and products that preserve scarce resources.

In this initial stage of developing the framework the focus is on developing the core sections appropriate for the 11-14 and 14-16 age ranges. The framework has been populated by applying the global challenges identified in the RSC roadmap as contexts to determine the minimum content appropriate for all students irrespective of their future pathways.

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Figure 5: The shaded area represents the focus for the initial phase of framework development
Some priority areas, such as human health, cover a range of chemical topics that are generally more appropriate for higher age ranges (see Figure 6).

However, it is essential that all of these priority areas are covered to some degree by students who only study the minimum chemistry content so that they are able to interact with each of the priority areas in their future lives.

The priority areas of future cities and lifestyle and recreation, in themselves, cover a range of interrelated areas and provide an engaging context within which the other challenges involving energy, food, human health, raw materials and feedstocks and water and air can be framed. Half of humanity now lives in cities, a figure which is expected to increase in the future. As a result, it is a great challenge to provide adequate resources and services to these urban populations. With increasing populations in urban areas one of the key challenges is the need to reduce the levels of energy and environmental resources that are consumed, while at the same time maintaining and improving quality of life for all. Using these two contexts in this way ensures that the other contexts built around global challenges fully incorporate the social, environmental and economic impacts of science. Using a central theme of improving the quality of life for all allows the challenges to be examined in terms of providing effective and sustainable services and resources in both urban and rural areas, and using technological advances to improve all aspects of lifestyle and recreation (see Figure 7).

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**Figure 6**: General representation of the spread of topics covered within each priority area that are appropriate for the different age ranges. For the 11-14 age range each of the priority areas is framed within the general contexts of future cities and lifestyle and recreation (represented by the coloured boxes). Beyond this age range the priority areas are used to define content within each age range (represented by the double-headed arrows) – however, some priority areas provide more appropriate contexts for particular age ranges (thick black lines) than others (dashed lines).
The first step in developing the framework for chemistry education involved investigating these contexts to establish the desired learning outcomes for students. If the chemical challenges of the future represent key contexts in which future citizens will encounter science then it is vital to recognise how and why citizens will need to interact with science in these contexts. Establishing the kinds of questions that citizens should be able to ask and answer about the science they come into contact with in their daily lives effectively equates to establishing the desired learning outcomes for students (see the 11-14 and 14-16 framework documents).

The desired learning outcomes represent what all students around the world should be able to do with their chemical knowledge in their future lives. These outcomes are not intended to be the basis of assessment of the core chemistry, but are more representative of the potential success criteria of ‘scientifically literate citizens’. The desired learning outcomes for the core section for 14-16-year-olds need to build on the 11-14 age range content and provide students with the ability to understand, question and interact with the science they will encounter in the media, on political agendas and in their daily lives. The selection of actual core chemistry content (the left-hand columns within the framework documents) is then identified as the scientific content needed for students to be able to carry out the desired learning outcomes. Identifying the content and skills needed to achieve these learning objectives creates a basic scientific toolkit that all students should be entitled to. Although the nature of the chemical challenges of the future may adapt through time as new developments are made and new issues arise, the content and skills set outlined should provide students with the ability to interpret new information and apply their knowledge to new situations.

Finally, the framework has been populated with examples of how the core chemistry could be delivered through the global challenges contexts. These columns serve both to justify the inclusion of the core chemistry statements and provide a useful tool to aid educators in contextualising their own existing and future curricula for delivery in the classroom.
COMPLETING THE FRAMEWORK

When success criteria for schools and colleges focus on assessment results there can be a strong drive to ‘teach to the test’. In this case, the form of assessment used has as much of a role in defining the teaching in the classroom as the content of the curriculum itself. If assessment does drive teaching and learning, it is vital that the style of assessment used promotes and rewards deep understanding of chemical concepts, the meaningful development of scientific skills and the application of independent thinking. The variety of possible assessment models, including objective testing, structured questions, multi-step calculations, analysis of contemporary materials and practical assessment, needs careful consideration. The development of guidance on the appropriate range and balance of assessment types will provide one of the central themes of the final framework document.

As chemistry is a physical and quantitative science, students need to have an appreciation and working knowledge of mathematics. Mathematics should be used to enhance and inform the science taught, and students need to be competent in the basics of mathematics in order to be able to interact with the core chemistry content. Identifying the required mathematical content and skills needed to support the understanding of the core chemistry content for each age range will be a vital component of the framework.

REFERENCES

1. RSC Strategy on a Page
   http://www.rsc.org/Membership/Memberzone/BoardsCommittees/RSCCouncil/Strategy/index.asp
3. Chemistry for Tomorrow’s World: A roadmap for the chemical sciences
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