Developing a framework for the biology curriculum

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Abstract The Royal Society of Biology is working with the bioscience community, and researchers and practising teachers in the education community, to inform its position on a coherent 5–19 framework to support future biology curriculum development. Our approach taken in developing the framework has been 'evolution not revolution', mapping existing curricula, developing the big questions of biology and revising statements within the context of 5–19 education across the UK nations. In this article, examples are given of decisions made regarding learning progressions through 11–16 biology and next steps in developing recommendations for other essential aspects of 11–16 biology.

Why develop a framework?

One of the priorities of the Royal Society of Biology (RSB) is to support biology education at all levels, through the stages of compulsory schooling into further and higher education and beyond, with training and professional development opportunities for the biosciences community. We recognise teachers in schools and universities with teaching awards and the Chartered Science Teacher (CSciTeach) professional register and support teachers' membership of this through our professional development programme. We have produced and collated resources that help support the teaching of biology and the biosciences in schools, colleges and universities, and have also developed content for students.

Over the last five years, the UK school education system has undergone a number of changes. The responsibility for 5–19 education is devolved to each of the home nations' own governments and there have been several rounds of curriculum reform across the UK, bringing in new content and ways of assessing students' understanding of science as well as their development of a range of skills. The RSB supports a period of stability to allow teachers and students to adapt to the changes that have occurred during these reforms. However, during this period, the society is engaging with the bioscience and education communities in order to develop a framework for a future 5–19 biology curriculum.

We want to ensure that students, at all educational stages and through all qualification routes, engage with a biology curriculum that is coherent and prepares them for their next steps in life, whether they go on to study biology at university, use biology in a related career, or use their biology knowledge as non-scientist citizens of the 21st century. We actively engage with education policy and, as part of an aim to be proactive in our approach, we brought together a number of experts to form the RSB curriculum committee, with the objective of developing a long-term view of what the school biology curriculum should look like.

Spanning primary and secondary education, our framework will make recommendations to inform biology curriculum development across the UK including:

- biological concepts;
- practical competencies in biology;
- mathematical skills in biology;
- ideas about the processes of scientific enquiry;
- development of scientific explanations;
- ideas about the impacts of biological science on society and the natural world.

The framework will comprise a suite of documents and is intended to be flexible. It will evolve as we gather more evidence and see the impacts that the most recent educational reforms have had. This article reflects on our approach and the process so far. It describes our mapping of the biology curriculum and our approach to revising statements for a framework that develops learning progression sensibly through ages 5–19. It gives examples of the rationale behind detailed content decisions at ages 11–16 in each of the five big questions of biology, as identified by RSB's curriculum committee. The cross-linking nature of our discipline, other essential aspects of 11–16 biology education, and possible next steps are also discussed.

Our approach

In 2014, the RSB convened a curriculum committee to produce recommendations such that we may influence policy makers and curriculum developers in the future. Our recommendations will be evidence-based and research-informed where possible, and will be accompanied by a discussion or rationale.

Members of the committee and its working groups represent a range of expertise:

- assessment and curriculum development specialists;
- bioscience higher education representatives;
- education researchers;
- initial teacher training representatives;
- primary teachers;
- primary teacher specialists;
- representatives from industry;
- secondary teachers;
- secondary students;
- undergraduate students.

The committee also consults with individuals representing other specialisms, including those from the RSB's member organisations and other learned societies across the sciences.

The approach taken by the curriculum committee was to proceed under the mantra of 'evolution not revolution', starting with an existing curriculum, identifying its deficiencies and suggesting how it can be improved, with a particular focus on progression within 5–19 biology and beyond and cohesion between areas of biology.

Mapping the biology curriculum

Taking inspiration from Wynne Harlen's *Principles and Big Ideas of Science Education* (2010) and *Working with Big Ideas of Science Education* (2015), we mapped the current English National Curriculum biology statements into five big questions of biology (Table 1) and, within those questions, themes that develop particular learning progressions and a description of that content.

Harlen (2010, 2015) identifies 'big ideas of science' and ideas about applying and explaining science and its implications for society. Of the ten big ideas of science, four describe biology. Harlen's work provides a narrative describing the ideas that all students should have had opportunity to learn by the end of compulsory education. Our big questions of biology do not exactly align with these four ideas of science; for example, photosynthesis and respiration have been brought together with the cellular basis of organisms, more prominence has been given to health and disease, while some big questions cross more than one of Harlen's four ideas.

Existing curriculum statements were mapped against RSB's five big questions of biology. These statements were taken directly from the English National Curriculum and GCSE biology, GCSE combined science and A-level biology subject content criteria produced by the Department for Education. Big questions were further split into themes and a brief content description. Unedited curriculum statements were collected under these themes and presented to the curriculum committee as a starting point for discussion and development of recommendations.

This mapping exercise quickly highlighted surprising gaps in the learning progressions in biology content in England, as shown in Figure 1. Topic-level mapping against big questions and themes was undertaken for specifications for Scotland, Wales, Northern Ireland and the International Baccalaureate.

Evolution not revolution

Following the mapping exercise, a core group was established to refine and develop the biology content detail across 5–19 education. This core group met six times and considered each big question in turn. The group comprised a curriculum development expert, an assessment expert, a teacher and RSB's Head of Education Policy, and was joined by an additional curriculum committee member acting as expert for each big question of biology. It drew on knowledge of existing curricula and specifications across the UK nations and

Table 1 Developing big questions of biology from Harlen

Harlen's big ideas of science	Big questions of biology
Organisms are organised on a cellular basis.	What are organisms and what are they made of? How do organisms grow and reproduce? How do organisms stay healthy?
Organisms require a supply of energy and materials for which they are often dependent on or in competition with other organisms.	What are organisms and what are they made of? How do organisms live together?
Genetic information is passed down from one generation of organisms to another.	How do organisms grow and reproduce?
The diversity of organisms, living and extinct, is the result of evolution.	Why are organisms so different?

<table>
<tr><th>Big questions</th><th>ages 5 - 7</th><th>ages 7 - 9</th><th>ages 9 - 11</th><th>ages 11 - 14</th><th>ages 14 -16</th><th>ages 16 - 19</th></tr>
<tr><td rowspan="4">**What are organisms and what are they made of?**
Cells to systems</td><td colspan="2">Requirements for life</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Tissues, organs and systems</td><td colspan="3">Tissues, organs and systems : Exchange and transport
Tissues, organs and systems : Coordination and control</td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="2">Biochemistry</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Cell structure and function</td></tr>
<tr><td rowspan="3">**How do organisms grow and reproduce?**
Growth, development and inheritance</td><td>Growth and development</td><td></td><td>Growth and development</td><td></td><td colspan="2">Growth and development</td></tr>
<tr><td colspan="5">Reproduction</td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Inheritance and the genome</td></tr>
<tr><td rowspan="3">**How do organisms live together?**
Organisms and their environments</td><td colspan="2">Interdependence of organisms</td><td></td><td colspan="3">Interdependence of organisms</td></tr>
<tr><td></td><td>Environmental interactions and processes</td><td></td><td colspan="3">Environmental interactions and processes</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Biodiversity and human impact</td></tr>
<tr><td rowspan="4">**How do organisms stay healthy?**
Health and disease</td><td colspan="5">Healthy lifestyles</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Communicable disease</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Treating disease</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>Defences against disease</td><td></td></tr>
<tr><td rowspan="3">**Why are organisms so different?**
Variation, classification and evolution</td><td colspan="3">Classification</td><td></td><td colspan="2">Classification</td></tr>
<tr><td></td><td></td><td></td><td colspan="3">Variation</td></tr>
<tr><td>Adaptations</td><td></td><td colspan="4">Adaptations and evolution</td></tr>
</table>

Figure 1 Initial mapping of National Curriculum in England statements against themes and content; empty boxes show where no content statements were identified under a theme for a given age range

internationally, considered differing transition points across the UK, and consulted others with expertise in primary, secondary or tertiary education and in other areas such as health and wellbeing.

For each big question, the following questions were considered by the group:

- Do the themes and learning progressions develop sensibly through compulsory education and post-16?
- Are there instances of unnecessary repetition of ideas between age ranges?
- Where there are gaps in a learning progression, should ideas be added or content rearranged?
- Do any of the statements need to be moved to a higher or lower age range to improve cohesion?
- Is there consistency of language, operational and technical, across the the age ranges and between themes?
- Are any of the statements outdated or scientifically incorrect?
- Do any of the statements need to be rewritten to improve clarity or remove unnecessary detail?
- Could any of the statements be removed, to lighten the content load and give students and teachers more time to develop core concepts?
- Which statements in the current curricula for chemistry and physics are relevant to biology, and how should they be considered in our recommendations for the biology curriculum?
- Is there appropriate coverage of topics often covered in personal, social and health education, or relationships and sex education, in a biological context?

While developing this content, with a focus on improved progression and cohesion, a rationale was written as a legacy document to explain how decisions were made and cross-links between themes were identified.

To ensure consistency and cohesion, the five big questions of biology, themes and revised content statements were reviewed by the core group, full curriculum committee and primary working group. Further cross-links were identified as well as opportunities for developing other essential aspects such as mathematical and practical skills, modelling, ethics, impacts and applications of biology. The RSB's member organisations and education committees and special interest groups were then invited to give initial feedback on the 5–19 exemplification through a closed consultation. Figure 2 shows the map presented in February 2018 at the Salters' Institute Centenary event and shared with stakeholders as part of the closed consultation.

Five big questions of biology: exemplar rationales behind detailed content decisions at 11–16

As discussed above, RSB's curriculum committee has considered five big questions of biology across 5–19 in our exemplification and has presented these questions, and themes within them, in Figure 2. Examples of the rationale behind detailed content decisions for particular themes or concepts within each big question at 11–16 are presented below. In some instances, the associated 7–11 and 16–19 statements are given to show learning progression into and out of 11–16.

What are organisms and what are they made of?

Photosynthesis and cellular respiration are concepts presented to students throughout 11–16, with differing levels of detail. This approach can give students the impression that a previous explanation was wrong or inadequate. Within the biochemistry theme of this big question, the committee has reviewed and improved photosynthesis and cellular respiration statements to give more guidance on the expected level of detail at 11–14 and 14–16, and removed repetition of simple ideas.

In the revised statements (Box 1), we have been more explicit about how the explanations presented are models of what occurs during photosynthesis and cellular respiration; for example, a simple, but 'good enough', model in the context of biochemistry at 11–14 progresses to a more detailed explanation in 14–16, which prepares students for further progression beyond 16. The related statement in 7–11 is intended to show that there is no expectation for students to use the terms photosynthesis or respiration before they have the underpinning knowledge to understand the process.

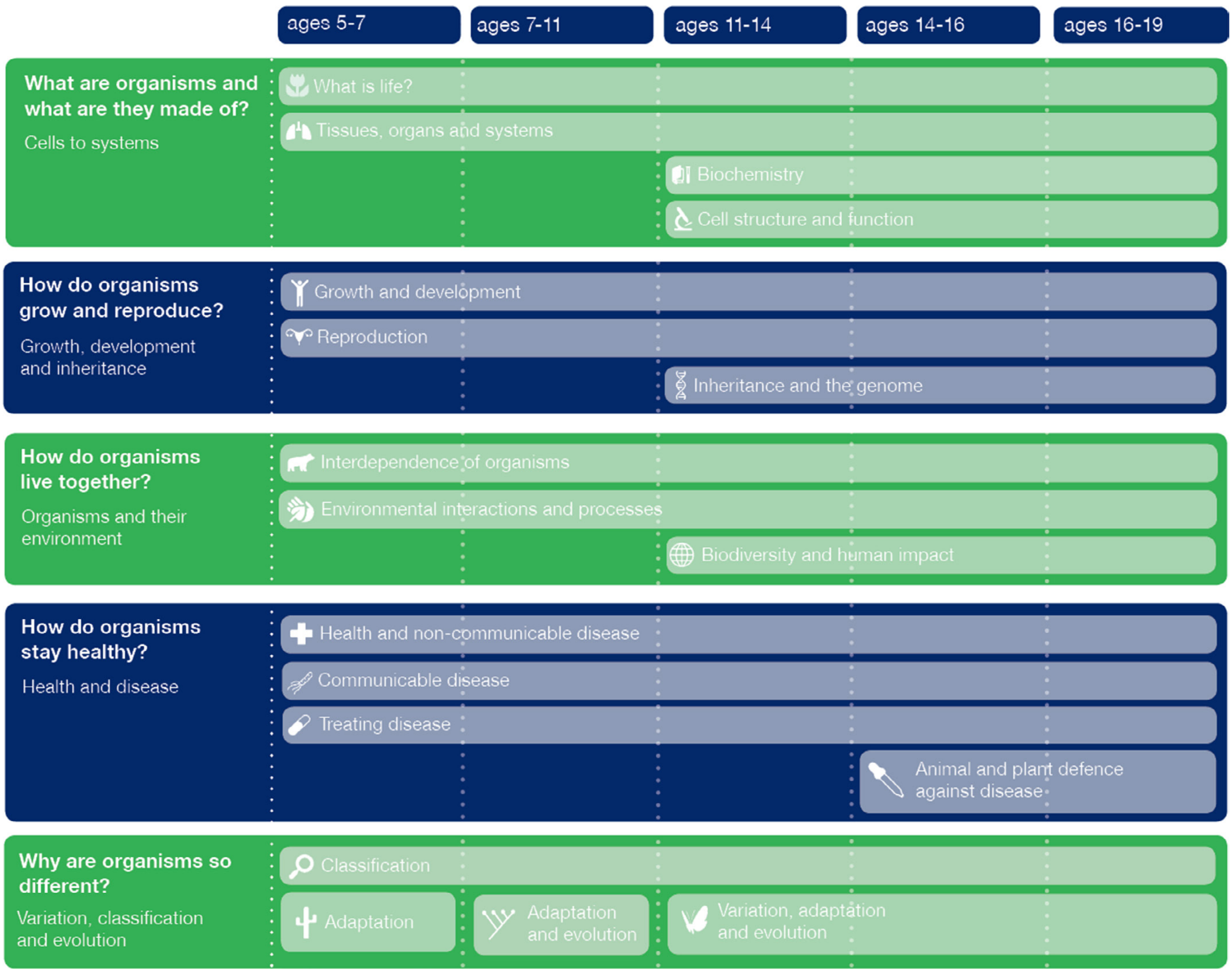

Figure 2 Mapping the biology curriculum

Box 1 Example of learning progression – photosynthesis

Right hand side – statements in RSB's 5–19 exemplification

7–11	
Observe and experience:	Explore the requirements of plants for life and growth (air, light, water, a suitable temperature, nutrients from soil, and room to grow) and how they vary from plant to plant.
11–14	
Name the process:	Plants make carbohydrates in their leaves by photosynthesis.
Simple summary:	The reactants and products of photosynthesis, and a word summary of the process.
Qualitative description:	The adaptations of leaves for photosynthesis.
14–16	
Process in two stages:	The first stage requires light and water.
	The second stage does not need light but uses carbon dioxide to make glucose and oxygen.
Quantitative description:	The effect of temperature, light intensity and carbon dioxide concentration on the rate of photosynthesis, and the interaction of these factors in limiting the rate of photosynthesis.
16–19	
Process as a simple model:	ATP and a reducing agent are synthesised in the light-dependent stage.
	ATP is broken down and the reducing agent is oxidised in the conversion of carbon dioxide to sugars in the light-independent stage.
	ATP synthesis is associated with the electron transfer chain in the membranes within chloroplasts.

How do organisms live together?

Maintaining local and global biodiversity and implications for humans are strong themes within this big question on organisms and their environment, with a broader focus on benefits to humans at 11–14 and consideration of the importance to almost all life of photosynthetic organisms, and human food and water security.

A conscious decision was made to introduce micro-organisms at 11–16, rather than in primary. When introduced, the RSB would like to emphasise positive interactions of micoorganisms, for example in digestion, soil and decomposition, and cycling materials through an ecosystem.

How do organisms grow and reproduce?

An understanding of growth, development and reproduction in plants and animals is important for all individuals. A particular emphasis has been placed on human reproduction at 11–16, to ensure all students engage with the biological underpinnings of topics that may be covered elsewhere in school by non-scientists as part of sex, health and relationships education.

In reviewing the themes within this big question we were able to make (Box 2) seemingly minor, but important edits to address gender imbalance and unconscious bias in our exemplification.

How do organisms stay healthy?

Health, communicable and non-communicable disease, treating disease and defence against disease in both plants and animals were identified as important areas of study for all students while in compulsory science education. To this end, we support a continued focus on the identification of pathogens that cause disease, lifestyle factors, the spread of communicable diseases and treatment of disease.

RSB's curriculum committee, primary working group and student group all identified mental health as a gap in current curricula. After consulting with external experts, it was agreed that the term 'mental ill health', as preferred by the NHS, should be used in 11–16 statements, with introduction to mental wellbeing at primary.

Why are organisms so different?

Classification is a concept that is revisited frequently in secondary biology; for example, 11- or 16-year-olds may be equally likely to encounter an activity involving simple classification keys. This is one area of 11–16 biology where we have included command words to improve

Box 2 Examples of addressing gender imbalance and unconscious bias

Key: **Bold** = words added to existing statements

~~Strikethrough~~ = words removed from existing statements

Edited statement	Rationale
The part played by ~~Watson,~~ Crick, **Franklin, Watson** and Wilkins ~~and Franklin~~ in the development of the DNA model.	Surnames listed alphabetically, ensuring the list does not read as (famous) male historical figures, followed by a female afterthought.
The structure and function of the **human** ~~male and~~ female **and male** reproductive systems.	Deliberate alphabetical choice of 'female and male' rather than 'male and female'.
The **effect of female and male lifestyles on fertility and the** use of hormones in modern reproductive technologies to treat infertility.	The focus of fertility treatment is often on women and IVF; the inclusion of lifestyle factors explicitly includes male infertility.

learning progression and remove repetition (Box 3). Elsewhere in 11–16, command words, such as describe, know, identify and recognise, have been omitted so as not to be unduly limiting on specification writers and secondary teachers.

Box 3 Example of learning progression – classification

7–11: Explore and use classification keys to help group, identify and name a variety of living things in their local and wider environment.

11–14: Construct a simple key that can be used to identify organisms.

14–16: Organisms can be classified using a hierarchical structure of groups, including domains, kingdoms and species.

16–19: Originally classification systems were based on observable features but more recent technological approaches provide a wider range of evidence to clarify relationships between organisms.

The cross-linking nature of biology

Many of the concepts within our 5–19 exemplification can be considered through different biological lenses and links can be identified between themes within our big questions of biology. The curriculum committee has identified cross-links between statements and concepts within our 5–19 exemplification (Box 4), and is beginning to consider how best to highlight the relationship of these statements.

Box 4 Examples of statements in *11–16 how do organisms grow and reproduce* that aid understanding of concepts in other big questions.

Awareness of the spread, prevention and treatment of sexually transmitted disease in **how do organisms stay healthy?**

- The spread of communicable disease in animals and plants, including sexually and non-sexually transmitted diseases.
- Diseases caused by bacteria, fungi and protists can be treated using antimicrobial drugs; however, diseases caused by viruses cannot.
- Benefits and risks of different forms of contraception.

Understanding how humans use and manipulate plants for our benefit in **how do organisms live together?**

- Different ways in which humans use plant hormones to manipulate plant growth and development.
- Benefits, issues and risks of using genetic technology in modern agriculture and medicine.
- Biotechnological and agricultural solutions, including genetic technologies, to meet the needs of the growing human population.

Considering genetics extended over time and mechanisms of evolution in **why are organisms so different?**

- Genetic variants result from mutations, which are changes in the DNA; these may occur during cell division or as a result of environmental factors.
- Inherited mutations can affect how well adapted offspring are to their environment.
- Evolution occurs through natural selection of genetic variants that give rise to phenotypes better adapted to their environment.

Other essential aspects of 11–16 biology education

Our understanding of the natural world around us is based upon evidence derived from testing hypotheses. For students to understand biology, they must also understand the processes of science and the importance of practical work. During the course of their studies, students should have the opportunity to:

- generate their own questions and consider how they could be answered;

- develop their awareness of health, safety and ethical issues;
- plan practical work (with consideration of health, safety and ethics);
- carry out practical work and manage risks associated with practical work;
- use technology and scientific instruments to facilitate and support practical work;
- evaluate results and other sources of information;
- analyse data;
- develop conclusions.

We believe that the study of biology should support students in understanding biology content and development of a range of skills. Some of these skills will be specific to the study of biology post 16 while others will be transferable skills applicable in a variety of contexts. These should include communication, numeracy, use of technology, independent and teamwork, logical reasoning and problem solving, creativity, resilience and confidence. The skills developed should support students to continue with the study of biology or other subjects as well as support them within society and the world of work.

For example, for further study post 16, any curriculum framework must ensure that students can understand, analyse and interpret data, including determining its validity and reliability, and its importance in a biological context. Students should therefore be given opportunities to develop their numerical skills through:

- collecting empirical data;
- manipulating primary and secondary data;
- selecting and using statistical tests;
- presentation of data in graphs and tables;
- interpretation of data from graphs and tables and texts.

In the changing world of work, it is reasonable to expect that students will increasingly be expected to apply these skills across STEM and non-STEM studies and careers. We hope that our 5–19 exemplification and wider framework will prepare students as non-scientist citizens (studying up to 16), prepare students as potential scientists (up to 16 and beyond, through vocational and academic routes) and ensure students achieve science literacy.

Next steps

The RSB is now focusing on developing an 11–16 framework document that will present essential aspects of biology discussed above within the context of the five big questions of biology and detailed exemplification of content.

We are creating a framework with recommendations for our discipline, and at this time do not intend to make recommendations on how the sciences are timetabled as school subjects, teaching order within age ranges, or detailed practical competencies for each age range in biology. However, there are areas we may want to consider for further work as the framework develops, including papers or resources to accompany our suite of documents.

We hope to use the work done so far with policy makers and curriculum designers in the lead-up to and during future curriculum reviews. We also intend to engage further with other scientific learned societies and subject associations, particularly the Institute of Physics and Royal Society of Chemistry. For further information on the RSB's framework for the biology curriculum as it develops, and details of opportunities for teachers to engage with the process, please visit www.rsb.org.uk/curriculum

Acknowledgements

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References

Harlen, W. ed. (2010) *Principles and Big Ideas of Science Education*. Hatfield: Association for Science Education. Available at: www.ase.org.uk/bigideas.

Harlen, W. ed. (2015) *Working with Big Ideas of Science Education*. Trieste: Global Network of Science Academics (IAP) Science Education Programme. Available at: www.ase.org.uk/bigideas.

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